baseband Documentation

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CONTENTS

Welcome to the Baseband documentation! Baseband is a package affiliated with the Astropy project for reading and writing VLBI and other radio baseband files, with the aim of simplifying and streamlining data conversion and standardization. It provides:

- File input/output objects for supported radio baseband formats, enabling selective decoding of data into `Numpy arrays`, and encoding user-defined arrays into baseband formats. Supported formats are listed under *specific file formats*.
- The ability to read from and write to an ordered sequence of files as if it was a single file.

If you used this package in your research, please cite it via DOI 10.5281/zenodo.1214268.

Part I

Overview

CHAPTER

ONE

INSTALLATION

1.1 Requirements

Baseband requires:

- Astropy v2.0 or later
- Numpy v1.9 or later

1.2 Installing Baseband

To install Baseband with pip, run:

```
pip3 install baseband
```

Note: To run without pip potentially updating Numpy and Astropy, run, include the `--no-deps` flag.

1.2.1 Obtaining Source Code

The source code and latest development version of Baseband can found on its GitHub repo. You can get your own clone using:

```
git clone git@github.com:mhvk/baseband.git
```

Of course, it is even better to fork it on GitHub, and then clone your own repository, so that you can more easily contribute!

1.2.2 Running Code without Installing

As Baseband is purely Python, it can be used without being built or installed, by appending the directory it is located in to the `PYTHON_PATH` environment variable. Alternatively, you can use `sys.path` within Python to append the path:

```
import sys
sys.path.append(BASEBAND_PATH)
```

where `BASEBAND_PATH` is the directory you downloaded or cloned Baseband into.

1.2.3 Installing Source Code

If you want Baseband to be more broadly available, either to all users on a system, or within, say, a virtual environment, use `setup.py` in the root directory by calling:

```
python3 setup.py install
```

For general information on `setup.py`, see its documentation . Many of the `setup.py` options are inherited from Astropy (specifically, from Astropy -affiliated package manager) and are described further in Astropy's installation documentation .

1.3 Testing the Installation

The root directory `setup.py` can also be used to test if Baseband can successfully be run on your system:

```
python3 setup.py test
```

or, inside of Python:

```
import baseband
baseband.test()
```

These tests require pytest to be installed. Further documentation can be found on the Astropy running tests documentation .

1.4 Building Documentation

Note: As with Astropy, building the documentation is unnecessary unless you are writing new documentation or do not have internet access, as Baseband's documentation is available online at baseband.readthedocs.io.

The Baseband documentation can be built again using `setup.py` from the root directory:

```
python3 setup.py build_docs
```

This requires to have Sphinx installed (and its dependencies).

CHAPTER

TWO

GETTING STARTED WITH BASEBAND

This quickstart tutorial is meant to help the reader hit the ground running with Baseband. For more detail, including writing to files, see *Using Baseband*.

For installation instructions, please see *Installing Baseband*.

When using Baseband, we typically will also use `numpy`, `astropy.units`, and `astropy.time.Time`. Let's import all of these:

```
>>> import baseband
>>> import numpy as np
>>> import astropy.units as u
>>> from astropy.time import Time
```

2.1 Opening Files

For this tutorial, we'll use two sample files:

```
>>> from baseband.data import SAMPLE_VDIF, SAMPLE_MARK5B
```

The first file is a VDIF one created from EVN/VLBA observations of Black Widow pulsar PSR B1957+20, while the second is a Mark 5B from EVN/WSRT observations of the same pulsar.

To open the VDIF file:

```
>>> fh_vdif = baseband.open(SAMPLE_VDIF)
```

Opening the Mark 5B file is slightly more involved, as not all required metadata is stored in the file itself:

```
>>> fh_m5b = baseband.open(SAMPLE_MARK5B, nchan=8, sample_rate=32*u.MHz,
...                        ref_time=Time('2014-06-13 12:00:00'))
```

Here, we've manually passed in as keywords the number of *channels*, the *sample rate* (number of samples per channel per second) as an `astropy.units.Quantity`, and a reference time within 500 days of the start of the observation as an `astropy.time.Time`. That last keyword is needed to properly read timestamps from the Mark 5B file.

`baseband.open` tries to open files using all available formats, returning whichever is successful. If you know the format of your file, you can pass its name with the `format` keyword, or directly use its format opener (for VDIF, it is `baseband.vdif.open`). Also, the `baseband.file_info` function can help determine the format and any missing information needed by `baseband.open` - see *Inspecting Files*.

Do you have a sequence of files you want to read in? You can pass a list of filenames to `baseband.open`, and it will open them up as if they were a single file! See *Reading or Writing to a Sequence of Files*.

2.2 Reading Files

Radio baseband files are generally composed of blocks of binary data, or *payloads*, stored alongside corresponding metadata, or *headers*. Each header and payload combination is known as a *data frame*, and most formats feature files composed of a long series of frames.

Baseband file objects are frame-reading wrappers around Python file objects, and have the same interface, including `seek` for seeking to different parts of the file, `tell` for reporting the file pointer's current position, and `read` for reading data. The main difference is that Baseband file objects read and navigate in units of samples.

Let's read some samples from the VDIF file:

```
>>> data = fh_vdif.read(3)
>>> data
array([[-1.      ,  1.      ,  1.      , -1.      , -1.      , -1.      ,
         3.316505,  3.316505],
       [-1.      ,  1.      , -1.      ,  1.      ,  1.      ,  1.      ,
         3.316505,  3.316505],
       [ 3.316505,  1.      , -1.      , -1.      ,  1.      ,  3.316505,
        -3.316505,  3.316505]], dtype=float32)
>>> data.shape
(3, 8)
```

Baseband decodes binary data into `ndarray` objects. Notice we input `3`, and received an array of shape `(3, 8)`; this is because there are 8 VDIF *threads*. Threads and channels represent different *components* of the data such as polarizations or frequency sub-bands, and the collection of all components at one point in time is referred to as a *complete sample*. Baseband reads in units of complete samples, and works with sample rates in units of complete samples per second (including with the Mark 5B example above). Like an `ndarray`, calling `fh_vdif.shape` returns the shape of the entire dataset:

```
>>> fh_vdif.shape
(40000, 8)
```

The first axis represents time, and all additional axes represent the shape of a complete sample. A labelled version of the complete sample shape is given by:

```
>>> fh_vdif.sample_shape
SampleShape(nthread=8)
```

Baseband extracts basic properties and header metadata from opened files. Notably, the start and end times of the file are given by:

```
>>> fh_vdif.start_time
<Time object: scale='utc' format='isot' value=2014-06-16T05:56:07.000000000>
>>> fh_vdif.stop_time
<Time object: scale='utc' format='isot' value=2014-06-16T05:56:07.001250000>
```

For an overview of the file, we can either print `fh_vdif` itself, or use the `info` method:

```
>>> fh_vdif
<VDIFStreamReader name=... offset=3
    sample_rate=32.0 MHz, samples_per_frame=20000,
    sample_shape=SampleShape(nthread=8),
    bps=2, complex_data=False, edv=3, station=65532,
    start_time=2014-06-16T05:56:07.000000000>
>>> fh_vdif.info
Stream information:
```

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```
start_time = 2014-06-16T05:56:07.000000000
stop_time = 2014-06-16T05:56:07.001250000
sample_rate = 32.0 MHz
shape = (40000, 8)
format = vdif
bps = 2
complex_data = False
readable = True

File information:
edv = 3
frame_rate = 1600.0 Hz
samples_per_frame = 20000
sample_shape = (8, 1)
```

Seeking is also done in units of complete samples, which is equivalent to seeking in timesteps. Let's move forward 100 complete samples:

```
>>> fh_vdif.seek(100)
100
```

Seeking from the end or current position is also possible, using the same syntax as for typical file objects. It is also possible to seek in units of time:

```
>>> fh_vdif.seek(-1000, 2)    # Seek 1000 samples from end.
39000
>>> fh_vdif.seek(10*u.us, 1)    # Seek 10 us from current position.
39320
```

`fh_vdif.tell` returns the current offset in samples or in time:

```
>>> fh_vdif.tell()
39320
>>> fh_vdif.tell(unit=u.us)    # Time since start of file.
<Quantity 1228.75 us>
>>> fh_vdif.tell(unit='time')
<Time object: scale='utc' format='isot' value=2014-06-16T05:56:07.001228750>
```

Finally, we close both files:

```
>>> fh_vdif.close()
>>> fh_m5b.close()
```

CHAPTER THREE

USING BASEBAND

For most file formats, one can simply import baseband and use `baseband.open` to access the file. This gives one a filehandle from which one can read decoded samples:

```
>>> import baseband
>>> from baseband.data import SAMPLE_DADA
>>> fh = baseband.open(SAMPLE_DADA)
>>> fh.read(3)
array([[ -38.-38.j,  -38.-38.j],
       [ -38.-38.j,  -40. +0.j],
       [-105.+60.j,   85.-15.j]], dtype=complex64)
>>> fh.close()
```

For other file formats, a bit more information is needed. Below, we cover the basics of *inspecting files*, *reading* from and *writing* to files, and *converting* from one format to another. We assume that Baseband as well as NumPy and the Astropy units module have been imported:

```
>>> import baseband
>>> import numpy as np
>>> import astropy.units as u
```

3.1 Inspecting Files

Baseband allows you to quickly determine basic properties of a file, including what format it is, using the `baseband.file_info` function. For instance, it shows that the sample VDIF file that comes with Baseband is very short (sample files can all be found in the `baseband.data` module):

```
>>> import baseband.data
>>> baseband.file_info(baseband.data.SAMPLE_VDIF)
Stream information:
start_time = 2014-06-16T05:56:07.000000000
stop_time = 2014-06-16T05:56:07.001250000
sample_rate = 32.0 MHz
shape = (40000, 8)
format = vdif
bps = 2
complex_data = False
readable = True

File information:
edv = 3
frame_rate = 1600.0 Hz
```

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```
samples_per_frame = 20000
sample_shape = (8, 1)
```

The same function will also tell you when more information is needed. For instance, for Mark 5B files one needs the number of channels used, as well as (roughly) when the data were taken:

```
>>> baseband.file_info(baseband.data.SAMPLE_MARK5B)
File information:
format = mark5b
frame_rate = 6400.0 Hz
bps = 2
complex_data = False
readable = False

missing:  nchan: needed to determine sample shape and rate.
          kday, ref_time: needed to infer full times.

errors:  start_time: unsupported operand type(s) for +: 'NoneType' and 'int'
         frame0: In order to read frames, the file handle should be initialized with nchan set.

>>> from astropy.time import Time
>>> baseband.file_info(baseband.data.SAMPLE_MARK5B, nchan=8, ref_time=Time('2014-01-01'))
Stream information:
start_time = 2014-06-13T05:30:01.000000000
stop_time = 2014-06-13T05:30:01.000625000
sample_rate = 32.0 MHz
shape = (20000, 8)
format = mark5b
bps = 2
complex_data = False
readable = True

File information:
frame_rate = 6400.0 Hz
samples_per_frame = 5000
sample_shape = (8,)
```

The information is gleaned from `info` properties on the various file and stream readers (see below).

Note: The one format for which `file_info` works a bit differently is GSB, as this format requires separate time-stamp and raw data files. Only the timestamp file can be inspected usefully.

3.2 Reading Files

3.2.1 Opening Files

As shown at the very start, files can be opened with the general `baseband.open` function. This will try to determine the file type using `file_info`, load the corresponding baseband module, and then open the file using that module's master input/output function.

Generally, if one knows the file type, one might as well work with the corresponding module directly. For instance, to explicitly use the DADA reader to open the sample DADA file included in Baseband, one can use the DADA module's `open` function:

```
>>> from baseband import dada
>>> from baseband.data import SAMPLE_DADA
>>> fh = dada.open(SAMPLE_DADA, 'rs')
>>> fh.read(3)
array([[ -38.-38.j,  -38.-38.j],
       [ -38.-38.j,  -40. +0.j],
       [-105.+60.j,   85.-15.j]], dtype=complex64)
>>> fh.close()
```

In general, file I/O and data manipulation use the same syntax across all file formats. When opening Mark 4 and Mark 5B files, however, some additional arguments may need to be passed (as was the case above for inspecting a Mark 5B file, and indeed this is a good way to find out what is needed). Notes on such features and quirks of individual formats can be found in the API entries of their open functions, and within the *Specific file format* documentation.

For the rest of this section, we will stick to VDIF files.

3.2.2 Decoding Data and the Sample File Pointer

By giving the openers a `'rs'` flag, which is the default, we open files in “stream reader” mode, where a file is accessed as if it were a stream of samples. For VDIF, `open` will then return an instance of `VDIFStreamReader`, which wraps a raw data file with methods to decode the binary *data frames* and seek to and read data *samples*. To decode the first 12 samples into a `ndarray`, we would use the `read` method:

```
>>> from baseband import vdif
>>> from baseband.data import SAMPLE_VDIF
>>> fh = vdif.open(SAMPLE_VDIF, 'rs')
>>> d = fh.read(12)
>>> type(d)
<... 'numpy.ndarray'>
>>> d.shape
(12, 8)
>>> d[:, 0].astype(int)    # First thread.
array([-1, -1,  3, -1,  1, -1,  3, -1,  1,  3, -1,  1])
```

As discussed in detail in the *VDIF section*, VDIF files are sequences of data frames, each of which is comprised of a *header* (which holds information like the time at which the data was taken) and a *payload*, or block of data. Multiple concurrent time streams can be stored within a single frame; each of these is called a “*channel*”. Moreover, groups of channels can be stored over multiple frames, each of which is called a “*thread*”. Our sample file is an “8-thread, single-channel file” (8 concurrent time streams with 1 stream per frame), and in the example above, `fh.read` decoded the first 12 samples from all 8 threads, mapping thread number to the second axis of the decoded data array. Reading files with multiple threads and channels will produce 3-dimensional arrays.

`fh` includes `shape`, `size` and `ndim`, which give the shape, total number of elements and dimensionality of the file’s entire dataset if it was decoded into an array. The number of *complete samples* - the set of samples from all available threads and channels for one point in time - in the file is given by the first element in `shape`:

```
>>> fh.shape    # Shape of all data from the file in decoded array form.
(40000, 8)
>>> fh.shape[0] # Number of complete samples.
40000
>>> fh.size
320000
>>> fh.ndim
2
```

The shape of a single complete sample, including names indicating the meaning of shape dimensions, is retrievable using:

```
>>> fh.sample_shape
SampleShape(nthread=8)
```

By default, dimensions of length unity are *squeezed*, or removed from the sample shape. To retain them, we can pass `squeeze=False` to `open`:

```
>>> fhns = vdif.open(SAMPLE_VDIF, 'rs', squeeze=False)
>>> fhns.sample_shape    # Sample shape now keeps channel dimension.
SampleShape(nthread=8, nchan=1)
>>> fhns.ndim            # fh.shape and fh.ndim also change with squeezing.
3
>>> d2 = fhns.read(12)
>>> d2.shape             # Decoded data has channel dimension.
(12, 8, 1)
>>> fhns.close()
```

Basic information about the file is obtained by either by `fh.info` or simply `fh` itself:

```
>>> fh.info
Stream information:
start_time = 2014-06-16T05:56:07.000000000
stop_time = 2014-06-16T05:56:07.001250000
sample_rate = 32.0 MHz
shape = (40000, 8)
format = vdif
bps = 2
complex_data = False
readable = True

File information:
edv = 3
frame_rate = 1600.0 Hz
samples_per_frame = 20000
sample_shape = (8, 1)

>>> fh
<VDIFStreamReader name=... offset=12
    sample_rate=32.0 MHz, samples_per_frame=20000,
    sample_shape=SampleShape(nthread=8),
    bps=2, complex_data=False, edv=3, station=65532,
    start_time=2014-06-16T05:56:07.000000000>
```

Not coincidentally, the first is identical to what we *found above* using `file_info`.

The filehandle itself also shows the `offset`, the current location of the sample file pointer. Above, it is at 12 since we have read in 12 (complete) samples. If we called `fh.read (12)` again we would get the next 12 samples. If we instead called `fh.read()`, it would read from the pointer's *current* position to the end of the file. If we wanted all the data in one array, we would move the file pointer back to the start of file, using `fh.seek`, before reading:

```
>>> fh.seek(0)      # Seek to sample 0.  Seek returns its offset in counts.
0
>>> d_complete = fh.read()
>>> d_complete.shape
(40000, 8)
```

We can also move the pointer with respect to the end of file by passing 2 as a second argument:

```
>>> fh.seek(-100, 2)    # Second arg is 0 (start of file) by default.
39900
>>> d_end = fh.read(100)
>>> np.array_equal(d_complete[-100:], d_end)
True
```

`-100` means 100 samples before the end of file, so `d_end` is equal to the last 100 entries of `d_complete`. Baseband only keeps the most recently accessed data frame in memory, making it possible to analyze (normally large) files through selective decoding using `seek` and `read`.

Note: As with file pointers in general, `fh.seek` will not return an error if one seeks beyond the end of file. Attempting to read beyond the end of file, however, will result in an `EOFError`.

To determine where the pointer is located, we use `fh.tell()`:

```
>>> fh.tell()
40000
>>> fh.close()
```

Caution should be used when decoding large blocks of data using `fh.read`. For typical files, the resulting arrays are far too large to hold in memory.

3.2.3 Seeking and Telling in Time With the Sample Pointer

We can use `seek` and `tell` with units of time rather than samples. To do this with `tell`, we can pass an appropriate `astropy.units.Unit` object to its optional `unit` parameter:

```
>>> fh = vdif.open(SAMPLE_VDIF, 'rs')
>>> fh.seek(40000)
40000
>>> fh.tell(unit=u.ms)
<Quantity 1.25 ms>
```

Passing the string `'time'` reports the pointer's location in absolute time:

```
>>> fh.tell(unit='time')
<Time object: scale='utc' format='isot' value=2014-06-16T05:56:07.001250000>
```

We can also pass an absolute `astropy.time.Time`, or a positive or negative time difference `TimeDelta` or `astropy.units.Quantity` to seek. If the offset is a `Time` object, the second argument to seek is ignored.:

```
>>> from astropy.time.core import TimeDelta
>>> from astropy.time import Time
>>> fh.seek(TimeDelta(-5e-4, format='sec'), 2)  # Seek -0.5 ms from end.
24000
>>> fh.seek(0.25*u.ms, 1)  # Seek 0.25 ms from current position.
32000
>>> # Seek to specific time.
>>> fh.seek(Time('2014-06-16T05:56:07.001125'))
36000
```

We can retrieve the time of the first sample in the file using `start_time`, the time immediately after the last sample using `stop_time`, and the time of the pointer's current location (equivalent to `fh.tell(unit='time')`) using `time`:

```
>>> fh.start_time
<Time object: scale='utc' format='isot' value=2014-06-16T05:56:07.000000000>
>>> fh.stop_time
<Time object: scale='utc' format='isot' value=2014-06-16T05:56:07.001250000>
>>> fh.time
<Time object: scale='utc' format='isot' value=2014-06-16T05:56:07.001125000>
>>> fh.close()
```

3.2.4 Extracting Header Information

The first header of the file is stored as the `header0` attribute of the stream reader object; it gives direct access to header properties via keyword lookup:

```
>>> with vdif.open(SAMPLE_VDIF, 'rs') as fh:
...     header0 = fh.header0
>>> header0['frame_length']
629
```

The full list of keywords is available by printing out `header0`:

```
>>> header0
<VDIFHeader3 invalid_data: False,
             legacy_mode: False,
             seconds: 14363767,
             _1_30_2: 0,
             ref_epoch: 28,
             frame_nr: 0,
             vdif_version: 1,
             lg2_nchan: 0,
             frame_length: 629,
             complex_data: False,
             bits_per_sample: 1,
             thread_id: 1,
             station_id: 65532,
             edv: 3,
             sampling_unit: True,
             sampling_rate: 16,
             sync_pattern: 0xacabfeed,
             loif_tuning: 859832320,
             _7_28_4: 15,
             dbe_unit: 2,
             if_nr: 0,
             subband: 1,
             sideband: True,
             major_rev: 1,
             minor_rev: 5,
             personality: 131>
```

A number of derived properties, such as the time (as a `Time` object), are also available through the header object.

```
>>> header0.time
<Time object: scale='utc' format='isot' value=2014-06-16T05:56:07.000000000>
```

These are listed in the API for each header class. For example, the sample VDIF file's headers are of class:

```
>>> type(header0)
<class 'baseband.vdif.header.VDIFHeader3'>
```

and so its attributes can be found here.

3.2.5 Reading Specific Components of the Data

By default, `fh.read()` returns complete samples, i.e. with all available threads, polarizations or channels. If we were only interested in decoding a *subset* of the complete sample, we can select specific components by passing indexing objects to the `subset` keyword in open. For example, if we only wanted thread 3 of the sample VDIF file:

```
>>> fh = vdif.open(SAMPLE_VDIF, 'rs', subset=3)
>>> fh.sample_shape
()
>>> d = fh.read(20000)
>>> d.shape
(20000,)
>>> fh.subset
(3,)
>>> fh.close()
```

Since by default data are squeezed, one obtains a data stream with just a single dimension. If one would like to keep all information, one has to pass `squeeze=False` and also make `subset` a list (or slice):

```
>>> fh = vdif.open(SAMPLE_VDIF, 'rs', subset=[3], squeeze=False)
>>> fh.sample_shape
SampleShape(nthread=1, nchan=1)
>>> d = fh.read(20000)
>>> d.shape
(20000, 1, 1)
>>> fh.close()
```

Data with multi-dimensional samples can be subset by passing a `tuple` of indexing objects with the same dimensional ordering as the (possibly squeezed) sample shape; in the case of the sample VDIF with `squeeze=False`, this is threads, then channels. For example, if we wished to select threads 1 and 3, and channel 0:

```
>>> fh = vdif.open(SAMPLE_VDIF, 'rs', subset=([1, 3], 0), squeeze=False)
>>> fh.sample_shape
SampleShape(nthread=2)
>>> fh.close()
```

Generally, `subset` accepts any object that can be used to index a `numpy.ndarray`, including advanced indexing (as done above, with `subset=([1, 3], 0)`). If possible, slices should be used instead of list of integers, since indexing with them returns a view rather than a copy and thus avoid unnecessary processing and memory allocation. (An exception to this is VDIF threads, where the subset is used to selectively read specific threads, and thus is not used for actual slicing of the data.)

3.3 Writing to Files and Format Conversion

3.3.1 Writing to a File

To write data to disk, we again use open. Writing data in a particular format requires both the header and data samples. For modifying an existing file, we have both the old header and old data handy.

As a simple example, let's read in the 8-thread, single-channel sample VDIF file and rewrite it as an single-thread, 8-channel one, which, for example, may be necessary for compatibility with DSPSR:

```
>>> import baseband.vdif as vdif
>>> from baseband.data import SAMPLE_VDIF
>>> fr = vdif.open(SAMPLE_VDIF, 'rs')
>>> fw = vdif.open('test_vdif.vdif', 'ws',
...                sample_rate=fr.sample_rate,
...                samples_per_frame=fr.samples_per_frame // 8,
...                nthread=1, nchan=fr.sample_shape.nthread,
...                complex_data=fr.complex_data, bps=fr.bps,
...                edv=fr.header0.edv, station=fr.header0.station,
...                time=fr.start_time)
```

The minimal parameters needed to generate a file are listed under the documentation for each format's open, though comprehensive lists can be found in the documentation for each format's stream writer class (eg. for VDIF, it's under `VDIFStreamWriter`). In practice we specify as many relevant header properties as available to obtain a particular file structure. If we possess the *exact* first header of the file, it can simply be passed to open via the `header` keyword. In the example above, though, we manually switch the values of `nthread` and `nchan`. Because VDIF EDV = 3 requires each frame's payload to contain 5000 bytes, and `nchan` is now a factor of 8 larger, we decrease `samples_per_frame`, the number of complete (i.e. all threads and channels included) samples per frame, by a factor of 8.

Encoding samples and writing data to file is done by passing data arrays into `fw`'s `write` method. The first dimension of the arrays is sample number, and the remaining dimensions must be as given by `fw.sample_shape`:

```
>>> fw.sample_shape
SampleShape(nchan=8)
```

In this case, the required dimensions are the same as the arrays from `fr.read`. We can thus write the data to file using:

```
>>> while fr.tell() < fr.shape[0]:
...     fw.write(fr.read(fr.samples_per_frame))
>>> fr.close()
>>> fw.close()
```

For our sample file, we could simply have written

```
fw.write(fr.read())
```

instead of the loop, but for large files, reading and writing should be done in smaller chunks to minimize memory usage. Baseband stores only the data frame or frame set being read or written to in memory.

We can check the validity of our new file by re-opening it:

```
>>> fr = vdif.open(SAMPLE_VDIF, 'rs')
>>> fh = vdif.open('test_vdif.vdif', 'rs')
>>> fh.sample_shape
SampleShape(nchan=8)
>>> np.all(fr.read() == fh.read())
True
>>> fr.close()
>>> fh.close()
```

Note: One can also use the top-level `open` function for writing, with the file format passed in via its `format` argument.

3.3.2 File Format Conversion

It is often preferable to convert data from one file format to another that offers wider compatibility, or better fits the structure of the data. As an example, we convert the sample Mark 4 data to VDIF.

Since we don't have a VDIF header handy, we pass the relevant Mark 4 header values into `vdif.open` to create one.

```
>>> import baseband.mark4 as mark4
>>> from baseband.data import SAMPLE_MARK4
>>> fr = mark4.open(SAMPLE_MARK4, 'rs', ntrack=64, decade=2010)
>>> spf = 640       # fanout * 160 = 640 invalid samples per Mark 4 frame
>>> fw = vdif.open('m4convert.vdif', 'ws', sample_rate=fr.sample_rate,
...                samples_per_frame=spf, nthread=1,
...                nchan=fr.sample_shape.nchan,
...                complex_data=fr.complex_data, bps=fr.bps,
...                edv=1, time=fr.start_time)
```

We choose `edv = 1` since it's the simplest VDIF EDV whose header includes a sampling rate. The concept of threads does not exist in Mark 4, so the file effectively has `nthread = 1`. As discussed in the *Mark 4 documentation*, the data at the start of each frame is effectively overwritten by the header and are represented by invalid samples in the stream reader. We set `samples_per_frame` to `640` so that each section of invalid data is captured in a single frame.

We now write the data to file, manually flagging each invalid data frame:

```
>>> while fr.tell() < fr.shape[0]:
...     d = fr.read(fr.samples_per_frame)
...     fw.write(d[:640], valid=False)
...     fw.write(d[640:])
>>> fr.close()
>>> fw.close()
```

Lastly, we check our new file:

```
>>> fr = mark4.open(SAMPLE_MARK4, 'rs', ntrack=64, decade=2010)
>>> fh = vdif.open('m4convert.vdif', 'rs')
>>> np.all(fr.read() == fh.read())
True
>>> fr.close()
>>> fh.close()
```

For file format conversion in general, we have to consider how to properly scale our data to make the best use of the dynamic range of the new encoded format. For VLBI formats like VDIF, Mark 4 and Mark 5B, samples of the same size have the same scale, which is why we did not have to rescale our data when writing 2-bits-per-sample Mark 4 data to a 2-bits-per-sample VDIF file. Rescaling is necessary, though, to convert DADA or GSB to VDIF. For examples of rescaling, see the `baseband/tests/test_conversion.py` file.

3.4 Reading or Writing to a Sequence of Files

Data from one continuous observation is sometimes spread over a sequence of files. Baseband includes the `sequentialfile` module for reading in a sequence as if it were one contiguous file. This module is called when a list, tuple or filename template is passed to eg. `baseband.open` or `baseband.vdif.open`, making the syntax for handling multiple files nearly identical to that for single ones.

As an example, we write the data from the sample VDIF file `baseband/data/sample.vdif` into a sequence of two files and then read the files back in. We first load the required data:

```
>>> from baseband import vdif
>>> from baseband.data import SAMPLE_VDIF
>>> import numpy as np
>>> fh = vdif.open(SAMPLE_VDIF, 'rs')
>>> d = fh.read()
```

We then create a sequence of filenames:

```
>>> filenames = ["seqvdif_{0}".format(i) for i in range(2)]
```

When passing filenames to open, we must also pass file_size, the file size in bytes, in addition to the usual kwargs for writing a file. Since we wish to split the sample file in two, and the file consists of two framesets, we set file_size to the byte size of one frameset (we could have equivalently set it to fh.fh_raw.seek(0, 2) // 2):

```
>>> file_size = 8 * fh.header0.frame_nbytes
>>> fw = vdif.open(filenames, 'ws', header0=fh.header0,
...                file_size=file_size, sample_rate=fh.sample_rate,
...                nthread=fh.sample_shape.nthread)
>>> fw.write(d)
>>> fw.close()    # This implicitly closes fwr.
```

Note: file_size sets the maximum size a file can reach before the writer writes to the next one, so setting file_size to a larger value than above will lead to the two files having different sizes. By default, file_size=None, meaning it can be arbitrarily large, in which case only one file will be created.

We now read the sequence and confirm their contents are identical to those of the sample file:

```
>>> fr = vdif.open(filenames, 'rs', sample_rate=fh.sample_rate)
>>> fr.header0.time == fh.header0.time
True
>>> np.all(fr.read() == d)
True
>>> fr.close()
```

When reading, the filename sequence **must be ordered in time**.

We can also open the second file on its own and confirm it contains the second frameset of the sample file:

```
>>> fsf = vdif.open(filenames[1], mode='rs', sample_rate=fh.sample_rate)
>>> fh.seek(fh.shape[0] // 2)    # Seek to start of second frameset.
20000
>>> fsf.header0.time == fh.time
True
>>> np.all(fsf.read() == fh.read())
True
>>> fsf.close()
```

In situations where the file_size is known, but not the total number of files to write, one may use the FileNameSequencer class to create an iterable without a user-defined size. The class is initialized with a template string that can be formatted with keywords, and a optional header that can either be an actual header or a dict with the relevant keywords. The template may also contain the special keyword '{file_nr}', which is equal to the indexing value (instead of a header entry).

As an example, let us create a sequencer:

```
>>> from baseband.helpers import sequentialfile as sf
>>> filenames = sf.FileNameSequencer('f.edv{edv:d}.{file_nr:03d}.vdif',
...                                  header=fh.header0)
```

Indexing the sequencer using square brackets returns a filename:

```
>>> filenames[0]
'f.edv3.000.vdif'
>>> filenames[42]
'f.edv3.042.vdif'
```

The sequencer has extracted the EDV from the header we passed in, and the file number from the index. We can use the sequencer to write a VDIF file sequence:

```
>>> fw = vdif.open(filenames, 'ws', header0=fh.header0,
...                file_size=file_size, sample_rate=fh.sample_rate,
...                nthread=fh.sample_shape.nthread)
>>> d = np.concatenate([d, d, d])
>>> fw.write(d)
>>> fw.close()
```

This creates 6 files:

```
>>> import glob
>>> len(glob.glob("f.edv*.vdif"))
6
```

We can read the file sequence using the same sequencer. In reading mode, the sequencer determines the number of files by finding the largest file available that fits the template:

```
>>> fr = vdif.open(filenames, 'rs', sample_rate=fh.sample_rate)
>>> fr.header0.time == fh.header0.time
True
>>> np.all(fr.read() == d)
True
>>> fr.close()
>>> fh.close()  # Close sample file as well.
```

Because DADA and GUPPI data are usually stored in file sequences with names derived from header values - eg. 'puppi_58132_J1810+1744_2176.0010.raw', their format openers have template support built-in. For usage details, please see the API entries for `baseband.dada.open` and `baseband.guppi.open`.

CHAPTER

FOUR

GLOSSARY

channel
A single component of the *complete sample*, or a *stream* thereof. They typically represent one frequency sub-band, the output from a single antenna, or (for channelized data) one spectral or Fourier channel, ie. one part of a Fourier spectrum.

complete sample
Set of all component samples - ie. from all threads, polarizations, channels, etc. - for one point in time. Its dimensions are given by the *sample shape*.

component
One individual *thread* and *channel*, or one polarization and channel, etc. Component samples each occupy one element in decoded data arrays. A component sample is composed of one *elementary sample* if it is real, and two if it is complex.

data frame
A block of time-sampled data, or *payload*, accompanied by a *header*. "Frame" for short.

data frameset
In the VDIF format, the set of all *data frames* representing the same segment of time. Each data frame consists of sets of *channels* from different *threads*.

elementary sample
The smallest subdivision of a complete sample, i.e. the real / imaginary part of one *component* of a *complete sample*.

header
Metadata accompanying a *data frame*.

payload
The data within a *data frame*.

sample
Data from one point in time. *Complete samples* contain samples from all *components*, while *elementary samples* are one part of one component.

sample rate
Rate of complete samples.

sample shape
The lengths of the dimensions of the complete sample.

squeezing
The removal of any dimensions of length unity from decoded data.

stream
Timeseries of *samples*; may refer to all of, or a subsection of, the dataset.

subset
A subset of a complete sample, in particular one defined by the user for selective decoding.

thread
A collection of *channels* from the *complete sample*, or a *stream* thereof. For VDIF, each thread is carried by a separate (set of) *data frame(s)*.

Part II

Specific File Formats

Baseband's code is subdivided into its supported file formats, and the following sections contain format specifications, usage notes, troubleshooting help and APIs for each.

CHAPTER

FIVE

VDIF

The VLBI Data Interchange Format (VDIF) was introduced in 2009 to standardize VLBI data transfer and storage. Detailed specifications are found in VDIF's specification document.

5.1 File Structure

A VDIF file is composed of *data frames*. Each has a *header* of eight 32-bit words (32 bytes; the exception is the "legacy VDIF" format, which is four words, or 16 bytes, long), and a *payload* that ranges from 32 bytes to ~134 megabytes. Both are little-endian. The first four words of a VDIF header hold the same information in all VDIF files, but the last four words hold optional user-defined data. The layout of these four words is specified by the file's **extended-data version**, or EDV. More detailed information on the header can be found in the *tutorial for supporting a new VDIF EDV*.

A data frame may carry one or multiple *channels*, and a *stream* of data frames all carrying the same (set of) channels is known as a *thread* and denoted by its thread ID. The collection of frames representing the same time segment (and all possible thread IDs) is called a *data frameset* (or just "frameset").

Strict time and thread ID ordering of frames in the stream, while considered part of VDIF best practices, is not mandated, and cannot be guaranteed during data transmission over the internet.

5.2 Usage Notes

This section covers reading and writing VDIF files with Baseband; general usage can be found under the *Using Baseband* section. For situations in which one is unsure of a file's format, Baseband features the general `baseband.open` and `baseband.file_info` functions, which are also discussed in *Using Baseband*. The examples below use the small sample file `baseband/data/sample.vdif`, and the `numpy`, `astropy.units`, and `baseband.vdif` modules:

```
>>> import numpy as np
>>> from baseband import vdif
>>> import astropy.units as u
>>> from baseband.data import SAMPLE_VDIF
```

Simple reading and writing of VDIF files can be done entirely using `open`. Opening in binary mode provides a normal file reader, but extended with methods to read a `VDIFFrameSet` data container for storing a frame set as well as `VDIFFrame` one for storing a single frame:

```
>>> fh = vdif.open(SAMPLE_VDIF, 'rb')
>>> fs = fh.read_frameset()
>>> fs.data.shape
(20000, 8, 1)
```

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```
>>> fr = fh.read_frame()
>>> fr.data.shape
(20000, 1)
>>> fh.close()
```

(As with other formats, `fr.data` is a read-only property of the frame.)

Opening in stream mode wraps the low-level routines such that reading and writing is in units of samples. It also provides access to header information:

```
>>> fh = vdif.open(SAMPLE_VDIF, 'rs')
>>> fh
<VDIFStreamReader name=... offset=0
    sample_rate=32.0 MHz, samples_per_frame=20000,
    sample_shape=SampleShape(nthread=8),
    bps=2, complex_data=False, edv=3, station=65532,
    start_time=2014-06-16T05:56:07.000000000>
>>> d = fh.read(12)
>>> d.shape
(12, 8)
>>> d[:, 0].astype(int)  # first thread
array([-1, -1,  3, -1,  1, -1,  3, -1,  1,  3, -1,  1])
>>> fh.close()
```

To set up a file for writing needs quite a bit of header information. Not coincidentally, what is given by the reader above suffices:

```
>>> from astropy.time import Time
>>> fw = vdif.open('try.vdif', 'ws', sample_rate=32*u.MHz,
...                samples_per_frame=20000, nchan=1, nthread=2,
...                complex_data=False, bps=2, edv=3, station=65532,
...                time=Time('2014-06-16T05:56:07.000000000'))
>>> with vdif.open(SAMPLE_VDIF, 'rs', subset=[1, 3]) as fh:
...     d = fh.read(20000)  # Get some data to write
>>> fw.write(d)
>>> fw.close()
>>> fh = vdif.open('try.vdif', 'rs')
>>> d2 = fh.read(12)
>>> np.all(d[:12] == d2)
True
>>> fh.close()
```

Here is a simple example to copy a VDIF file. We use the `sort=False` option to ensure the frames are written exactly in the same order, so the files should be identical:

```
>>> with vdif.open(SAMPLE_VDIF, 'rb') as fr, vdif.open('try.vdif', 'wb') as fw:
...     while True:
...         try:
...             fw.write_frameset(fr.read_frameset(sort=False))
...         except:
...             break
```

For small files, one could just do:

```
>>> with vdif.open(SAMPLE_VDIF, 'rs') as fr, \
...         vdif.open('try.vdif', 'ws', header0=fr.header0,
...                   sample_rate=fr.sample_rate,
```

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```
...                 nthread=fr.sample_shape.nthread) as fw:
...     fw.write(fr.read())
```

This copies everything to memory, though, and some header information is lost.

5.3 Troubleshooting

In situations where the VDIF files being handled are corrupted or modified in an unusual way, using `open` will likely lead to an exception being raised or to unexpected behavior. In such cases, it may still be possible to read in the data. Below, we provide a few solutions and workarounds to do so.

Note: This list is certainly incomplete. If you have an issue (solved or otherwise) you believe should be on this list, please e-mail the *contributors*.

5.3.1 AssertionError when checking EDV in header `verify` function

All VDIF header classes (other than `VDIFLegacyHeader`) check, using their `verify` function, that the EDV read from file matches the class EDV. If they do not, the following line

```
assert self.edv is None or self.edv == self['edv']
```

returns an AssertionError. If this occurs because the VDIF EDV is not yet supported by Baseband, support can be added by implementing a custom header class. If the EDV is supported, but the header deviates from the format found in the VLBI.org EDV registry, the best solution is to create a custom header class, then override the subclass selector in `VDIFHeader`. Tutorials for doing either can be found *here*.

5.3.2 EOFError encountered in `_get_frame_rate` when reading

When the sample rate is not input by the user and cannot be deduced from header information (if EDV = 1 or, the sample rate is found in the header), Baseband tries to determine the frame rate using the private method `_get_frame_rate` in `VDIFStreamReader` (and then multiply by the samples per frame to obtain the sample rate). This function raises `EOFError` if the file contains less than one second of data, or is corrupt. In either case the file can be opened still by explicitly passing in the sample rate to `open` via the `sample_rate` keyword.

5.4 Reference/API

5.4.1 baseband.vdif Package

VLBI Data Interchange Format (VDIF) reader/writer

For the VDIF specification, see http://www.vlbi.org/vdif

Functions

`open`(name[, mode])	Open VDIF file(s) for reading or writing.

open

`baseband.vdif.open`(*name*, *mode='rs'*, ***kwargs*)

Open VDIF file(s) for reading or writing.

Opened as a binary file, one gets a wrapped filehandle that adds methods to read/write a frame. Opened as a stream, the handle is wrapped further, with methods such as reading and writing to the file as if it were a stream of samples.

Parameters

name
[str or filehandle, or sequence of str] File name, filehandle, or sequence of file names (see Notes).

mode
[{'rb', 'wb', 'rs', or 'ws'}, optional] Whether to open for reading or writing, and as a regular binary file or as a stream. Default: 'rs', for reading a stream.

****kwargs**
Additional arguments when opening the file as a stream.

— For reading a stream
[(see `VDIFStreamReader`)]

sample_rate
[`Quantity`, optional] Number of complete samples per second, i.e. the rate at which each channel in each thread is sampled. If `None` (default), will be inferred from the header or by scanning one second of the file.

squeeze
[bool, optional] If `True` (default), remove any dimensions of length unity from decoded data.

subset
[indexing object or tuple of objects, optional] Specific components of the complete sample to decode (after possible squeezing). If a single indexing object is passed, it selects threads. If a tuple is passed, the first selects threads and the second selects channels. If the tuple is empty (default), all components are read.

fill_value
[float or complex, optional] Value to use for invalid or missing data. Default: 0.

verify
[bool, optional] Whether to do basic checks of frame integrity when reading. The first frameset of the stream is always checked. Default: `True`.

— For writing a stream
[(see `VDIFStreamWriter`)]

header0
[`VDIFHeader`] Header for the first frame, holding time information, etc. Can instead give keyword arguments to construct a header (see `**kwargs`).

sample_rate
[`Quantity`] Number of complete samples per second, i.e. the rate at which each channel in each thread is sampled. For EDV 1 and 3, can alternatively set `sample_rate` within the header.

nthread
[int, optional] Number of threads (e.g., 2 for 2 polarisations). Default: 1.

squeeze
[bool, optional] If True (default), writer accepts squeezed arrays as input, and adds any dimensions of length unity.

file_size
[int or None, optional] When writing to a sequence of files, the maximum size of one file in bytes. If None (default), the file size is unlimited, and only the first file will be written to.

****kwargs**
If the header is not given, an attempt will be made to construct one with any further keyword arguments. See VDIFStreamWriter.

Notes

One can also pass to name a list, tuple, or subclass of FileNameSequencer. For writing to multiple files, the file_size keyword must be passed or only the first file will be written to. One may also pass in a sequentialfile object (opened in 'rb' mode for reading or 'w+b' for writing), though for typical use cases it is practically identical to passing in a list or template.

Classes

VDIFFrame(header, payload[, valid, verify])	Representation of a VDIF data frame, consisting of a header and payload.
VDIFFrameSet(frames[, header0])	Representation of a set of VDIF frames, combining different threads.
VDIFHeader(words[, edv, verify])	VDIF Header, supporting different Extended Data Versions.
VDIFPayload(words[, header, nchan, bps, . . .])	Container for decoding and encoding VDIF payloads.

VDIFFrame

class baseband.vdif.**VDIFFrame**(*header*, *payload*, *valid=None*, *verify=True*)
Bases: baseband.vlbi_base.frame.VLBIFrameBase

Representation of a VDIF data frame, consisting of a header and payload.

Parameters

header
[VDIFHeader] Wrapper around the encoded header words, providing access to the header information.

payload
[VDIFPayload] Wrapper around the payload, provding mechanisms to decode it.

valid
[bool or None] Whether the data are valid. If None (default), is inferred from header. Note that header is changed in-place if True or False.

verify
[bool] Whether or not to do basic assertions that check the integrity (e.g., that channel information and whether or not data are complex are consistent between header and data). Default: True.

Notes

The Frame can also be instantiated using class methods:

> fromfile : read header and payload from a filehandle
>
> fromdata : encode data as payload

Of course, one can also do the opposite:

> tofile : method to write header and payload to filehandle
>
> data : property that yields full decoded payload

One can decode part of the payload by indexing or slicing the frame. If the frame does not contain valid data, all values returned are set to `self.fill_value`.

A number of properties are defined: `shape`, `dtype` and `size` are the shape, type and number of complete samples of the data array, and `nbytes` the frame size in bytes. Furthermore, the frame acts as a dictionary, with keys those of the header. Any attribute that is not defined on the frame itself, such as `.time` will be looked up on the header as well.

Attributes Summary

`data`	Full decoded frame.
`dtype`	Numeric type of the frame data.
`fill_value`	Value to replace invalid data in the frame.
`nbytes`	Size of the encoded frame in bytes.
`ndim`	Number of dimensions of the frame data.
`sample_shape`	Shape of a sample in the frame (nchan,).
`shape`	Shape of the frame data.
`size`	Total number of component samples in the frame data.
`valid`	Whether frame contains valid data.

Methods Summary

`from_mark5b_frame`(mark5b_frame[, verify])	Construct an Mark5B over VDIF frame (EDV=0xab).
`fromdata`(data[, header, verify])	Construct frame from data and header.
`fromfile`(fh[, edv, verify])	Read a frame from a filehandle.
`keys`(self)	
`tofile`(self, fh)	Write encoded frame to filehandle.
`verify`(self)	Verify integrity.

Attributes Documentation

`data`
: Full decoded frame.

`dtype`
: Numeric type of the frame data.

`fill_value`
: Value to replace invalid data in the frame.

`nbytes`
Size of the encoded frame in bytes.

`ndim`
Number of dimensions of the frame data.

`sample_shape`
Shape of a sample in the frame (nchan,).

`shape`
Shape of the frame data.

`size`
Total number of component samples in the frame data.

`valid`
Whether frame contains valid data.

This is just the opposite of the `invalid_data` item in the header. If set, that header item is adjusted correspondingly.

Methods Documentation

`classmethod from_mark5b_frame`(*mark5b_frame*, *verify=True*, ***kwargs*)
Construct an Mark5B over VDIF frame (EDV=0xab).

Any additional keywords can be used to set VDIF header properties not found in the Mark 5B header (such as station).

See https://vlbi.org/wp-content/uploads/2019/03/vdif_extension_0xab.pdf

`classmethod fromdata`(*data*, *header=None*, *verify=True*, ***kwargs*)
Construct frame from data and header.

Parameters

data
[`ndarray`] Array holding complex or real data to be encoded.

header
[`VDIFHeader` or None] If not given, will attempt to generate one using the keywords.

verify
[bool, optional] Whether or not to do basic assertions that check the integrity (e.g., that channel information and whether or not data are complex are consistent between header and data). Default: `True`.

****kwargs**
If `header` is not given, these are used to initialize one.

`classmethod fromfile`(*fh*, *edv=None*, *verify=True*)
Read a frame from a filehandle.

Parameters

fh
[filehandle] From which the header and payload are read.

edv
[int, False, or None, optional] Extended Data Version. `False` is for legacy headers. If `None` (default), it will be determined from the words themselves.

verify
[bool, optional] Whether or not to do basic assertions that check the integrity (e.g., that channel information and whether or not data are complex are consistent between header and data). Default: `True`.

keys(*self*)

tofile(*self*, *fh*)
Write encoded frame to filehandle.

verify(*self*)
Verify integrity.

Checks consistency between the header information and payload data shape and type.

VDIFFrameSet

class baseband.vdif.**VDIFFrameSet**(*frames*, *header0=None*)
Bases: `object`

Representation of a set of VDIF frames, combining different threads.

Parameters

frames
[list of `VDIFFrame`] Should all cover the same time span.

header0
[`VDIFHeader`] First header of the frame set. If `None` (default), is extracted from `frames[0]`.

Notes

The FrameSet can also be read instantiated using class methods:

fromfile : read frames from a filehandle, optionally selecting threads

fromdata : encode data as a set of frames

Of course, one can also do the opposite:

tofile : write frames to filehandle

data : property that yields full decoded frame payloads

One can decode part of the payload by indexing or slicing the frame. If the frame does not contain valid data, all values returned are set to `self.fill_value`.

A number of properties are defined: `shape`, `dtype` and `size` are the shape, type and number of complete samples of the data array, and `nbytes` the frame size in bytes. Like a VDIFFrame, the frame set acts as a dictionary, with keys those of the header of the first frame (available via `.header0`). Any attribute that is not defined on the frame set itself, such as `.time` will also be looked up on the header.

Attributes Summary

`data`	Full decoded frame.
`dtype`	Numeric type of the frameset data.
`fill_value`	Value to replace invalid data in the frameset.
`nbytes`	Size of the encoded frame in bytes.
`ndim`	Number of dimensions of the frameset data.
`sample_shape`	Shape of a sample in the frameset (nthread, nchan).
`shape`	Shape of the frameset data.
`size`	Total number of component samples in the frameset data.
`valid`	Whether frameset contains valid data.

Methods Summary

`fromdata`(data[, headers, verify])	Construct a set of frames from data and headers.
`fromfile`(fh[, thread_ids, edv, verify])	Read a frame set from a file, starting at the current location.
`keys`(self)	
`tofile`(self, fh)	Write all encoded frames to filehandle.

Attributes Documentation

data
Full decoded frame.

dtype
Numeric type of the frameset data.

fill_value
Value to replace invalid data in the frameset.

nbytes
Size of the encoded frame in bytes.

ndim
Number of dimensions of the frameset data.

sample_shape
Shape of a sample in the frameset (nthread, nchan).

shape
Shape of the frameset data.

size
Total number of component samples in the frameset data.

valid
Whether frameset contains valid data.

Methods Documentation

classmethod fromdata(*data*, *headers=None*, *verify=True*, ***kwargs*)
Construct a set of frames from data and headers.

Parameters

data
[ndarray] Array holding complex or real data to be encoded. Dimensions should be (samples_per_frame, nthread, nchan).

headers
[VDIFHeader, list of same, or None] If a single header, a list with increasing `thread_id` is generated. If not given, will attempt to generate a header from the keyword arguments.

verify
[bool] Whether or not to do basic assertions that check the integrety (e.g., that channel information and whether or not data are complex are consistent between header and data). Default: `True`.

****kwargs**
If `header` is not given, these are used to initialize one.

Returns

frameset
[VDIFFrameSet]

classmethod fromfile(*fh*, *thread_ids=None*, *edv=None*, *verify=True*)
Read a frame set from a file, starting at the current location.

Parameters

fh
[filehandle] Handle to the VDIF file. Should be at the location where the frames are read from.

thread_ids
[list or None, optional] The thread ids that should be read. If `None` (default), continue reading threads as long as the frame number does not increase.

edv
[int or None, optional] The expected extended data version for the VDIF Header. If `None` (default), use that of the first frame. (Passing it in slightly improves file integrity checking.)

verify
[bool, optional] Whether to do (light) sanity checks on the header. Default: `True`.

Returns

frameset
[VDIFFrameSet] Its `frames` property holds a list of frames (in order of either their `thread_id` or following the input `thread_ids` list). Use the `data` attribute to convert to an array.

keys(*self*)

tofile(*self*, *fh*)
Write all encoded frames to filehandle.

VDIFHeader

class baseband.vdif.**VDIFHeader**(*words*, *edv=None*, *verify=True*, ***kwargs*)

Bases: `baseband.vlbi_base.header.VLBIHeaderBase`

VDIF Header, supporting different Extended Data Versions.

Will initialize a header instance appropriate for a given EDV. See https://vlbi.org/wp-content/uploads/2019/03/VDIF_specification_Release_1.1.1.pdf

Parameters

words
[tuple of int, or None] Eight (or four for legacy VDIF) 32-bit unsigned int header words. If `None`, set to a tuple of zeros for later initialisation.

edv
[int, False, or None, optional] Extended data version. If `False`, a legacy header is used. If `None` (default), it is determined from the header. (Given it explicitly is mostly useful for a slight speed-up.)

verify
[bool] Whether to do basic verification of integrity. Default: `True`.

Returns

header
[`VDIFHeader` subclass] As appropriate for the extended data version.

Attributes Summary

`bps`	Bits per elementary sample.
`edv`	VDIF Extended Data Version (EDV).
`frame_nbytes`	Size of the frame in bytes.
`mutable`	Whether the header can be modified.
`nbytes`	Size of the header in bytes.
`nchan`	Number of channels in the frame.
`payload_nbytes`	Size of the payload in bytes.
`samples_per_frame`	Number of complete samples in the frame.
`station`	Station ID: two ASCII characters, or 16-bit int.
`time`	Converts ref_epoch, seconds, and frame_nr to Time object.

Methods Summary

`copy`(self)	Create a mutable and independent copy of the header.
`from_mark5b_header`(mark5b_header, bps, . . .)	Construct an Mark5B over VDIF header (EDV=0xab).
`fromfile`(fh[, edv, verify])	Read VDIF Header from file.
`fromkeys`(**kwargs)	Initialise a header from parsed values.
`fromvalues`([edv, verify])	Initialise a header from parsed values.

Continued on next page

Table 8 – continued from previous page

get_time(self[, frame_rate])	Converts ref_epoch, seconds, and frame_nr to Time object.
keys(self)	
same_stream(self, other)	Whether header is consistent with being from the same stream.
set_time(self, time[, frame_rate])	Converts Time object to ref_epoch, seconds, and frame_nr.
tofile(self, fh)	Write VLBI frame header to filehandle.
update(self, *[, verify])	Update the header by setting keywords or properties.
verify(self)	Verify that the length of the words is consistent.

Attributes Documentation

bps
Bits per elementary sample.

edv
VDIF Extended Data Version (EDV).

frame_nbytes
Size of the frame in bytes.

mutable
Whether the header can be modified.

nbytes
Size of the header in bytes.

nchan
Number of channels in the frame.

payload_nbytes
Size of the payload in bytes.

samples_per_frame
Number of complete samples in the frame.

station
Station ID: two ASCII characters, or 16-bit int.

time
Converts ref_epoch, seconds, and frame_nr to Time object.

Uses 'ref_epoch', which stores the number of half-years from 2000, and 'seconds'. By default, it also calculates the offset using the current frame number. For non-zero 'frame_nr', this requires the frame rate, which is calculated from the sample rate in the header.

Parameters

frame_rate
[Quantity, optional] For non-zero 'frame_nr', this is required to calculate the corresponding offset.

Returns

time
[Time]

Methods Documentation

`copy`(*self*)

Create a mutable and independent copy of the header.

Keyword arguments can be passed on as needed by possible subclasses.

classmethod from_mark5b_header(*mark5b_header*, *bps*, *nchan*, ***kwargs*)

Construct an Mark5B over VDIF header (EDV=0xab).

See https://vlbi.org/wp-content/uploads/2019/03/vdif_extension_0xab.pdf

Note that the Mark 5B header does not encode the bits-per-sample and the number of channels used in the payload, so these need to be given separately. A complete frame can be encapsulated with `from_mark5b_frame`.

Parameters

mark5b_header
[`Mark5BHeader`] Used to set time, etc.

bps
[int] Bits per elementary sample.

nchan
[int] Number of channels carried in the Mark 5B payload.

****kwargs**
Any further arguments. Strictly, none are necessary to create a valid VDIF header, but this can be used to pass on, e.g., `invalid_data`.

classmethod fromfile(*fh*, *edv=None*, *verify=True*)

Read VDIF Header from file.

Parameters

fh
[filehandle] To read data from.

edv
[int, False, or None, optional] Extended data version. If `False`, a legacy header is used. If `None` (default), it is determined from the header. (Given it explicitly is mostly useful for a slight speed-up.)

verify
[bool, optional] Whether to do basic verification of integrity. Default: `True`.

classmethod fromkeys(***kwargs*)

Initialise a header from parsed values.

Like `fromvalues()`, but without any interpretation of keywords.

Raises

KeyError
[if not all keys required are pass in.]

classmethod fromvalues(*edv=False*, ***, *verify=True*, ***kwargs*)

Initialise a header from parsed values.

Here, the parsed values must be given as keyword arguments, i.e., for any `header = cls(<data>)`, `cls.fromvalues(**header) == header`.

However, unlike for the `fromkeys()` class method, data can also be set using arguments named after methods, such as `bps` and `time`.

Given defaults:

invalid_data : `False` legacy_mode : `False` vdif_version : 1 thread_id : 0 frame_nr : 0 sync_pattern : 0xACABFEED for EDV 1 and 3, 0xa5ea5 for EDV 2

Values set by other keyword arguments (if present):

bits_per_sample : from `bps` frame_length : from `samples_per_frame` or `frame_nbytes` lg2_nchan : from `nchan` station_id : from `station` sampling_rate, sampling_unit : from `sample_rate` ref_epoch, seconds, frame_nr : from `time`

Note that to set `time` to non-integer seconds one also needs to pass in `frame_rate` or `sample_rate`.

`get_time`(*self*, *frame_rate=None*)
Converts ref_epoch, seconds, and frame_nr to Time object.

Uses 'ref_epoch', which stores the number of half-years from 2000, and 'seconds'. By default, it also calculates the offset using the current frame number. For non-zero 'frame_nr', this requires the frame rate, which is calculated from the sample rate in the header.

Parameters

frame_rate
[`Quantity`, optional] For non-zero 'frame_nr', this is required to calculate the corresponding offset.

Returns

time
[`Time`]

`keys`(*self*)

`same_stream`(*self*, *other*)
Whether header is consistent with being from the same stream.

`set_time`(*self*, *time*, *frame_rate=None*)
Converts Time object to ref_epoch, seconds, and frame_nr.

For non-integer seconds, a frame rate is needed to calculate the 'frame_nr'.

Parameters

time
[`Time`] The time to use for this header.

frame_rate
[`Quantity`, optional] For calculating 'frame_nr' from the fractional seconds.

`tofile`(*self*, *fh*)
Write VLBI frame header to filehandle.

`update`(*self*, *, *verify=True*, ***kwargs*)
Update the header by setting keywords or properties.

Here, any keywords matching header keys are applied first, and any remaining ones are used to set header properties, in the order set by the class (in `_properties`).

Parameters

verify
[bool, optional] If `True` (default), verify integrity after updating.

****kwargs**
Arguments used to set keywords and properties.

`verify`(*self*)
Verify that the length of the words is consistent.

Subclasses should override this to do more thorough checks.

VDIFPayload

class `baseband.vdif.`**`VDIFPayload`**(*words*, *header=None*, *nchan=1*, *bps=2*, *complex_data=False*)
Bases: `baseband.vlbi_base.payload.VLBIPayloadBase`

Container for decoding and encoding VDIF payloads.

Parameters

words
[`ndarray`] Array containg LSB unsigned words (with the right size) that encode the payload.

header
[`VDIFHeader`] If given, used to infer the number of channels, bps, and whether the data are complex.

nchan
[int, optional] Number of channels, used if `header` is not given. Default: 1.

bps
[int, optional] Bits per elementary sample, used if `header` is not given. Default: 2.

complex_data
[bool, optional] Whether the data are complex, used if `header` is not given. Default: `False`.

Attributes Summary

`data`	Full decoded payload.
`dtype`	Numeric type of the decoded data array.
`nbytes`	Size of the payload in bytes.
`ndim`	Number of dimensions of the decoded data array.
`shape`	Shape of the decoded data array.
`size`	Total number of component samples in the decoded data array.

Methods Summary

fromdata(data[, header, bps, edv])	Encode data as payload, using header information.
fromfile(fh, header)	Read payload from filehandle and decode it into data.
tofile(self, fh)	Write payload to filehandle.

Attributes Documentation

data
Full decoded payload.

dtype
Numeric type of the decoded data array.

nbytes
Size of the payload in bytes.

ndim
Number of dimensions of the decoded data array.

shape
Shape of the decoded data array.

size
Total number of component samples in the decoded data array.

Methods Documentation

classmethod fromdata(*data*, *header=None*, *bps=2*, *edv=None*)
Encode data as payload, using header information.

Parameters

data
[ndarray] Values to be encoded.

header
[VDIFHeader, optional] If given, used to infer the encoding, and to verify the number of channels and whether the data are complex.

bps
[int, optional] Bits per elementary sample, used if `header` is not given. Default: 2.

edv
[int, optional] Should be given if `header` is not given and the payload is encoded as Mark 5 data (i.e., `edv=0xab`).

classmethod fromfile(*fh*, *header*)
Read payload from filehandle and decode it into data.

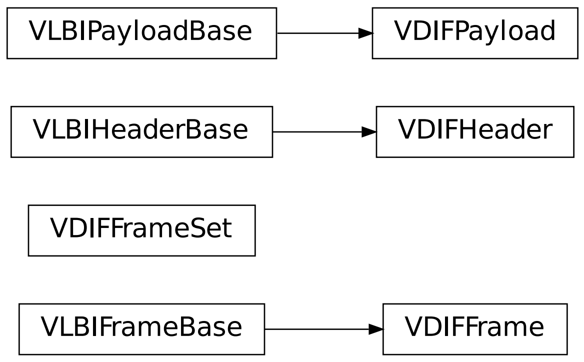
Parameters

fh
[filehandle] To read data from.

header
[VDIFHeader] Used to infer the payload size, number of channels, bits per sample, and whether the data are complex.

tofile(*self*, *fh*)
Write payload to filehandle.

Class Inheritance Diagram



5.4.2 baseband.vdif.header Module

Definitions for VLBI VDIF Headers.

Implements a VDIFHeader class used to store header words, and decode/encode the information therein.

For the VDIF specification, see https://www.vlbi.org/vdif

Classes

`VDIFHeader`(words[, edv, verify])	VDIF Header, supporting different Extended Data Versions.
`VDIFBaseHeader`(words[, edv, verify])	Base for non-legacy VDIF headers that use 8 32-bit words.
`VDIFSampleRateHeader`(words[, edv, verify])	Base for VDIF headers that include the sample rate (EDV= 1, 3, 4).
`VDIFLegacyHeader`(words[, edv, verify])	Legacy VDIF header that uses only 4 32-bit words.
`VDIFHeader0`(words[, edv, verify])	VDIF Header for EDV=0.
`VDIFHeader1`(words[, edv, verify])	VDIF Header for EDV=1.
`VDIFHeader2`(words[, edv, verify])	VDIF Header for EDV=2.
`VDIFHeader3`(words[, edv, verify])	VDIF Header for EDV=3.
`VDIFMark5BHeader`(words[, edv, verify])	Mark 5B over VDIF (EDV=0xab).

VDIFHeader

class baseband.vdif.header.**VDIFHeader**(*words*, *edv=None*, *verify=True*, ***kwargs*)
Bases: `baseband.vlbi_base.header.VLBIHeaderBase`

VDIF Header, supporting different Extended Data Versions.

Will initialize a header instance appropriate for a given EDV. See https://vlbi.org/wp-content/uploads/2019/03/VDIF_specification_Release_1.1.1.pdf

Parameters

words
[tuple of int, or None] Eight (or four for legacy VDIF) 32-bit unsigned int header words. If `None`, set to a tuple of zeros for later initialisation.

edv
[int, False, or None, optional] Extended data version. If `False`, a legacy header is used. If `None` (default), it is determined from the header. (Given it explicitly is mostly useful for a slight speed-up.)

verify
[bool] Whether to do basic verification of integrity. Default: `True`.

Returns

header
[`VDIFHeader` subclass] As appropriate for the extended data version.

Attributes Summary

`bps`	Bits per elementary sample.
`edv`	VDIF Extended Data Version (EDV).
`frame_nbytes`	Size of the frame in bytes.
`mutable`	Whether the header can be modified.
`nbytes`	Size of the header in bytes.
`nchan`	Number of channels in the frame.
`payload_nbytes`	Size of the payload in bytes.
`samples_per_frame`	Number of complete samples in the frame.
`station`	Station ID: two ASCII characters, or 16-bit int.
`time`	Converts ref_epoch, seconds, and frame_nr to Time object.

Methods Summary

`copy`(self)	Create a mutable and independent copy of the header.
`from_mark5b_header`(mark5b_header, bps, . . .)	Construct an Mark5B over VDIF header (EDV=0xab).
`fromfile`(fh[, edv, verify])	Read VDIF Header from file.
`fromkeys`(**kwargs)	Initialise a header from parsed values.
`fromvalues`([edv, verify])	Initialise a header from parsed values.
`get_time`(self[, frame_rate])	Converts ref_epoch, seconds, and frame_nr to Time object.
`keys`(self)	
`same_stream`(self, other)	Whether header is consistent with being from the same stream.

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Table 13 – continued from previous page

`set_time`(self, time[, frame_rate])	Converts Time object to ref_epoch, seconds, and frame_nr.
`tofile`(self, fh)	Write VLBI frame header to filehandle.
`update`(self, *[, verify])	Update the header by setting keywords or properties.
`verify`(self)	Verify that the length of the words is consistent.

Attributes Documentation

`bps`
Bits per elementary sample.

`edv`
VDIF Extended Data Version (EDV).

`frame_nbytes`
Size of the frame in bytes.

`mutable`
Whether the header can be modified.

`nbytes`
Size of the header in bytes.

`nchan`
Number of channels in the frame.

`payload_nbytes`
Size of the payload in bytes.

`samples_per_frame`
Number of complete samples in the frame.

`station`
Station ID: two ASCII characters, or 16-bit int.

`time`
Converts ref_epoch, seconds, and frame_nr to Time object.

Uses 'ref_epoch', which stores the number of half-years from 2000, and 'seconds'. By default, it also calculates the offset using the current frame number. For non-zero 'frame_nr', this requires the frame rate, which is calculated from the sample rate in the header.

Parameters

frame_rate
[`Quantity`, optional] For non-zero 'frame_nr', this is required to calculate the corresponding offset.

Returns

time
[`Time`]

Methods Documentation

`copy`(*self*)
Create a mutable and independent copy of the header.

Keyword arguments can be passed on as needed by possible subclasses.

classmethod from_mark5b_header(*mark5b_header*, *bps*, *nchan*, ***kwargs*)

Construct an Mark5B over VDIF header (EDV=0xab).

See https://vlbi.org/wp-content/uploads/2019/03/vdif_extension_0xab.pdf

Note that the Mark 5B header does not encode the bits-per-sample and the number of channels used in the payload, so these need to be given separately. A complete frame can be encapsulated with `from_mark5b_frame`.

Parameters

mark5b_header
[`Mark5BHeader`] Used to set time, etc.

bps
[int] Bits per elementary sample.

nchan
[int] Number of channels carried in the Mark 5B payload.

****kwargs**
Any further arguments. Strictly, none are necessary to create a valid VDIF header, but this can be used to pass on, e.g., `invalid_data`.

classmethod fromfile(*fh*, *edv=None*, *verify=True*)

Read VDIF Header from file.

Parameters

fh
[filehandle] To read data from.

edv
[int, False, or None, optional] Extended data version. If `False`, a legacy header is used. If `None` (default), it is determined from the header. (Given it explicitly is mostly useful for a slight speed-up.)

verify
[bool, optional] Whether to do basic verification of integrity. Default: `True`.

classmethod fromkeys(***kwargs*)

Initialise a header from parsed values.

Like `fromvalues()`, but without any interpretation of keywords.

Raises

KeyError
[if not all keys required are pass in.]

classmethod fromvalues(*edv=False*, ***, *verify=True*, ***kwargs*)

Initialise a header from parsed values.

Here, the parsed values must be given as keyword arguments, i.e., for any `header = cls(<data>)`, `cls.fromvalues(**header) == header`.

However, unlike for the `fromkeys()` class method, data can also be set using arguments named after methods, such as `bps` and `time`.

Given defaults:

invalid_data : `False` legacy_mode : `False` vdif_version : 1 thread_id : 0 frame_nr : 0 sync_pattern : 0xACABFEED for EDV 1 and 3, 0xa5ea5 for EDV 2

Values set by other keyword arguments (if present):

bits_per_sample : from `bps` frame_length : from `samples_per_frame` or `frame_nbytes` lg2_nchan : from `nchan` station_id : from `station` sampling_rate, sampling_unit : from `sample_rate` ref_epoch, seconds, frame_nr : from `time`

Note that to set `time` to non-integer seconds one also needs to pass in `frame_rate` or `sample_rate`.

`get_time`(*self*, *frame_rate=None*)

Converts ref_epoch, seconds, and frame_nr to Time object.

Uses 'ref_epoch', which stores the number of half-years from 2000, and 'seconds'. By default, it also calculates the offset using the current frame number. For non-zero 'frame_nr', this requires the frame rate, which is calculated from the sample rate in the header.

Parameters

frame_rate
[`Quantity`, optional] For non-zero 'frame_nr', this is required to calculate the corresponding offset.

Returns

time
[`Time`]

`keys`(*self*)

`same_stream`(*self*, *other*)

Whether header is consistent with being from the same stream.

`set_time`(*self*, *time*, *frame_rate=None*)

Converts Time object to ref_epoch, seconds, and frame_nr.

For non-integer seconds, a frame rate is needed to calculate the 'frame_nr'.

Parameters

time
[`Time`] The time to use for this header.

frame_rate
[`Quantity`, optional] For calculating 'frame_nr' from the fractional seconds.

`tofile`(*self*, *fh*)

Write VLBI frame header to filehandle.

`update`(*self*, *, *verify=True*, ***kwargs*)

Update the header by setting keywords or properties.

Here, any keywords matching header keys are applied first, and any remaining ones are used to set header properties, in the order set by the class (in `_properties`).

Parameters

verify
[bool, optional] If `True` (default), verify integrity after updating.

****kwargs**
Arguments used to set keywords and properties.

`verify`(*self*)
Verify that the length of the words is consistent.

Subclasses should override this to do more thorough checks.

VDIFBaseHeader

`class baseband.vdif.header.VDIFBaseHeader`(*words*, *edv=None*, *verify=True*, ***kwargs*)
Bases: `baseband.vdif.header.VDIFHeader`

Base for non-legacy VDIF headers that use 8 32-bit words.

Attributes Summary

`bps`	Bits per elementary sample.
`edv`	VDIF Extended Data Version (EDV).
`frame_nbytes`	Size of the frame in bytes.
`mutable`	Whether the header can be modified.
`nbytes`	Size of the header in bytes.
`nchan`	Number of channels in the frame.
`payload_nbytes`	Size of the payload in bytes.
`samples_per_frame`	Number of complete samples in the frame.
`station`	Station ID: two ASCII characters, or 16-bit int.
`time`	Converts ref_epoch, seconds, and frame_nr to Time object.

Methods Summary

`copy`(self)	Create a mutable and independent copy of the header.
`from_mark5b_header`(mark5b_header, bps, . . .)	Construct an Mark5B over VDIF header (EDV=0xab).
`fromfile`(fh[, edv, verify])	Read VDIF Header from file.
`fromkeys`(**kwargs)	Initialise a header from parsed values.
`fromvalues`([edv, verify])	Initialise a header from parsed values.
`get_time`(self[, frame_rate])	Converts ref_epoch, seconds, and frame_nr to Time object.
`keys`(self)	
`same_stream`(self, other)	Whether header is consistent with being from the same stream.
`set_time`(self, time[, frame_rate])	Converts Time object to ref_epoch, seconds, and frame_nr.
`tofile`(self, fh)	Write VLBI frame header to filehandle.
`update`(self, *[, verify])	Update the header by setting keywords or properties.
`verify`(self)	Basic checks of header integrity.

Attributes Documentation

bps
Bits per elementary sample.

edv
VDIF Extended Data Version (EDV).

frame_nbytes
Size of the frame in bytes.

mutable
Whether the header can be modified.

nbytes
Size of the header in bytes.

nchan
Number of channels in the frame.

payload_nbytes
Size of the payload in bytes.

samples_per_frame
Number of complete samples in the frame.

station
Station ID: two ASCII characters, or 16-bit int.

time
Converts ref_epoch, seconds, and frame_nr to Time object.

Uses 'ref_epoch', which stores the number of half-years from 2000, and 'seconds'. By default, it also calculates the offset using the current frame number. For non-zero 'frame_nr', this requires the frame rate, which is calculated from the sample rate in the header.

Parameters

frame_rate
[Quantity, optional] For non-zero 'frame_nr', this is required to calculate the corresponding offset.

Returns

time
[Time]

Methods Documentation

copy(*self*)
Create a mutable and independent copy of the header.

Keyword arguments can be passed on as needed by possible subclasses.

classmethod from_mark5b_header(*mark5b_header*, *bps*, *nchan*, ***kwargs*)
Construct an Mark5B over VDIF header (EDV=0xab).

See https://vlbi.org/wp-content/uploads/2019/03/vdif_extension_0xab.pdf

Note that the Mark 5B header does not encode the bits-per-sample and the number of channels used in the payload, so these need to be given separately. A complete frame can be encapsulated with `from_mark5b_frame`.

Parameters

mark5b_header
[`Mark5BHeader`] Used to set time, etc.

bps
[int] Bits per elementary sample.

nchan
[int] Number of channels carried in the Mark 5B payload.

****kwargs**
Any further arguments. Strictly, none are necessary to create a valid VDIF header, but this can be used to pass on, e.g., `invalid_data`.

classmethod fromfile(*fh*, *edv=None*, *verify=True*)
Read VDIF Header from file.

Parameters

fh
[filehandle] To read data from.

edv
[int, False, or None, optional] Extended data version. If `False`, a legacy header is used. If `None` (default), it is determined from the header. (Given it explicitly is mostly useful for a slight speed-up.)

verify
[bool, optional] Whether to do basic verification of integrity. Default: `True`.

classmethod fromkeys(***kwargs*)
Initialise a header from parsed values.

Like `fromvalues()`, but without any interpretation of keywords.

Raises

KeyError
[if not all keys required are pass in.]

classmethod fromvalues(*edv=False*, *, *verify=True*, ***kwargs*)
Initialise a header from parsed values.

Here, the parsed values must be given as keyword arguments, i.e., for any `header = cls(<data>)`, `cls.fromvalues(**header) == header`.

However, unlike for the `fromkeys()` class method, data can also be set using arguments named after methods, such as `bps` and `time`.

Given defaults:

invalid_data : `False` legacy_mode : `False` vdif_version : 1 thread_id : 0 frame_nr : 0 sync_pattern : 0xACABFEED for EDV 1 and 3, 0xa5ea5 for EDV 2

Values set by other keyword arguments (if present):

bits_per_sample : from `bps` frame_length : from `samples_per_frame` or `frame_nbytes` lg2_nchan : from `nchan` station_id : from `station` sampling_rate, sampling_unit : from `sample_rate` ref_epoch, seconds, frame_nr : from `time`

Note that to set `time` to non-integer seconds one also needs to pass in `frame_rate` or `sample_rate`.

`get_time`(*self*, *frame_rate=None*)

Converts ref_epoch, seconds, and frame_nr to Time object.

Uses 'ref_epoch', which stores the number of half-years from 2000, and 'seconds'. By default, it also calculates the offset using the current frame number. For non-zero 'frame_nr', this requires the frame rate, which is calculated from the sample rate in the header.

Parameters

frame_rate
[`Quantity`, optional] For non-zero 'frame_nr', this is required to calculate the corresponding offset.

Returns

time
[`Time`]

`keys`(*self*)

`same_stream`(*self*, *other*)

Whether header is consistent with being from the same stream.

`set_time`(*self*, *time*, *frame_rate=None*)

Converts Time object to ref_epoch, seconds, and frame_nr.

For non-integer seconds, a frame rate is needed to calculate the 'frame_nr'.

Parameters

time
[`Time`] The time to use for this header.

frame_rate
[`Quantity`, optional] For calculating 'frame_nr' from the fractional seconds.

`tofile`(*self*, *fh*)

Write VLBI frame header to filehandle.

`update`(*self*, ***, *verify=True*, ***kwargs*)

Update the header by setting keywords or properties.

Here, any keywords matching header keys are applied first, and any remaining ones are used to set header properties, in the order set by the class (in `_properties`).

Parameters

verify
[bool, optional] If `True` (default), verify integrity after updating.

****kwargs**
Arguments used to set keywords and properties.

verify(*self*)
Basic checks of header integrity.

VDIFSampleRateHeader

class baseband.vdif.header.**VDIFSampleRateHeader**(*words*, *edv=None*, *verify=True*, ***kwargs*)
Bases: baseband.vdif.header.VDIFBaseHeader

Base for VDIF headers that include the sample rate (EDV= 1, 3, 4).

Attributes Summary

bps	Bits per elementary sample.
edv	VDIF Extended Data Version (EDV).
frame_nbytes	Size of the frame in bytes.
frame_rate	Number of frames per second.
mutable	Whether the header can be modified.
nbytes	Size of the header in bytes.
nchan	Number of channels in the frame.
payload_nbytes	Size of the payload in bytes.
sample_rate	Number of complete samples per second.
samples_per_frame	Number of complete samples in the frame.
station	Station ID: two ASCII characters, or 16-bit int.
time	Converts ref_epoch, seconds, and frame_nr to Time object.

Methods Summary

copy(self)	Create a mutable and independent copy of the header.
from_mark5b_header(mark5b_header, bps, . . .)	Construct an Mark5B over VDIF header (EDV=0xab).
fromfile(fh[, edv, verify])	Read VDIF Header from file.
fromkeys(**kwargs)	Initialise a header from parsed values.
fromvalues([edv, verify])	Initialise a header from parsed values.
get_time(self[, frame_rate])	Converts ref_epoch, seconds, and frame_nr to Time object.
keys(self)	
same_stream(self, other)	Whether header is consistent with being from the same stream.
set_time(self, time[, frame_rate])	Converts Time object to ref_epoch, seconds, and frame_nr.
tofile(self, fh)	Write VLBI frame header to filehandle.
update(self, *[, verify])	Update the header by setting keywords or properties.
verify(self)	Basic checks of header integrity.

Attributes Documentation

bps
Bits per elementary sample.

`edv`
VDIF Extended Data Version (EDV).

`frame_nbytes`
Size of the frame in bytes.

`frame_rate`
Number of frames per second.

Assumes the 'sampling_rate' header field represents a per-channel sample rate for complex samples, or half the sample rate for real ones.

`mutable`
Whether the header can be modified.

`nbytes`
Size of the header in bytes.

`nchan`
Number of channels in the frame.

`payload_nbytes`
Size of the payload in bytes.

`sample_rate`
Number of complete samples per second.

Assumes the 'sampling_rate' header field represents a per-channel sample rate for complex samples, or half the sample rate for real ones.

`samples_per_frame`
Number of complete samples in the frame.

`station`
Station ID: two ASCII characters, or 16-bit int.

`time`
Converts ref_epoch, seconds, and frame_nr to Time object.

Uses 'ref_epoch', which stores the number of half-years from 2000, and 'seconds'. By default, it also calculates the offset using the current frame number. For non-zero 'frame_nr', this requires the frame rate, which is calculated from the sample rate in the header. The latter can also be explicitly passed on.

Parameters

frame_rate
[`Quantity`, optional] For non-zero 'frame_nr', this is used to calculate the corresponding offset. If not given, the frame rate from the header is used (if it is non-zero).

Returns

time
[`Time`]

Methods Documentation

`copy`(*self*)
Create a mutable and independent copy of the header.

Keyword arguments can be passed on as needed by possible subclasses.

classmethod from_mark5b_header(*mark5b_header*, *bps*, *nchan*, ***kwargs*)

Construct an Mark5B over VDIF header (EDV=0xab).

See https://vlbi.org/wp-content/uploads/2019/03/vdif_extension_0xab.pdf

Note that the Mark 5B header does not encode the bits-per-sample and the number of channels used in the payload, so these need to be given separately. A complete frame can be encapsulated with `from_mark5b_frame`.

Parameters

mark5b_header
[`Mark5BHeader`] Used to set time, etc.

bps
[int] Bits per elementary sample.

nchan
[int] Number of channels carried in the Mark 5B payload.

****kwargs**
Any further arguments. Strictly, none are necessary to create a valid VDIF header, but this can be used to pass on, e.g., `invalid_data`.

classmethod fromfile(*fh*, *edv=None*, *verify=True*)

Read VDIF Header from file.

Parameters

fh
[filehandle] To read data from.

edv
[int, False, or None, optional] Extended data version. If `False`, a legacy header is used. If `None` (default), it is determined from the header. (Given it explicitly is mostly useful for a slight speed-up.)

verify
[bool, optional] Whether to do basic verification of integrity. Default: `True`.

classmethod fromkeys(***kwargs*)

Initialise a header from parsed values.

Like `fromvalues()`, but without any interpretation of keywords.

Raises

KeyError
[if not all keys required are pass in.]

classmethod fromvalues(*edv=False*, ***, *verify=True*, ***kwargs*)

Initialise a header from parsed values.

Here, the parsed values must be given as keyword arguments, i.e., for any `header = cls(<data>)`, `cls.fromvalues(**header) == header`.

However, unlike for the `fromkeys()` class method, data can also be set using arguments named after methods, such as `bps` and `time`.

Given defaults:

invalid_data : `False` legacy_mode : `False` vdif_version : 1 thread_id : 0 frame_nr : 0 sync_pattern : 0xACABFEED for EDV 1 and 3, 0xa5ea5 for EDV 2

Values set by other keyword arguments (if present):

bits_per_sample : from `bps` frame_length : from `samples_per_frame` or `frame_nbytes` lg2_nchan : from `nchan` station_id : from `station` sampling_rate, sampling_unit : from `sample_rate` ref_epoch, seconds, frame_nr : from `time`

Note that to set `time` to non-integer seconds one also needs to pass in `frame_rate` or `sample_rate`.

`get_time`(*self*, *frame_rate=None*)
Converts ref_epoch, seconds, and frame_nr to Time object.

Uses 'ref_epoch', which stores the number of half-years from 2000, and 'seconds'. By default, it also calculates the offset using the current frame number. For non-zero 'frame_nr', this requires the frame rate, which is calculated from the sample rate in the header. The latter can also be explicitly passed on.

Parameters

frame_rate
[`Quantity`, optional] For non-zero 'frame_nr', this is used to calculate the corresponding offset. If not given, the frame rate from the header is used (if it is non-zero).

Returns

time
[`Time`]

`keys`(*self*)

`same_stream`(*self*, *other*)
Whether header is consistent with being from the same stream.

`set_time`(*self*, *time*, *frame_rate=None*)
Converts Time object to ref_epoch, seconds, and frame_nr.

Parameters

time
[`Time`] The time to use for this header.

frame_rate
[`Quantity`, optional] For calculating 'frame_nr' from the fractional seconds. If not given, the frame rate from the header is used (if it is non-zero).

`tofile`(*self*, *fh*)
Write VLBI frame header to filehandle.

`update`(*self*, *, *verify=True*, ***kwargs*)
Update the header by setting keywords or properties.

Here, any keywords matching header keys are applied first, and any remaining ones are used to set header properties, in the order set by the class (in `_properties`).

Parameters

verify
[bool, optional] If `True` (default), verify integrity after updating.

****kwargs**
Arguments used to set keywords and properties.

`verify`(*self*)
Basic checks of header integrity.

VDIFLegacyHeader

class `baseband.vdif.header.`**`VDIFLegacyHeader`**(*words*, *edv=None*, *verify=True*, ***kwargs*)
Bases: `baseband.vdif.header.VDIFHeader`

Legacy VDIF header that uses only 4 32-bit words.

See Section 6 of https://vlbi.org/wp-content/uploads/2019/03/VDIF_specification_Release_1.1.1.pdf

Attributes Summary

`bps`	Bits per elementary sample.
`edv`	VDIF Extended Data Version (EDV).
`frame_nbytes`	Size of the frame in bytes.
`mutable`	Whether the header can be modified.
`nbytes`	Size of the header in bytes.
`nchan`	Number of channels in the frame.
`payload_nbytes`	Size of the payload in bytes.
`samples_per_frame`	Number of complete samples in the frame.
`station`	Station ID: two ASCII characters, or 16-bit int.
`time`	Converts ref_epoch, seconds, and frame_nr to Time object.

Methods Summary

`copy`(self)	Create a mutable and independent copy of the header.
`from_mark5b_header`(mark5b_header, bps, …)	Construct an Mark5B over VDIF header (EDV=0xab).
`fromfile`(fh[, edv, verify])	Read VDIF Header from file.
`fromkeys`(**kwargs)	Initialise a header from parsed values.
`fromvalues`([edv, verify])	Initialise a header from parsed values.
`get_time`(self[, frame_rate])	Converts ref_epoch, seconds, and frame_nr to Time object.
`keys`(self)	
`same_stream`(self, other)	Whether header is consistent with being from the same stream.
`set_time`(self, time[, frame_rate])	Converts Time object to ref_epoch, seconds, and frame_nr.
`tofile`(self, fh)	Write VLBI frame header to filehandle.
`update`(self, *[, verify])	Update the header by setting keywords or properties.
`verify`(self)	Basic checks of header integrity.

Attributes Documentation

bps
Bits per elementary sample.

edv
VDIF Extended Data Version (EDV).

frame_nbytes
Size of the frame in bytes.

mutable
Whether the header can be modified.

nbytes
Size of the header in bytes.

nchan
Number of channels in the frame.

payload_nbytes
Size of the payload in bytes.

samples_per_frame
Number of complete samples in the frame.

station
Station ID: two ASCII characters, or 16-bit int.

time
Converts ref_epoch, seconds, and frame_nr to Time object.

Uses 'ref_epoch', which stores the number of half-years from 2000, and 'seconds'. By default, it also calculates the offset using the current frame number. For non-zero 'frame_nr', this requires the frame rate, which is calculated from the sample rate in the header.

Parameters

frame_rate
[Quantity, optional] For non-zero 'frame_nr', this is required to calculate the corresponding offset.

Returns

time
[Time]

Methods Documentation

copy(*self*)
Create a mutable and independent copy of the header.

Keyword arguments can be passed on as needed by possible subclasses.

classmethod from_mark5b_header(*mark5b_header*, *bps*, *nchan*, ***kwargs*)
Construct an Mark5B over VDIF header (EDV=0xab).

See https://vlbi.org/wp-content/uploads/2019/03/vdif_extension_0xab.pdf

Note that the Mark 5B header does not encode the bits-per-sample and the number of channels used in the payload, so these need to be given separately. A complete frame can be encapsulated with `from_mark5b_frame`.

Parameters

mark5b_header
[`Mark5BHeader`] Used to set time, etc.

bps
[int] Bits per elementary sample.

nchan
[int] Number of channels carried in the Mark 5B payload.

****kwargs**
Any further arguments. Strictly, none are necessary to create a valid VDIF header, but this can be used to pass on, e.g., `invalid_data`.

classmethod fromfile(*fh*, *edv=None*, *verify=True*)
Read VDIF Header from file.

Parameters

fh
[filehandle] To read data from.

edv
[int, False, or None, optional] Extended data version. If `False`, a legacy header is used. If `None` (default), it is determined from the header. (Given it explicitly is mostly useful for a slight speed-up.)

verify
[bool, optional] Whether to do basic verification of integrity. Default: `True`.

classmethod fromkeys(***kwargs*)
Initialise a header from parsed values.

Like `fromvalues()`, but without any interpretation of keywords.

Raises

KeyError
[if not all keys required are pass in.]

classmethod fromvalues(*edv=False*, *, *verify=True*, ***kwargs*)
Initialise a header from parsed values.

Here, the parsed values must be given as keyword arguments, i.e., for any `header = cls(<data>)`, `cls.fromvalues(**header) == header`.

However, unlike for the `fromkeys()` class method, data can also be set using arguments named after methods, such as `bps` and `time`.

Given defaults:

invalid_data : `False` legacy_mode : `False` vdif_version : 1 thread_id : 0 frame_nr : 0 sync_pattern : 0xACABFEED for EDV 1 and 3, 0xa5ea5 for EDV 2

Values set by other keyword arguments (if present):

bits_per_sample : from `bps` frame_length : from `samples_per_frame` or `frame_nbytes` lg2_nchan : from `nchan` station_id : from `station` sampling_rate, sampling_unit : from `sample_rate` ref_epoch, seconds, frame_nr : from `time`

Note that to set `time` to non-integer seconds one also needs to pass in `frame_rate` or `sample_rate`.

get_time(*self*, *frame_rate=None*)
Converts ref_epoch, seconds, and frame_nr to Time object.

Uses 'ref_epoch', which stores the number of half-years from 2000, and 'seconds'. By default, it also calculates the offset using the current frame number. For non-zero 'frame_nr', this requires the frame rate, which is calculated from the sample rate in the header.

Parameters

frame_rate
[`Quantity`, optional] For non-zero 'frame_nr', this is required to calculate the corresponding offset.

Returns

time
[`Time`]

keys(*self*)

same_stream(*self*, *other*)
Whether header is consistent with being from the same stream.

set_time(*self*, *time*, *frame_rate=None*)
Converts Time object to ref_epoch, seconds, and frame_nr.

For non-integer seconds, a frame rate is needed to calculate the 'frame_nr'.

Parameters

time
[`Time`] The time to use for this header.

frame_rate
[`Quantity`, optional] For calculating 'frame_nr' from the fractional seconds.

tofile(*self*, *fh*)
Write VLBI frame header to filehandle.

update(*self*, *, *verify=True*, ***kwargs*)
Update the header by setting keywords or properties.

Here, any keywords matching header keys are applied first, and any remaining ones are used to set header properties, in the order set by the class (in `_properties`).

Parameters

verify
[bool, optional] If `True` (default), verify integrity after updating.

****kwargs**
Arguments used to set keywords and properties.

verify(*self*)
Basic checks of header integrity.

VDIFHeader0

class baseband.vdif.header.**VDIFHeader0**(*words*, *edv=None*, *verify=True*, ***kwargs*)
Bases: baseband.vdif.header.VDIFBaseHeader

VDIF Header for EDV=0.

EDV=0 implies the extended user data fields are not used.

Attributes Summary

bps	Bits per elementary sample.
edv	VDIF Extended Data Version (EDV).
frame_nbytes	Size of the frame in bytes.
mutable	Whether the header can be modified.
nbytes	Size of the header in bytes.
nchan	Number of channels in the frame.
payload_nbytes	Size of the payload in bytes.
samples_per_frame	Number of complete samples in the frame.
station	Station ID: two ASCII characters, or 16-bit int.
time	Converts ref_epoch, seconds, and frame_nr to Time object.

Methods Summary

copy(self)	Create a mutable and independent copy of the header.
from_mark5b_header(mark5b_header, bps, . . .)	Construct an Mark5B over VDIF header (EDV=0xab).
fromfile(fh[, edv, verify])	Read VDIF Header from file.
fromkeys(**kwargs)	Initialise a header from parsed values.
fromvalues([edv, verify])	Initialise a header from parsed values.
get_time(self[, frame_rate])	Converts ref_epoch, seconds, and frame_nr to Time object.
keys(self)	
same_stream(self, other)	Whether header is consistent with being from the same stream.
set_time(self, time[, frame_rate])	Converts Time object to ref_epoch, seconds, and frame_nr.
tofile(self, fh)	Write VLBI frame header to filehandle.
update(self, *[, verify])	Update the header by setting keywords or properties.
verify(self)	Basic checks of header integrity.

Attributes Documentation

bps
Bits per elementary sample.

edv

VDIF Extended Data Version (EDV).

`frame_nbytes`
Size of the frame in bytes.

`mutable`
Whether the header can be modified.

`nbytes`
Size of the header in bytes.

`nchan`
Number of channels in the frame.

`payload_nbytes`
Size of the payload in bytes.

`samples_per_frame`
Number of complete samples in the frame.

`station`
Station ID: two ASCII characters, or 16-bit int.

`time`
Converts ref_epoch, seconds, and frame_nr to Time object.

Uses 'ref_epoch', which stores the number of half-years from 2000, and 'seconds'. By default, it also calculates the offset using the current frame number. For non-zero 'frame_nr', this requires the frame rate, which is calculated from the sample rate in the header.

Parameters

frame_rate
[`Quantity`, optional] For non-zero 'frame_nr', this is required to calculate the corresponding offset.

Returns

time
[`Time`]

Methods Documentation

`copy`(*self*)
Create a mutable and independent copy of the header.

Keyword arguments can be passed on as needed by possible subclasses.

`classmethod from_mark5b_header`(*mark5b_header*, *bps*, *nchan*, ***kwargs*)
Construct an Mark5B over VDIF header (EDV=0xab).

See https://vlbi.org/wp-content/uploads/2019/03/vdif_extension_0xab.pdf

Note that the Mark 5B header does not encode the bits-per-sample and the number of channels used in the payload, so these need to be given separately. A complete frame can be encapsulated with `from_mark5b_frame`.

Parameters

mark5b_header
[Mark5BHeader] Used to set time, etc.

bps
[int] Bits per elementary sample.

nchan
[int] Number of channels carried in the Mark 5B payload.

****kwargs**
Any further arguments. Strictly, none are necessary to create a valid VDIF header, but this can be used to pass on, e.g., `invalid_data`.

classmethod fromfile(*fh*, *edv=None*, *verify=True*)
Read VDIF Header from file.

Parameters

fh
[filehandle] To read data from.

edv
[int, False, or None, optional] Extended data version. If `False`, a legacy header is used. If `None` (default), it is determined from the header. (Given it explicitly is mostly useful for a slight speed-up.)

verify
[bool, optional] Whether to do basic verification of integrity. Default: `True`.

classmethod fromkeys(***kwargs*)
Initialise a header from parsed values.

Like `fromvalues()`, but without any interpretation of keywords.

Raises

KeyError
[if not all keys required are pass in.]

classmethod fromvalues(*edv=False*, ***, *verify=True*, ***kwargs*)
Initialise a header from parsed values.

Here, the parsed values must be given as keyword arguments, i.e., for any `header = cls(<data>)`, `cls.fromvalues(**header) == header`.

However, unlike for the `fromkeys()` class method, data can also be set using arguments named after methods, such as `bps` and `time`.

Given defaults:

invalid_data : `False` legacy_mode : `False` vdif_version : 1 thread_id : 0 frame_nr : 0 sync_pattern : 0xACABFEED for EDV 1 and 3, 0xa5ea5 for EDV 2

Values set by other keyword arguments (if present):

bits_per_sample : from `bps` frame_length : from `samples_per_frame` or `frame_nbytes` lg2_nchan : from `nchan` station_id : from `station` sampling_rate, sampling_unit : from `sample_rate` ref_epoch, seconds, frame_nr : from `time`

Note that to set `time` to non-integer seconds one also needs to pass in `frame_rate` or `sample_rate`.

get_time(*self*, *frame_rate=None*)
Converts ref_epoch, seconds, and frame_nr to Time object.

Uses 'ref_epoch', which stores the number of half-years from 2000, and 'seconds'. By default, it also calculates the offset using the current frame number. For non-zero 'frame_nr', this requires the frame rate, which is calculated from the sample rate in the header.

Parameters

frame_rate
[`Quantity`, optional] For non-zero 'frame_nr', this is required to calculate the corresponding offset.

Returns

time
[`Time`]

keys(*self*)

same_stream(*self*, *other*)
Whether header is consistent with being from the same stream.

set_time(*self*, *time*, *frame_rate=None*)
Converts Time object to ref_epoch, seconds, and frame_nr.

For non-integer seconds, a frame rate is needed to calculate the 'frame_nr'.

Parameters

time
[`Time`] The time to use for this header.

frame_rate
[`Quantity`, optional] For calculating 'frame_nr' from the fractional seconds.

tofile(*self*, *fh*)
Write VLBI frame header to filehandle.

update(*self*, ***, *verify=True*, ***kwargs*)
Update the header by setting keywords or properties.

Here, any keywords matching header keys are applied first, and any remaining ones are used to set header properties, in the order set by the class (in `_properties`).

Parameters

verify
[bool, optional] If `True` (default), verify integrity after updating.

****kwargs**
Arguments used to set keywords and properties.

verify(*self*)
Basic checks of header integrity.

VDIFHeader1

class baseband.vdif.header.**VDIFHeader1**(*words*, *edv=None*, *verify=True*, ***kwargs*)

Bases: `baseband.vdif.header.VDIFSampleRateHeader`

VDIF Header for EDV=1.

See https://vlbi.org/wp-content/uploads/2019/03/vdif_extension_0x01.pdf

Attributes Summary

`bps`	Bits per elementary sample.
`edv`	VDIF Extended Data Version (EDV).
`frame_nbytes`	Size of the frame in bytes.
`frame_rate`	Number of frames per second.
`mutable`	Whether the header can be modified.
`nbytes`	Size of the header in bytes.
`nchan`	Number of channels in the frame.
`payload_nbytes`	Size of the payload in bytes.
`sample_rate`	Number of complete samples per second.
`samples_per_frame`	Number of complete samples in the frame.
`station`	Station ID: two ASCII characters, or 16-bit int.
`time`	Converts ref_epoch, seconds, and frame_nr to Time object.

Methods Summary

`copy`(self)	Create a mutable and independent copy of the header.
`from_mark5b_header`(mark5b_header, bps, …)	Construct an Mark5B over VDIF header (EDV=0xab).
`fromfile`(fh[, edv, verify])	Read VDIF Header from file.
`fromkeys`(**kwargs)	Initialise a header from parsed values.
`fromvalues`([edv, verify])	Initialise a header from parsed values.
`get_time`(self[, frame_rate])	Converts ref_epoch, seconds, and frame_nr to Time object.
`keys`(self)	
`same_stream`(self, other)	Whether header is consistent with being from the same stream.
`set_time`(self, time[, frame_rate])	Converts Time object to ref_epoch, seconds, and frame_nr.
`tofile`(self, fh)	Write VLBI frame header to filehandle.
`update`(self, *[, verify])	Update the header by setting keywords or properties.
`verify`(self)	Basic checks of header integrity.

Attributes Documentation

bps

Bits per elementary sample.

edv

VDIF Extended Data Version (EDV).

`frame_nbytes`
Size of the frame in bytes.

`frame_rate`
Number of frames per second.

Assumes the 'sampling_rate' header field represents a per-channel sample rate for complex samples, or half the sample rate for real ones.

`mutable`
Whether the header can be modified.

`nbytes`
Size of the header in bytes.

`nchan`
Number of channels in the frame.

`payload_nbytes`
Size of the payload in bytes.

`sample_rate`
Number of complete samples per second.

Assumes the 'sampling_rate' header field represents a per-channel sample rate for complex samples, or half the sample rate for real ones.

`samples_per_frame`
Number of complete samples in the frame.

`station`
Station ID: two ASCII characters, or 16-bit int.

`time`
Converts ref_epoch, seconds, and frame_nr to Time object.

Uses 'ref_epoch', which stores the number of half-years from 2000, and 'seconds'. By default, it also calculates the offset using the current frame number. For non-zero 'frame_nr', this requires the frame rate, which is calculated from the sample rate in the header. The latter can also be explicitly passed on.

Parameters

frame_rate
[`Quantity`, optional] For non-zero 'frame_nr', this is used to calculate the corresponding offset. If not given, the frame rate from the header is used (if it is non-zero).

Returns

time
[`Time`]

Methods Documentation

`copy`(*self*)
Create a mutable and independent copy of the header.

Keyword arguments can be passed on as needed by possible subclasses.

`classmethod from_mark5b_header`(*mark5b_header*, *bps*, *nchan*, ***kwargs*)
Construct an Mark5B over VDIF header (EDV=0xab).

See https://vlbi.org/wp-content/uploads/2019/03/vdif_extension_0xab.pdf

Note that the Mark 5B header does not encode the bits-per-sample and the number of channels used in the payload, so these need to be given separately. A complete frame can be encapsulated with `from_mark5b_frame`.

Parameters

mark5b_header
[`Mark5BHeader`] Used to set time, etc.

bps
[int] Bits per elementary sample.

nchan
[int] Number of channels carried in the Mark 5B payload.

****kwargs**
Any further arguments. Strictly, none are necessary to create a valid VDIF header, but this can be used to pass on, e.g., `invalid_data`.

classmethod fromfile(*fh*, *edv=None*, *verify=True*)
Read VDIF Header from file.

Parameters

fh
[filehandle] To read data from.

edv
[int, False, or None, optional] Extended data version. If `False`, a legacy header is used. If `None` (default), it is determined from the header. (Given it explicitly is mostly useful for a slight speed-up.)

verify
[bool, optional] Whether to do basic verification of integrity. Default: `True`.

classmethod fromkeys(***kwargs*)
Initialise a header from parsed values.

Like `fromvalues()`, but without any interpretation of keywords.

Raises

KeyError
[if not all keys required are pass in.]

classmethod fromvalues(*edv=False*, *, *verify=True*, ***kwargs*)
Initialise a header from parsed values.

Here, the parsed values must be given as keyword arguments, i.e., for any `header = cls(<data>)`, `cls.fromvalues(**header) == header`.

However, unlike for the `fromkeys()` class method, data can also be set using arguments named after methods, such as `bps` and `time`.

Given defaults:

invalid_data : `False` legacy_mode : `False` vdif_version : 1 thread_id : 0 frame_nr : 0 sync_pattern : 0xACABFEED for EDV 1 and 3, 0xa5ea5 for EDV 2

Values set by other keyword arguments (if present):

bits_per_sample : from `bps` frame_length : from `samples_per_frame` or `frame_nbytes` lg2_nchan : from `nchan` station_id : from `station` sampling_rate, sampling_unit : from `sample_rate` ref_epoch, seconds, frame_nr : from `time`

Note that to set `time` to non-integer seconds one also needs to pass in `frame_rate` or `sample_rate`.

`get_time`(*self*, *frame_rate=None*)

Converts ref_epoch, seconds, and frame_nr to Time object.

Uses 'ref_epoch', which stores the number of half-years from 2000, and 'seconds'. By default, it also calculates the offset using the current frame number. For non-zero 'frame_nr', this requires the frame rate, which is calculated from the sample rate in the header. The latter can also be explicitly passed on.

Parameters

frame_rate
[`Quantity`, optional] For non-zero 'frame_nr', this is used to calculate the corresponding offset. If not given, the frame rate from the header is used (if it is non-zero).

Returns

time
[`Time`]

`keys`(*self*)

`same_stream`(*self*, *other*)

Whether header is consistent with being from the same stream.

`set_time`(*self*, *time*, *frame_rate=None*)

Converts Time object to ref_epoch, seconds, and frame_nr.

Parameters

time
[`Time`] The time to use for this header.

frame_rate
[`Quantity`, optional] For calculating 'frame_nr' from the fractional seconds. If not given, the frame rate from the header is used (if it is non-zero).

`tofile`(*self*, *fh*)

Write VLBI frame header to filehandle.

`update`(*self*, *, *verify=True*, ***kwargs*)

Update the header by setting keywords or properties.

Here, any keywords matching header keys are applied first, and any remaining ones are used to set header properties, in the order set by the class (in `_properties`).

Parameters

verify
[bool, optional] If `True` (default), verify integrity after updating.

****kwargs**
Arguments used to set keywords and properties.

verify(*self*)
Basic checks of header integrity.

VDIFHeader2

class baseband.vdif.header.**VDIFHeader2**(*words*, *edv=None*, *verify=True*, ***kwargs*)
Bases: baseband.vdif.header.VDIFBaseHeader

VDIF Header for EDV=2.

See https://vlbi.org/wp-content/uploads/2019/03/alma-vdif-edv.pdf

Notes

This header is untested. It may need to have subclasses, based on possible different sync values.

Attributes Summary

bps	Bits per elementary sample.
edv	VDIF Extended Data Version (EDV).
frame_nbytes	Size of the frame in bytes.
mutable	Whether the header can be modified.
nbytes	Size of the header in bytes.
nchan	Number of channels in the frame.
payload_nbytes	Size of the payload in bytes.
samples_per_frame	Number of complete samples in the frame.
station	Station ID: two ASCII characters, or 16-bit int.
time	Converts ref_epoch, seconds, and frame_nr to Time object.

Methods Summary

copy(self)	Create a mutable and independent copy of the header.
from_mark5b_header(mark5b_header, bps, . . .)	Construct an Mark5B over VDIF header (EDV=0xab).
fromfile(fh[, edv, verify])	Read VDIF Header from file.
fromkeys(**kwargs)	Initialise a header from parsed values.
fromvalues([edv, verify])	Initialise a header from parsed values.
get_time(self[, frame_rate])	Converts ref_epoch, seconds, and frame_nr to Time object.
keys(self)	
same_stream(self, other)	Whether header is consistent with being from the same stream.
set_time(self, time[, frame_rate])	Converts Time object to ref_epoch, seconds, and frame_nr.
tofile(self, fh)	Write VLBI frame header to filehandle.
update(self, *[, verify])	Update the header by setting keywords or properties.
verify(self)	Basic checks of header integrity.

Attributes Documentation

`bps`
Bits per elementary sample.

`edv`
VDIF Extended Data Version (EDV).

`frame_nbytes`
Size of the frame in bytes.

`mutable`
Whether the header can be modified.

`nbytes`
Size of the header in bytes.

`nchan`
Number of channels in the frame.

`payload_nbytes`
Size of the payload in bytes.

`samples_per_frame`
Number of complete samples in the frame.

`station`
Station ID: two ASCII characters, or 16-bit int.

`time`
Converts ref_epoch, seconds, and frame_nr to Time object.

Uses 'ref_epoch', which stores the number of half-years from 2000, and 'seconds'. By default, it also calculates the offset using the current frame number. For non-zero 'frame_nr', this requires the frame rate, which is calculated from the sample rate in the header.

Parameters

frame_rate
[`Quantity`, optional] For non-zero 'frame_nr', this is required to calculate the corresponding offset.

Returns

time
[`Time`]

Methods Documentation

`copy`(*self*)
Create a mutable and independent copy of the header.

Keyword arguments can be passed on as needed by possible subclasses.

`classmethod from_mark5b_header`(*mark5b_header*, *bps*, *nchan*, ***kwargs*)
Construct an Mark5B over VDIF header (EDV=0xab).

See https://vlbi.org/wp-content/uploads/2019/03/vdif_extension_0xab.pdf

Note that the Mark 5B header does not encode the bits-per-sample and the number of channels used in the payload, so these need to be given separately. A complete frame can be encapsulated with `from_mark5b_frame`.

Parameters

mark5b_header
[`Mark5BHeader`] Used to set time, etc.

bps
[int] Bits per elementary sample.

nchan
[int] Number of channels carried in the Mark 5B payload.

****kwargs**
Any further arguments. Strictly, none are necessary to create a valid VDIF header, but this can be used to pass on, e.g., `invalid_data`.

classmethod fromfile(*fh*, *edv=None*, *verify=True*)
Read VDIF Header from file.

Parameters

fh
[filehandle] To read data from.

edv
[int, False, or None, optional] Extended data version. If `False`, a legacy header is used. If `None` (default), it is determined from the header. (Given it explicitly is mostly useful for a slight speed-up.)

verify
[bool, optional] Whether to do basic verification of integrity. Default: `True`.

classmethod fromkeys(***kwargs*)
Initialise a header from parsed values.

Like `fromvalues()`, but without any interpretation of keywords.

Raises

KeyError
[if not all keys required are pass in.]

classmethod fromvalues(*edv=False*, *, *verify=True*, ***kwargs*)
Initialise a header from parsed values.

Here, the parsed values must be given as keyword arguments, i.e., for any `header = cls(<data>)`, `cls.fromvalues(**header) == header`.

However, unlike for the `fromkeys()` class method, data can also be set using arguments named after methods, such as `bps` and `time`.

Given defaults:

invalid_data : `False` legacy_mode : `False` vdif_version : 1 thread_id : 0 frame_nr : 0 sync_pattern : 0xACABFEED for EDV 1 and 3, 0xa5ea5 for EDV 2

Values set by other keyword arguments (if present):

bits_per_sample : from `bps` frame_length : from `samples_per_frame` or `frame_nbytes` lg2_nchan : from `nchan` station_id : from `station` sampling_rate, sampling_unit : from `sample_rate` ref_epoch, seconds, frame_nr : from `time`

Note that to set `time` to non-integer seconds one also needs to pass in `frame_rate` or `sample_rate`.

`get_time`(*self*, *frame_rate=None*)
Converts ref_epoch, seconds, and frame_nr to Time object.

Uses 'ref_epoch', which stores the number of half-years from 2000, and 'seconds'. By default, it also calculates the offset using the current frame number. For non-zero 'frame_nr', this requires the frame rate, which is calculated from the sample rate in the header.

Parameters

frame_rate
[`Quantity`, optional] For non-zero 'frame_nr', this is required to calculate the corresponding offset.

Returns

time
[`Time`]

`keys`(*self*)

`same_stream`(*self*, *other*)
Whether header is consistent with being from the same stream.

`set_time`(*self*, *time*, *frame_rate=None*)
Converts Time object to ref_epoch, seconds, and frame_nr.

For non-integer seconds, a frame rate is needed to calculate the 'frame_nr'.

Parameters

time
[`Time`] The time to use for this header.

frame_rate
[`Quantity`, optional] For calculating 'frame_nr' from the fractional seconds.

`tofile`(*self*, *fh*)
Write VLBI frame header to filehandle.

`update`(*self*, ***, *verify=True*, ***kwargs*)
Update the header by setting keywords or properties.

Here, any keywords matching header keys are applied first, and any remaining ones are used to set header properties, in the order set by the class (in `_properties`).

Parameters

verify
[bool, optional] If `True` (default), verify integrity after updating.

****kwargs**
Arguments used to set keywords and properties.

verify(*self*)
Basic checks of header integrity.

VDIFHeader3

class baseband.vdif.header.**VDIFHeader3**(*words*, *edv=None*, *verify=True*, ***kwargs*)
Bases: baseband.vdif.header.VDIFSampleRateHeader

VDIF Header for EDV=3.

See https://vlbi.org/wp-content/uploads/2019/03/vdif_extension_0x03.pdf

Attributes Summary

bps	Bits per elementary sample.
edv	VDIF Extended Data Version (EDV).
frame_nbytes	Size of the frame in bytes.
frame_rate	Number of frames per second.
mutable	Whether the header can be modified.
nbytes	Size of the header in bytes.
nchan	Number of channels in the frame.
payload_nbytes	Size of the payload in bytes.
sample_rate	Number of complete samples per second.
samples_per_frame	Number of complete samples in the frame.
station	Station ID: two ASCII characters, or 16-bit int.
time	Converts ref_epoch, seconds, and frame_nr to Time object.

Methods Summary

copy(self)	Create a mutable and independent copy of the header.
from_mark5b_header(mark5b_header, bps, . . .)	Construct an Mark5B over VDIF header (EDV=0xab).
fromfile(fh[, edv, verify])	Read VDIF Header from file.
fromkeys(**kwargs)	Initialise a header from parsed values.
fromvalues([edv, verify])	Initialise a header from parsed values.
get_time(self[, frame_rate])	Converts ref_epoch, seconds, and frame_nr to Time object.
keys(self)	
same_stream(self, other)	Whether header is consistent with being from the same stream.
set_time(self, time[, frame_rate])	Converts Time object to ref_epoch, seconds, and frame_nr.
tofile(self, fh)	Write VLBI frame header to filehandle.
update(self, *[, verify])	Update the header by setting keywords or properties.
verify(self)	Basic checks of header integrity.

Attributes Documentation

`bps`
Bits per elementary sample.

`edv`
VDIF Extended Data Version (EDV).

`frame_nbytes`
Size of the frame in bytes.

`frame_rate`
Number of frames per second.

Assumes the 'sampling_rate' header field represents a per-channel sample rate for complex samples, or half the sample rate for real ones.

`mutable`
Whether the header can be modified.

`nbytes`
Size of the header in bytes.

`nchan`
Number of channels in the frame.

`payload_nbytes`
Size of the payload in bytes.

`sample_rate`
Number of complete samples per second.

Assumes the 'sampling_rate' header field represents a per-channel sample rate for complex samples, or half the sample rate for real ones.

`samples_per_frame`
Number of complete samples in the frame.

`station`
Station ID: two ASCII characters, or 16-bit int.

`time`
Converts ref_epoch, seconds, and frame_nr to Time object.

Uses 'ref_epoch', which stores the number of half-years from 2000, and 'seconds'. By default, it also calculates the offset using the current frame number. For non-zero 'frame_nr', this requires the frame rate, which is calculated from the sample rate in the header. The latter can also be explicitly passed on.

Parameters

frame_rate
[`Quantity`, optional] For non-zero 'frame_nr', this is used to calculate the corresponding offset. If not given, the frame rate from the header is used (if it is non-zero).

Returns

time
[`Time`]

Methods Documentation

`copy`(*self*)

Create a mutable and independent copy of the header.

Keyword arguments can be passed on as needed by possible subclasses.

`classmethod from_mark5b_header`(*mark5b_header*, *bps*, *nchan*, ***kwargs*)

Construct an Mark5B over VDIF header (EDV=0xab).

See https://vlbi.org/wp-content/uploads/2019/03/vdif_extension_0xab.pdf

Note that the Mark 5B header does not encode the bits-per-sample and the number of channels used in the payload, so these need to be given separately. A complete frame can be encapsulated with `from_mark5b_frame`.

Parameters

mark5b_header
[`Mark5BHeader`] Used to set time, etc.

bps
[int] Bits per elementary sample.

nchan
[int] Number of channels carried in the Mark 5B payload.

****kwargs**
Any further arguments. Strictly, none are necessary to create a valid VDIF header, but this can be used to pass on, e.g., `invalid_data`.

`classmethod fromfile`(*fh*, *edv=None*, *verify=True*)

Read VDIF Header from file.

Parameters

fh
[filehandle] To read data from.

edv
[int, False, or None, optional] Extended data version. If `False`, a legacy header is used. If `None` (default), it is determined from the header. (Given it explicitly is mostly useful for a slight speed-up.)

verify
[bool, optional] Whether to do basic verification of integrity. Default: `True`.

`classmethod fromkeys`(***kwargs*)

Initialise a header from parsed values.

Like `fromvalues()`, but without any interpretation of keywords.

Raises

KeyError
[if not all keys required are pass in.]

`classmethod fromvalues`(*edv=False*, *, *verify=True*, ***kwargs*)

Initialise a header from parsed values.

Here, the parsed values must be given as keyword arguments, i.e., for any `header = cls(<data>)`, `cls.fromvalues(**header) == header`.

However, unlike for the `fromkeys()` class method, data can also be set using arguments named after methods, such as `bps` and `time`.

Given defaults:

invalid_data : `False` legacy_mode : `False` vdif_version : 1 thread_id : 0 frame_nr : 0 sync_pattern : 0xACABFEED for EDV 1 and 3, 0xa5ea5 for EDV 2

Values set by other keyword arguments (if present):

bits_per_sample : from `bps` frame_length : from `samples_per_frame` or `frame_nbytes` lg2_nchan : from `nchan` station_id : from `station` sampling_rate, sampling_unit : from `sample_rate` ref_epoch, seconds, frame_nr : from `time`

Note that to set `time` to non-integer seconds one also needs to pass in `frame_rate` or `sample_rate`.

`get_time`(*self*, *frame_rate=None*)

Converts ref_epoch, seconds, and frame_nr to Time object.

Uses 'ref_epoch', which stores the number of half-years from 2000, and 'seconds'. By default, it also calculates the offset using the current frame number. For non-zero 'frame_nr', this requires the frame rate, which is calculated from the sample rate in the header. The latter can also be explicitly passed on.

Parameters

frame_rate
[`Quantity`, optional] For non-zero 'frame_nr', this is used to calculate the corresponding offset. If not given, the frame rate from the header is used (if it is non-zero).

Returns

time
[`Time`]

`keys`(*self*)

`same_stream`(*self*, *other*)

Whether header is consistent with being from the same stream.

`set_time`(*self*, *time*, *frame_rate=None*)

Converts Time object to ref_epoch, seconds, and frame_nr.

Parameters

time
[`Time`] The time to use for this header.

frame_rate
[`Quantity`, optional] For calculating 'frame_nr' from the fractional seconds. If not given, the frame rate from the header is used (if it is non-zero).

`tofile`(*self*, *fh*)

Write VLBI frame header to filehandle.

`update`(*self*, ***, *verify=True*, ***kwargs*)

Update the header by setting keywords or properties.

Here, any keywords matching header keys are applied first, and any remaining ones are used to set header properties, in the order set by the class (in `_properties`).

Parameters

verify
[bool, optional] If `True` (default), verify integrity after updating.

****kwargs**
Arguments used to set keywords and properties.

`verify`(*self*)
Basic checks of header integrity.

VDIFMark5BHeader

class `baseband.vdif.header.`**`VDIFMark5BHeader`**(*words*, *edv=None*, *verify=True*, ***kwargs*)
Bases: `baseband.vdif.header.VDIFBaseHeader`, `baseband.mark5b.header.Mark5BHeader`

Mark 5B over VDIF (EDV=0xab).

See https://vlbi.org/wp-content/uploads/2019/03/vdif_extension_0xab.pdf

Attributes Summary

`bps`	Bits per elementary sample.
`edv`	VDIF Extended Data Version (EDV).
`fraction`	Fractional seconds (decoded from 'bcd_fraction').
`frame_nbytes`	Size of the frame in bytes.
`jday`	Last three digits of MJD (decoded from 'bcd_jday').
`kday`	
`mutable`	Whether the header can be modified.
`nbytes`	Size of the header in bytes.
`nchan`	Number of channels in the frame.
`payload_nbytes`	Size of the payload in bytes.
`samples_per_frame`	Number of complete samples in the frame.
`seconds`	Integer seconds on day (decoded from 'bcd_seconds').
`station`	Station ID: two ASCII characters, or 16-bit int.
`time`	Convert ref_epoch, seconds, and fractional seconds to Time object.

Methods Summary

`copy`(self)	Create a mutable and independent copy of the header.
`from_mark5b_header`(mark5b_header, bps, …)	Construct an Mark5B over VDIF header (EDV=0xab).
`fromfile`(fh[, edv, verify])	Read VDIF Header from file.
`fromkeys`(**kwargs)	Initialise a header from parsed values.
`fromvalues`([edv, verify])	Initialise a header from parsed values.

Continued on next page

Table 29 – continued from previous page

get_time(self[, frame_rate])	Convert ref_epoch, seconds, and fractional seconds to Time object.
infer_kday(self, ref_time)	Uses a reference time to set a header's kday.
keys(self)	
same_stream(self, other)	Whether header is consistent with being from the same stream.
set_time(self, time[, frame_rate])	Converts Time object to ref_epoch, seconds, and frame_nr.
tofile(self, fh)	Write VLBI frame header to filehandle.
update(self, *[, crc, verify])	Update the header by setting keywords or properties.
verify(self)	Basic checks of header integrity.

Attributes Documentation

bps
Bits per elementary sample.

edv
VDIF Extended Data Version (EDV).

fraction
Fractional seconds (decoded from 'bcd_fraction').

The fraction is stored to 0.1 ms accuracy. Following mark5access, this is "unrounded" to give the exact time of the start of the frame for any total bit rate below 512 Mbps. For rates above this value, it is no longer guaranteed that subsequent frames have unique rates.

Note to the above: since a Mark5B frame contains 80000 bits, the total bit rate for which times can be unique would in principle be 800 Mbps. However, standard VLBI only uses bit rates that are powers of 2 in MHz.

frame_nbytes
Size of the frame in bytes.

jday
Last three digits of MJD (decoded from 'bcd_jday').

kday = None

mutable
Whether the header can be modified.

nbytes
Size of the header in bytes.

nchan
Number of channels in the frame.

payload_nbytes
Size of the payload in bytes.

samples_per_frame
Number of complete samples in the frame.

seconds
Integer seconds on day (decoded from 'bcd_seconds').

`station`

Station ID: two ASCII characters, or 16-bit int.

`time`

Convert ref_epoch, seconds, and fractional seconds to Time object.

Uses 'ref_epoch', which stores the number of half-years from 2000, and 'seconds', from the VDIF part of the header, and the fractional seconds from the Mark 5B part.

Since some Mark 5B headers do not store the fractional seconds, one can also calculates the offset using the current frame number by passing in a sample rate.

Furthermore, fractional seconds are stored only to 0.1 ms accuracy. In the code, this is "unrounded" to give the exact time of the start of the frame for any total bit rate below 512 Mbps. For rates above this value, it is no longer guaranteed that subsequent frames have unique rates, and one should pass in an explicit sample rate instead.

Parameters

frame_rate
[`Quantity`, optional] For non-zero 'frame_nr', this is used to calculate the corresponding offset.

Returns

time
[`Time`]

Methods Documentation

`copy`(*self*)

Create a mutable and independent copy of the header.

Keyword arguments can be passed on as needed by possible subclasses.

`classmethod from_mark5b_header`(*mark5b_header*, *bps*, *nchan*, ***kwargs*)

Construct an Mark5B over VDIF header (EDV=0xab).

See https://vlbi.org/wp-content/uploads/2019/03/vdif_extension_0xab.pdf

Note that the Mark 5B header does not encode the bits-per-sample and the number of channels used in the payload, so these need to be given separately. A complete frame can be encapsulated with `from_mark5b_frame`.

Parameters

mark5b_header
[`Mark5BHeader`] Used to set time, etc.

bps
[int] Bits per elementary sample.

nchan
[int] Number of channels carried in the Mark 5B payload.

****kwargs**
Any further arguments. Strictly, none are necessary to create a valid VDIF header, but this can be used to pass on, e.g., `invalid_data`.

classmethod fromfile(*fh*, *edv=None*, *verify=True*)

Read VDIF Header from file.

Parameters

fh
[filehandle] To read data from.

edv
[int, False, or None, optional] Extended data version. If `False`, a legacy header is used. If `None` (default), it is determined from the header. (Given it explicitly is mostly useful for a slight speed-up.)

verify
[bool, optional] Whether to do basic verification of integrity. Default: `True`.

classmethod fromkeys(***kwargs*)

Initialise a header from parsed values.

Like `fromvalues()`, but without any interpretation of keywords.

Raises

KeyError
[if not all keys required are pass in.]

classmethod fromvalues(*edv=False*, ***, *verify=True*, ***kwargs*)

Initialise a header from parsed values.

Here, the parsed values must be given as keyword arguments, i.e., for any `header = cls(<data>)`, `cls.fromvalues(**header) == header`.

However, unlike for the `fromkeys()` class method, data can also be set using arguments named after methods, such as `bps` and `time`.

Given defaults:

invalid_data : `False` legacy_mode : `False` vdif_version : 1 thread_id : 0 frame_nr : 0 sync_pattern : 0xACABFEED for EDV 1 and 3, 0xa5ea5 for EDV 2

Values set by other keyword arguments (if present):

bits_per_sample : from `bps` frame_length : from `samples_per_frame` or `frame_nbytes` lg2_nchan : from `nchan` station_id : from `station` sampling_rate, sampling_unit : from `sample_rate` ref_epoch, seconds, frame_nr : from `time`

Note that to set `time` to non-integer seconds one also needs to pass in `frame_rate` or `sample_rate`.

get_time(*self*, *frame_rate=None*)

Convert ref_epoch, seconds, and fractional seconds to Time object.

Uses 'ref_epoch', which stores the number of half-years from 2000, and 'seconds', from the VDIF part of the header, and the fractional seconds from the Mark 5B part.

Since some Mark 5B headers do not store the fractional seconds, one can also calculates the offset using the current frame number by passing in a sample rate.

Furthermore, fractional seconds are stored only to 0.1 ms accuracy. In the code, this is "unrounded" to give the exact time of the start of the frame for any total bit rate below 512 Mbps. For rates above this value, it is no longer guaranteed that subsequent frames have unique rates, and one should pass in an explicit sample rate instead.

Parameters

frame_rate
[`Quantity`, optional] For non-zero 'frame_nr', this is used to calculate the corresponding offset.

Returns

time
[`Time`]

infer_kday(*self*, *ref_time*)
Uses a reference time to set a header's `kday`.

Parameters

ref_time
[`Time`] Reference time within 500 days of the observation time.

keys(*self*)

same_stream(*self*, *other*)
Whether header is consistent with being from the same stream.

set_time(*self*, *time*, *frame_rate=None*)
Converts Time object to ref_epoch, seconds, and frame_nr.

For non-integer seconds, a frame rate is needed to calculate the 'frame_nr'.

Parameters

time
[`Time`] The time to use for this header.

frame_rate
[`Quantity`, optional] For calculating 'frame_nr' from the fractional seconds.

tofile(*self*, *fh*)
Write VLBI frame header to filehandle.

update(*self*, ***, *crc=None*, *verify=True*, ***kwargs*)
Update the header by setting keywords or properties.

Here, any keywords matching header keys are applied first, and any remaining ones are used to set header properties, in the order set by the class (in `_properties`).

Parameters

crc
[int or None, optional] If `None` (default), recalculate the CRC after updating.

verify
[bool, optional] If `True` (default), verify integrity after updating.

****kwargs**
Arguments used to set keywords and properties.

verify(*self*)
Basic checks of header integrity.

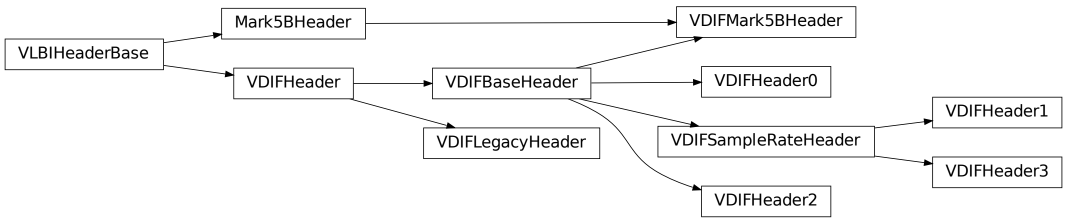
Variables

VDIF_HEADER_CLASSES	Dict for storing VDIF header class definitions, indexed by their EDV.

VDIF_HEADER_CLASSES

baseband.vdif.header.**VDIF_HEADER_CLASSES = {-1: <class 'baseband.vdif.header.VDIFLegacyHeader'>, 0: <class '**
Dict for storing VDIF header class definitions, indexed by their EDV.

Class Inheritance Diagram



5.4.3 baseband.vdif.payload Module

Definitions for VLBI VDIF payloads.

Implements a VDIFPayload class used to store payload words, and decode to or encode from a data array.

See the VDIF specification page for payload specifications.

Functions

init_luts()	Sets up the look-up tables for levels as a function of input byte.
decode_1bit(words)	
decode_2bit(words)	Decodes data stored using 2 bits per sample.
decode_4bit(words)	Decodes data stored using 4 bits per sample.
encode_1bit(values)	Encodes values using 1 bit per sample, packing the result into bytes.
encode_2bit(values)	Encodes values using 2 bits per sample, packing the result into bytes.

Continued on next page

Table 31 – continued from previous page

encode_4bit(values)	Encodes values using 4 bits per sample, packing the result into bytes.

init_luts

`baseband.vdif.payload.`**`init_luts`**`()`

Sets up the look-up tables for levels as a function of input byte.

Returns

lut1bit, lut2bit, lut4but
[ndarray] Look-up table for decoding bytes to samples of 1, 2, and 4 bits, resp.

Notes

Look-up tables are two-dimensional arrays whose first axis is indexed by byte value (in uint8 form) and whose second axis represents sample temporal order. Table values are decoded sample values. Sec. 10 in the VDIF Specification states that samples are encoded by offset-binary, such that all 0 bits is lowest and all 1 bits is highest. I.e., for 2-bit sampling, the order is 00, 01, 10, 11. These are decoded using `decoder_levels`.

For example, the 2-bit sample sequence `-1, -1, 1, 1` is encoded as `0b10100101` (or `165` in uint8 form). To translate this back to sample values, access `lut2bit` using the byte as the key:

```
>>> lut2bit[0b10100101]
array([-1., -1.,  1.,  1.], dtype=float32)
```

decode_1bit

`baseband.vdif.payload.`**`decode_1bit`**`(`*words*`)`

decode_2bit

`baseband.vdif.payload.`**`decode_2bit`**`(`*words*`)`

Decodes data stored using 2 bits per sample.

decode_4bit

`baseband.vdif.payload.`**`decode_4bit`**`(`*words*`)`

Decodes data stored using 4 bits per sample.

encode_1bit

`baseband.vdif.payload.`**`encode_1bit`**`(`*values*`)`

Encodes values using 1 bit per sample, packing the result into bytes.

encode_2bit

`baseband.vdif.payload.`**`encode_2bit`**(*values*)

Encodes values using 2 bits per sample, packing the result into bytes.

encode_4bit

`baseband.vdif.payload.`**`encode_4bit`**(*values*)

Encodes values using 4 bits per sample, packing the result into bytes.

Classes

`VDIFPayload`(words[, header, nchan, bps, . . .])	Container for decoding and encoding VDIF payloads.

VDIFPayload

`class` `baseband.vdif.payload.`**`VDIFPayload`**(*words*, *header=None*, *nchan=1*, *bps=2*, *complex_data=False*)

Bases: `baseband.vlbi_base.payload.VLBIPayloadBase`

Container for decoding and encoding VDIF payloads.

Parameters

words
[`ndarray`] Array containg LSB unsigned words (with the right size) that encode the payload.

header
[`VDIFHeader`] If given, used to infer the number of channels, bps, and whether the data are complex.

nchan
[int, optional] Number of channels, used if `header` is not given. Default: 1.

bps
[int, optional] Bits per elementary sample, used if `header` is not given. Default: 2.

complex_data
[bool, optional] Whether the data are complex, used if `header` is not given. Default: `False`.

Attributes Summary

`data`	Full decoded payload.
`dtype`	Numeric type of the decoded data array.
`nbytes`	Size of the payload in bytes.
`ndim`	Number of dimensions of the decoded data array.
`shape`	Shape of the decoded data array.
`size`	Total number of component samples in the decoded data array.

Methods Summary

`fromdata`(data[, header, bps, edv])	Encode data as payload, using header information.
`fromfile`(fh, header)	Read payload from filehandle and decode it into data.
`tofile`(self, fh)	Write payload to filehandle.

Attributes Documentation

`data`
Full decoded payload.

`dtype`
Numeric type of the decoded data array.

`nbytes`
Size of the payload in bytes.

`ndim`
Number of dimensions of the decoded data array.

`shape`
Shape of the decoded data array.

`size`
Total number of component samples in the decoded data array.

Methods Documentation

`classmethod fromdata`(*data*, *header=None*, *bps=2*, *edv=None*)
Encode data as payload, using header information.

Parameters

data
[`ndarray`] Values to be encoded.

header
[`VDIFHeader`, optional] If given, used to infer the encoding, and to verify the number of channels and whether the data are complex.

bps
[int, optional] Bits per elementary sample, used if `header` is not given. Default: 2.

edv
[int, optional] Should be given if `header` is not given and the payload is encoded as Mark 5 data (i.e., `edv=0xab`).

`classmethod fromfile`(*fh*, *header*)
Read payload from filehandle and decode it into data.

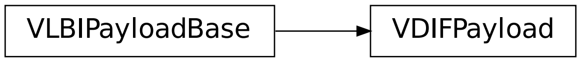
Parameters

fh
[filehandle] To read data from.

header
[VDIFHeader] Used to infer the payload size, number of channels, bits per sample, and whether the data are complex.

`tofile`(*self*, *fh*)
Write payload to filehandle.

Class Inheritance Diagram



5.4.4 baseband.vdif.frame Module

Definitions for VLBI VDIF frames and frame sets.

Implements a VDIFFrame class that can be used to hold a header and a payload, providing access to the values encoded in both. Also, define a VDIFFrameSet class that combines a set of frames from different threads.

For the VDIF specification, see https://www.vlbi.org/vdif

Classes

`VDIFFrame`(header, payload[, valid, verify])	Representation of a VDIF data frame, consisting of a header and payload.
`VDIFFrameSet`(frames[, header0])	Representation of a set of VDIF frames, combining different threads.

VDIFFrame

class `baseband.vdif.frame.`**`VDIFFrame`**(*header*, *payload*, *valid=None*, *verify=True*)
Bases: `baseband.vlbi_base.frame.VLBIFrameBase`

Representation of a VDIF data frame, consisting of a header and payload.

Parameters

header
[VDIFHeader] Wrapper around the encoded header words, providing access to the header information.

payload
[VDIFPayload] Wrapper around the payload, provding mechanisms to decode it.

valid
[bool or None] Whether the data are valid. If `None` (default), is inferred from header. Note

that `header` is changed in-place if `True` or `False`.

verify

[bool] Whether or not to do basic assertions that check the integrity (e.g., that channel information and whether or not data are complex are consistent between header and data). Default: `True`.

Notes

The Frame can also be instantiated using class methods:

fromfile : read header and payload from a filehandle

fromdata : encode data as payload

Of course, one can also do the opposite:

tofile : method to write header and payload to filehandle

data : property that yields full decoded payload

One can decode part of the payload by indexing or slicing the frame. If the frame does not contain valid data, all values returned are set to `self.fill_value`.

A number of properties are defined: `shape`, `dtype` and `size` are the shape, type and number of complete samples of the data array, and `nbytes` the frame size in bytes. Furthermore, the frame acts as a dictionary, with keys those of the header. Any attribute that is not defined on the frame itself, such as `.time` will be looked up on the header as well.

Attributes Summary

`data`	Full decoded frame.
`dtype`	Numeric type of the frame data.
`fill_value`	Value to replace invalid data in the frame.
`nbytes`	Size of the encoded frame in bytes.
`ndim`	Number of dimensions of the frame data.
`sample_shape`	Shape of a sample in the frame (nchan,).
`shape`	Shape of the frame data.
`size`	Total number of component samples in the frame data.
`valid`	Whether frame contains valid data.

Methods Summary

`from_mark5b_frame`(mark5b_frame[, verify])	Construct an Mark5B over VDIF frame (EDV=0xab).
`fromdata`(data[, header, verify])	Construct frame from data and header.
`fromfile`(fh[, edv, verify])	Read a frame from a filehandle.
`keys`(self)	
`tofile`(self, fh)	Write encoded frame to filehandle.
`verify`(self)	Verify integrity.

Attributes Documentation

`data`
Full decoded frame.

`dtype`
Numeric type of the frame data.

`fill_value`
Value to replace invalid data in the frame.

`nbytes`
Size of the encoded frame in bytes.

`ndim`
Number of dimensions of the frame data.

`sample_shape`
Shape of a sample in the frame (nchan,).

`shape`
Shape of the frame data.

`size`
Total number of component samples in the frame data.

`valid`
Whether frame contains valid data.

This is just the opposite of the `invalid_data` item in the header. If set, that header item is adjusted correspondingly.

Methods Documentation

classmethod from_mark5b_frame(*mark5b_frame*, *verify=True*, ***kwargs*)
Construct an Mark5B over VDIF frame (EDV=0xab).

Any additional keywords can be used to set VDIF header properties not found in the Mark 5B header (such as station).

See https://vlbi.org/wp-content/uploads/2019/03/vdif_extension_0xab.pdf

classmethod fromdata(*data*, *header=None*, *verify=True*, ***kwargs*)
Construct frame from data and header.

Parameters

data
[`ndarray`] Array holding complex or real data to be encoded.

header
[`VDIFHeader` or None] If not given, will attempt to generate one using the keywords.

verify
[bool, optional] Whether or not to do basic assertions that check the integrity (e.g., that channel information and whether or not data are complex are consistent between header and data). Default: `True`.

****kwargs**
If `header` is not given, these are used to initialize one.

classmethod fromfile(*fh*, *edv=None*, *verify=True*)
Read a frame from a filehandle.

Parameters

fh
[filehandle] From which the header and payload are read.

edv
[int, False, or None, optional] Extended Data Version. `False` is for legacy headers. If `None` (default), it will be determined from the words themselves.

verify
[bool, optional] Whether or not to do basic assertions that check the integrity (e.g., that channel information and whether or not data are complex are consistent between header and data). Default: `True`.

keys(*self*)

tofile(*self*, *fh*)
Write encoded frame to filehandle.

verify(*self*)
Verify integrity.

Checks consistency between the header information and payload data shape and type.

VDIFFrameSet

class baseband.vdif.frame.**VDIFFrameSet**(*frames*, *header0=None*)
Bases: `object`

Representation of a set of VDIF frames, combining different threads.

Parameters

frames
[list of `VDIFFrame`] Should all cover the same time span.

header0
[`VDIFHeader`] First header of the frame set. If `None` (default), is extracted from `frames[0]`.

Notes

The FrameSet can also be read instantiated using class methods:

fromfile : read frames from a filehandle, optionally selecting threads

fromdata : encode data as a set of frames

Of course, one can also do the opposite:

tofile : write frames to filehandle

data : property that yields full decoded frame payloads

One can decode part of the payload by indexing or slicing the frame. If the frame does not contain valid data, all values returned are set to `self.fill_value`.

A number of properties are defined: `shape`, `dtype` and `size` are the shape, type and number of complete samples of the data array, and `nbytes` the frame size in bytes. Like a VDIFFrame, the frame set acts as a dictionary, with keys those of the header of the first frame (available via `.header0`). Any attribute that is not defined on the frame set itself, such as `.time` will also be looked up on the header.

Attributes Summary

`data`	Full decoded frame.
`dtype`	Numeric type of the frameset data.
`fill_value`	Value to replace invalid data in the frameset.
`nbytes`	Size of the encoded frame in bytes.
`ndim`	Number of dimensions of the frameset data.
`sample_shape`	Shape of a sample in the frameset (nthread, nchan).
`shape`	Shape of the frameset data.
`size`	Total number of component samples in the frameset data.
`valid`	Whether frameset contains valid data.

Methods Summary

`fromdata`(data[, headers, verify])	Construct a set of frames from data and headers.
`fromfile`(fh[, thread_ids, edv, verify])	Read a frame set from a file, starting at the current location.
`keys`(self)	
`tofile`(self, fh)	Write all encoded frames to filehandle.

Attributes Documentation

data
Full decoded frame.

dtype
Numeric type of the frameset data.

fill_value
Value to replace invalid data in the frameset.

nbytes
Size of the encoded frame in bytes.

ndim
Number of dimensions of the frameset data.

sample_shape
Shape of a sample in the frameset (nthread, nchan).

shape
Shape of the frameset data.

size
Total number of component samples in the frameset data.

`valid`
Whether frameset contains valid data.

Methods Documentation

classmethod `fromdata`(*data*, *headers=None*, *verify=True*, ***kwargs*)
Construct a set of frames from data and headers.

Parameters

data
[`ndarray`] Array holding complex or real data to be encoded. Dimensions should be (samples_per_frame, nthread, nchan).

headers
[`VDIFHeader`, list of same, or None] If a single header, a list with increasing `thread_id` is generated. If not given, will attempt to generate a header from the keyword arguments.

verify
[bool] Whether or not to do basic assertions that check the integrety (e.g., that channel information and whether or not data are complex are consistent between header and data). Default: `True`.

****kwargs**
If `header` is not given, these are used to initialize one.

Returns

frameset
[`VDIFFrameSet`]

classmethod `fromfile`(*fh*, *thread_ids=None*, *edv=None*, *verify=True*)
Read a frame set from a file, starting at the current location.

Parameters

fh
[filehandle] Handle to the VDIF file. Should be at the location where the frames are read from.

thread_ids
[list or None, optional] The thread ids that should be read. If `None` (default), continue reading threads as long as the frame number does not increase.

edv
[int or None, optional] The expected extended data version for the VDIF Header. If `None` (default), use that of the first frame. (Passing it in slightly improves file integrity checking.)

verify
[bool, optional] Whether to do (light) sanity checks on the header. Default: `True`.

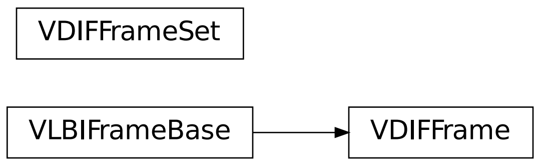
Returns

frameset
[`VDIFFrameSet`] Its `frames` property holds a list of frames (in order of either their `thread_id` or following the input `thread_ids` list). Use the `data` attribute to convert to an array.

keys(*self*)

tofile(*self*, *fh*)
Write all encoded frames to filehandle.

Class Inheritance Diagram



5.4.5 baseband.vdif.base Module

Functions

open(name[, mode])	Open VDIF file(s) for reading or writing.

open

`baseband.vdif.base.`**open**(*name*, *mode='rs'*, ***kwargs*)
Open VDIF file(s) for reading or writing.

Opened as a binary file, one gets a wrapped filehandle that adds methods to read/write a frame. Opened as a stream, the handle is wrapped further, with methods such as reading and writing to the file as if it were a stream of samples.

Parameters

name
[str or filehandle, or sequence of str] File name, filehandle, or sequence of file names (see Notes).

mode
[{'rb', 'wb', 'rs', or 'ws'}, optional] Whether to open for reading or writing, and as a regular binary file or as a stream. Default: 'rs', for reading a stream.

****kwargs**
Additional arguments when opening the file as a stream.

— For reading a stream
[(see `VDIFStreamReader`)]

sample_rate
[`Quantity`, optional] Number of complete samples per second, i.e. the rate at which each

channel in each thread is sampled. If None (default), will be inferred from the header or by scanning one second of the file.

squeeze
[bool, optional] If True (default), remove any dimensions of length unity from decoded data.

subset
[indexing object or tuple of objects, optional] Specific components of the complete sample to decode (after possible squeezing). If a single indexing object is passed, it selects threads. If a tuple is passed, the first selects threads and the second selects channels. If the tuple is empty (default), all components are read.

fill_value
[float or complex, optional] Value to use for invalid or missing data. Default: 0.

verify
[bool, optional] Whether to do basic checks of frame integrity when reading. The first frameset of the stream is always checked. Default: True.

— For writing a stream
[(see VDIFStreamWriter)]

header0
[VDIFHeader] Header for the first frame, holding time information, etc. Can instead give keyword arguments to construct a header (see `**kwargs`).

sample_rate
[Quantity] Number of complete samples per second, i.e. the rate at which each channel in each thread is sampled. For EDV 1 and 3, can alternatively set `sample_rate` within the header.

nthread
[int, optional] Number of threads (e.g., 2 for 2 polarisations). Default: 1.

squeeze
[bool, optional] If True (default), writer accepts squeezed arrays as input, and adds any dimensions of length unity.

file_size
[int or None, optional] When writing to a sequence of files, the maximum size of one file in bytes. If None (default), the file size is unlimited, and only the first file will be written to.

****kwargs**
If the header is not given, an attempt will be made to construct one with any further keyword arguments. See VDIFStreamWriter.

Notes

One can also pass to `name` a list, tuple, or subclass of FileNameSequencer. For writing to multiple files, the `file_size` keyword must be passed or only the first file will be written to. One may also pass in a sequentialfile object (opened in 'rb' mode for reading or 'w+b' for writing), though for typical use cases it is practically identical to passing in a list or template.

Classes

VDIFFileReader(fh_raw)	Simple reader for VDIF files.

Continued on next page

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VDIFFileWriter(fh_raw)	Simple writer for VDIF files.
VDIFStreamBase(fh_raw, header0[, . . .])	Base for VDIF streams.
VDIFStreamReader(fh_raw[, sample_rate, . . .])	VLBI VDIF format reader.
VDIFStreamWriter(fh_raw[, header0, . . .])	VLBI VDIF format writer.

VDIFFileReader

class baseband.vdif.base.**VDIFFileReader**(*fh_raw*)

Bases: baseband.vlbi_base.base.VLBIFileReaderBase

Simple reader for VDIF files.

Wraps a binary filehandle, providing methods to help interpret the data, such as `read_frame`, `read_frameset` and `get_frame_rate`.

Parameters

fh_raw
[filehandle] Filehandle of the raw binary data file.

Attributes Summary

info()	

Methods Summary

close(self)	
find_header(self[, template_header, . . .])	Find the nearest header from the current position.
get_frame_rate(self)	Determine the number of frames per second.
read_frame(self)	Read a single frame (header plus payload).
read_frameset(self[, thread_ids, edv, verify])	Read a single frame (header plus payload).
read_header(self)	Read a single header from the file.
temporary_offset(self)	Context manager for temporarily seeking to another file position.

Attributes Documentation

info

Methods Documentation

close(*self*)

find_header(*self*, *template_header=None*, *frame_nbytes=None*, *edv=None*, *maximum=None*, *forward=True*)

Find the nearest header from the current position.

Search for a valid header at a given position which is consistent with `template_header` or with a header a frame size ahead. Note that the latter turns out to be an unexpectedly weak check on real data!

If successful, the file pointer is left at the start of the header.

Parameters

template_header
[VDIFHeader] If given, used to infer the frame size and EDV.

frame_nbytes
[int] Frame size in bytes, used if `template_header` is not given.

edv
[int] EDV of the header, used if `template_header` is not given.

maximum
[int, optional] Maximum number of bytes forward to search through. Default: twice the frame size.

forward
[bool, optional] Seek forward if `True` (default), backward if `False`.

Returns

header
[VDIFHeader or None] Retrieved VDIF header, or `None` if nothing found.

get_frame_rate(*self*)
Determine the number of frames per second.

This method first tries to determine the frame rate by looking for the highest frame number in the first second of data. If that fails, it attempts to extract the sample rate from the header.

Returns

frame_rate
[Quantity] Frames per second.

read_frame(*self*)
Read a single frame (header plus payload).

Returns

frame
[VDIFFrame] With `.header` and `.data` properties that return the VDIFHeader and data encoded in the frame, respectively.

read_frameset(*self*, *thread_ids=None*, *edv=None*, *verify=True*)
Read a single frame (header plus payload).

Parameters

thread_ids
[list, optional] The thread ids that should be read. If `None` (default), read all threads.

edv
[int, optional] The expected extended data version for the VDIF Header. If `None`, use that of the first frame. (Passing it in slightly improves file integrity checking.)

verify
[bool, optional] Whether to do basic checks of frame integrity. Default: `True`.

Returns

frameset
[VDIFFrameSet] With .headers and .data properties that return a list of VDIFHeader and the data encoded in the frame set, respectively.

read_header(*self*)
Read a single header from the file.

Returns

header
[VDIFHeader]

temporary_offset(*self*)
Context manager for temporarily seeking to another file position.

To be used as part of a with statement:

```
with fh_raw.temporary_offset() [as fh_raw]:
    with-block
```

On exiting the with-block, the file pointer is moved back to its original position.

VDIFFileWriter

class baseband.vdif.base.**VDIFFileWriter**(*fh_raw*)
Bases: baseband.vlbi_base.base.VLBIFileBase

Simple writer for VDIF files.

Adds write_frame and write_frameset methods to the basic VLBI binary file wrapper.

Methods Summary

close(self)	
temporary_offset(self)	Context manager for temporarily seeking to another file position.
write_frame(self, data[, header])	Write a single frame (header plus payload).
write_frameset(self, data[, header])	Write a single frame set (headers plus payloads).

Methods Documentation

close(*self*)

temporary_offset(*self*)
Context manager for temporarily seeking to another file position.

To be used as part of a with statement:

```
with fh_raw.temporary_offset() [as fh_raw]:
    with-block
```

On exiting the with-block, the file pointer is moved back to its original position.

write_frame(*self*, *data*, *header=None*, ***kwargs*)

Write a single frame (header plus payload).

Parameters

data

[ndarray or VDIFFrame] If an array, a header should be given, which will be used to get the information needed to encode the array, and to construct the VDIF frame.

header

[VDIFHeader] Can instead give keyword arguments to construct a header. Ignored if data is a VDIFFrame instance.

****kwargs**

If header is not given, these are used to initialize one.

write_frameset(*self*, *data*, *header=None*, ***kwargs*)

Write a single frame set (headers plus payloads).

Parameters

data

[ndarray or VDIFFrameSet] If an array, a header should be given, which will be used to get the information needed to encode the array, and to construct the VDIF frame set.

header

[VDIFHeader, list of same] Can instead give keyword arguments to construct a header. Ignored if data is a VDIFFrameSet instance. If a list, should have a length matching the number of threads in data; if a single header, thread_ids corresponding to the number of threads are generated automatically.

****kwargs**

If header is not given, these are used to initialize one.

VDIFStreamBase

class baseband.vdif.base.**VDIFStreamBase**(*fh_raw*, *header0*, *sample_rate=None*, *nthread=1*, *squeeze=True*, *subset=()*, *fill_value=0.0*, *verify=True*)

Bases: baseband.vlbi_base.base.VLBIStreamBase

Base for VDIF streams.

Attributes Summary

bps	Bits per elementary sample.
complex_data	Whether the data are complex.
header0	First header of the file.
sample_rate	Number of complete samples per second.
sample_shape	Shape of a complete sample (possibly subset or squeezed).
samples_per_frame	Number of complete samples per frame.
squeeze	Whether data arrays have dimensions with length unity removed.

Continued on next page

Table 45 – continued from previous page

`start_time`	Start time of the file.
`subset`	Specific components of the complete sample to decode.
`time`	Time of the sample pointer's current offset in file.
`verify`	Whether to do consistency checks on frames being read.

Methods Summary

`close`(self)	
`tell`(self[, unit])	Current offset in the file.

Attributes Documentation

bps
Bits per elementary sample.

complex_data
Whether the data are complex.

header0
First header of the file.

sample_rate
Number of complete samples per second.

sample_shape
Shape of a complete sample (possibly subset or squeezed).

samples_per_frame
Number of complete samples per frame.

squeeze
Whether data arrays have dimensions with length unity removed.

If `True`, data read out has such dimensions removed, and data passed in for writing has them inserted.

start_time
Start time of the file.

See also `time` for the time of the sample pointer's current offset.

subset
Specific components of the complete sample to decode.

The order of dimensions is the same as for `sample_shape`. Set by the class initializer.

time
Time of the sample pointer's current offset in file.

See also `start_time` for the start time of the file.

verify
Whether to do consistency checks on frames being read.

Methods Documentation

close(*self*)

tell(*self*, *unit=None*)

Current offset in the file.

Parameters

unit
[Unit or str, optional] Time unit the offset should be returned in. By default, no unit is used, i.e., an integer enumerating samples is returned. For the special string 'time', the absolute time is calculated.

Returns

offset
[int, Quantity, or Time] Offset in current file (or time at current position).

VDIFStreamReader

class baseband.vdif.base.**VDIFStreamReader**(*fh_raw*, *sample_rate=None*, *squeeze=True*, *subset=()*, *fill_value=0.0*, *verify=True*)

Bases: baseband.vdif.base.VDIFStreamBase, baseband.vlbi_base.base.VLBIStreamReaderBase

VLBI VDIF format reader.

Allows access to a VDIF file as a continuous series of samples.

Parameters

fh_raw
[filehandle] Filehandle of the raw VDIF stream.

sample_rate
[Quantity, optional] Number of complete samples per second, i.e. the rate at which each channel in each thread is sampled. If None (default), will be inferred from the header or by scanning one second of the file.

squeeze
[bool, optional] If True (default), remove any dimensions of length unity from decoded data.

subset
[indexing object or tuple of objects, optional] Specific components of the complete sample to decode (after possible squeezing). If a single indexing object is passed, it selects threads. If a tuple is passed, the first selects threads and the second selects channels. If the tuple is empty (default), all components are read.

fill_value
[float or complex, optional] Value to use for invalid or missing data. Default: 0.

verify
[bool, optional] Whether to do basic checks of frame integrity when reading. The first frameset of the stream is always checked. Default: True.

Attributes Summary

bps	Bits per elementary sample.
complex_data	Whether the data are complex.
dtype	
fill_value	Value to use for invalid or missing data.
header0	First header of the file.
info()	Standardized information on stream readers.
ndim	Number of dimensions of the (squeezed/subset) stream data.
sample_rate	Number of complete samples per second.
sample_shape	Shape of a complete sample (possibly subset or squeezed).
samples_per_frame	Number of complete samples per frame.
shape	Shape of the (squeezed/subset) stream data.
size	Total number of component samples in the (squeezed/subset) stream data.
squeeze	Whether data arrays have dimensions with length unity removed.
start_time	Start time of the file.
stop_time	Time at the end of the file, just after the last sample.
subset	Specific components of the complete sample to decode.
time	Time of the sample pointer's current offset in file.
verify	Whether to do consistency checks on frames being read.

Methods Summary

close(self)	
read(self[, count, out])	Read a number of complete (or subset) samples.
readable(self)	Whether the file can be read and decoded.
seek(self, offset[, whence])	Change the stream position.
tell(self[, unit])	Current offset in the file.

Attributes Documentation

bps
Bits per elementary sample.

complex_data
Whether the data are complex.

dtype

fill_value
Value to use for invalid or missing data. Default: 0.

header0
First header of the file.

info
Standardized information on stream readers.

The `info` descriptor provides a few standard attributes, all of which can also be accessed directly on the stream filehandle. More detailed information on the underlying file is stored in its info, accessible via `info.file_info`.

Attributes

start_time
[`Time`] Time of the first complete sample.

stop_time
[`Time`] Time of the complete sample just beyond the end of the file.

sample_rate
[`Quantity`] Complete samples per unit of time.

shape
[tuple] Equivalent shape of the whole file, i.e., combining the number of complete samples and the shape of those samples.

bps
[int] Number of bits used to encode each elementary sample.

complex_data
[bool] Whether the data are complex.

readable
[bool] Whether the first sample could be read and decoded.

`ndim`
Number of dimensions of the (squeezed/subset) stream data.

`sample_rate`
Number of complete samples per second.

`sample_shape`
Shape of a complete sample (possibly subset or squeezed).

`samples_per_frame`
Number of complete samples per frame.

`shape`
Shape of the (squeezed/subset) stream data.

`size`
Total number of component samples in the (squeezed/subset) stream data.

`squeeze`
Whether data arrays have dimensions with length unity removed.

If `True`, data read out has such dimensions removed, and data passed in for writing has them inserted.

`start_time`
Start time of the file.

See also `time` for the time of the sample pointer's current offset, and (if available) `stop_time` for the time at the end of the file.

`stop_time`
Time at the end of the file, just after the last sample.

See also `start_time` for the start time of the file, and `time` for the time of the sample pointer's current offset.

subset
Specific components of the complete sample to decode.

The order of dimensions is the same as for `sample_shape`. Set by the class initializer.

time
Time of the sample pointer's current offset in file.

See also `start_time` for the start time, and (if available) `stop_time` for the end time, of the file.

verify
Whether to do consistency checks on frames being read.

Methods Documentation

close(*self*)

read(*self*, *count=None*, *out=None*)
Read a number of complete (or subset) samples.

The range retrieved can span multiple frames.

Parameters

count
[int or None, optional] Number of complete/subset samples to read. If `None` (default) or negative, the whole file is read. Ignored if `out` is given.

out
[None or array, optional] Array to store the data in. If given, `count` will be inferred from the first dimension; the other dimension should equal `sample_shape`.

Returns

out
[`ndarray` of float or complex] The first dimension is sample-time, and the remainder given by `sample_shape`.

readable(*self*)
Whether the file can be read and decoded.

seek(*self*, *offset*, *whence=0*)
Change the stream position.

This works like a normal filehandle seek, but the offset is in samples (or a relative or absolute time).

Parameters

offset
[int, `Quantity`, or `Time`] Offset to move to. Can be an (integer) number of samples, an offset in time units, or an absolute time.

whence
[{0, 1, 2, 'start', 'current', or 'end'}, optional] Like regular seek, the offset is taken to be from the start if `whence=0` (default), from the current position if 1, and from the end if 2. One can alternativey use 'start', 'current', or 'end' for 0, 1, or 2, respectively. Ignored if `offset` is a time.

`tell`(*self*, *unit=None*)

Current offset in the file.

Parameters

unit
[`Unit` or str, optional] Time unit the offset should be returned in. By default, no unit is used, i.e., an integer enumerating samples is returned. For the special string 'time', the absolute time is calculated.

Returns

offset
[int, `Quantity`, or `Time`] Offset in current file (or time at current position).

VDIFStreamWriter

class `baseband.vdif.base.`**`VDIFStreamWriter`**(*fh_raw*, *header0=None*, *sample_rate=None*, *nthread=1*, *squeeze=True*, ***kwargs*)

Bases: `baseband.vdif.base.VDIFStreamBase`, `baseband.vlbi_base.base.VLBIStreamWriterBase`

VLBI VDIF format writer.

Encodes and writes sequences of samples to file.

Parameters

fh_raw
[filehandle] Which will write filled sets of frames to storage.

header0
[`VDIFHeader`] Header for the first frame, holding time information, etc. Can instead give keyword arguments to construct a header (see `**kwargs`).

sample_rate
[`Quantity`] Number of complete samples per second, i.e. the rate at which each channel in each thread is sampled. For EDV 1 and 3, can alternatively set `sample_rate` within the header.

nthread
[int, optional] Number of threads (e.g., 2 for 2 polarisations). Default: 1.

squeeze
[bool, optional] If `True` (default), `write` accepts squeezed arrays as input, and adds any dimensions of length unity.

****kwargs**
If no header is given, an attempt is made to construct one from these. For a standard header, this would include the following.

— Header keywords
[(see `fromvalues()`)]

time
[`Time`] Start time of the file. Can instead pass on `ref_epoch` and `seconds`.

nchan
[int, optional] Number of channels (default: 1). Note: different numbers of channels per thread is not supported.

complex_data
[bool, optional] Whether data are complex. Default: `False`.

bps
[int, optional] Bits per elementary sample, i.e. per real or imaginary component for complex data. Default: 1.

samples_per_frame
[int] Number of complete samples per frame. Can alternatively use `frame_length`, the number of 8-byte words for header plus payload. For some EDV, this number is fixed (e.g., `frame_length=629` for `edv=3`, which corresponds to 20000 real 2-bit samples per frame).

station
[2 characters, optional] Station ID. Can also be an unsigned 2-byte integer. Default: 0.

edv
[{`False`, 0, 1, 2, 3, 4, 0xab}] Extended Data Version.

Attributes Summary

`bps`	Bits per elementary sample.
`complex_data`	Whether the data are complex.
`header0`	First header of the file.
`sample_rate`	Number of complete samples per second.
`sample_shape`	Shape of a complete sample (possibly subset or squeezed).
`samples_per_frame`	Number of complete samples per frame.
`squeeze`	Whether data arrays have dimensions with length unity removed.
`start_time`	Start time of the file.
`subset`	Specific components of the complete sample to decode.
`time`	Time of the sample pointer's current offset in file.
`verify`	Whether to do consistency checks on frames being read.

Methods Summary

`close`(self)	
`tell`(self[, unit])	Current offset in the file.
`write`(self, data[, valid])	Write data, buffering by frames as needed.

Attributes Documentation

`bps`
Bits per elementary sample.

`complex_data`
Whether the data are complex.

header0
First header of the file.

sample_rate
Number of complete samples per second.

sample_shape
Shape of a complete sample (possibly subset or squeezed).

samples_per_frame
Number of complete samples per frame.

squeeze
Whether data arrays have dimensions with length unity removed.

If `True`, data read out has such dimensions removed, and data passed in for writing has them inserted.

start_time
Start time of the file.

See also `time` for the time of the sample pointer's current offset.

subset
Specific components of the complete sample to decode.

The order of dimensions is the same as for `sample_shape`. Set by the class initializer.

time
Time of the sample pointer's current offset in file.

See also `start_time` for the start time of the file.

verify
Whether to do consistency checks on frames being read.

Methods Documentation

close(*self*)

tell(*self*, *unit=None*)
Current offset in the file.

Parameters

unit
[`Unit` or str, optional] Time unit the offset should be returned in. By default, no unit is used, i.e., an integer enumerating samples is returned. For the special string 'time', the absolute time is calculated.

Returns

offset
[int, `Quantity`, or `Time`] Offset in current file (or time at current position).

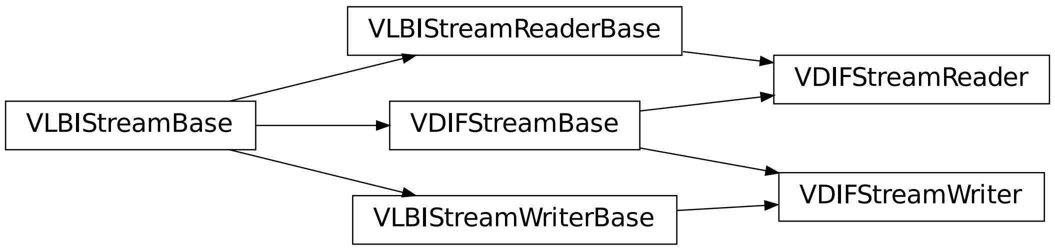
write(*self*, *data*, *valid=True*)
Write data, buffering by frames as needed.

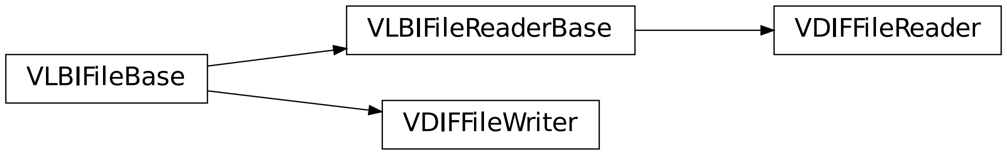
Parameters

data
[`ndarray`] Piece of data to be written, with sample dimensions as given by `sample_shape`. This should be properly scaled to make best use of the dynamic range delivered by the encoding.

valid
[bool, optional] Whether the current data are valid. Default: `True`.

Class Inheritance Diagram





CHAPTER

SIX

MARK 5B

The Mark 5B format is the output format of the Mark 5B disk-based VLBI data system. It is described in its design specifications.

6.1 File Structure

Each *data frame* consists of a *header* consisting of four 32-bit words (16 bytes) followed by a *payload* of 2500 32-bit words (10000 bytes). The header contains a sync word, frame number, and timestamp (accurate to 1 ms), as well as user-specified data; see Sec. 1 of the design specifications for details. The payload supports 2^n bit streams, for $0 \leq n \leq 5$, and the first sample of each stream corresponds precisely to the header time. *elementary samples* may be 1 or 2 bits in size, with the latter being stored in two successive bit streams. The number of *channels* is equal to the number of bit-streams divided by the number of bits per elementary sample (Baseband currently only supports files where all bit-streams are active). Files begin at a header (unlike for Mark 4), and an integer number of frames fit within 1 second.

The Mark 5B system also outputs files with the active bit-stream mask, number of frames per second, and observational metadata (Sec. 1.3 of the design specifications). Baseband does not yet use these files, and instead requires the user specify, for example, the *sample rate*.

6.2 Usage

This section covers reading and writing Mark 5B files with Baseband; general usage can be found under the *Using Baseband* section. For situations in which one is unsure of a file's format, Baseband features the general `baseband.open` and `baseband.file_info` functions, which are also discussed in *Using Baseband*. The examples below use the small sample file `baseband/data/sample.m5b`, and the `numpy`, `astropy.units`, `astropy.time.Time`, and `baseband.mark5b` modules:

```
>>> import numpy as np
>>> import astropy.units as u
>>> from astropy.time import Time
>>> from baseband import mark5b
>>> from baseband.data import SAMPLE_MARK5B
```

Opening a Mark 5B file with `open` in binary mode provides a normal file reader extended with methods to read a `Mark5BFrame`. The number of channels, kiloday (thousands of MJD) and number of bits per sample must all be passed when using `read_frame`:

```
>>> fb = mark5b.open(SAMPLE_MARK5B, 'rb', kday=56000, nchan=8)
>>> frame = fb.read_frame()
```

(continues on next page)

(continued from previous page)

```
>>> frame.shape
(5000, 8)
>>> fb.close()
```

Our sample file has 2-bit *component* samples, which is also the default for `read_frame`, so it does not need to be passed. Also, we may pass a reference `Time` object within 500 days of the observation start time to `ref_time`, rather than `kday`.

Opening as a stream wraps the low-level routines such that reading and writing is in units of samples. It also provides access to header information. Here, we also must provide `nchan`, `sample_rate`, and `ref_time` or `kday`:

```
>>> fh = mark5b.open(SAMPLE_MARK5B, 'rs', sample_rate=32*u.MHz, nchan=8,
...                  ref_time=Time('2014-06-13 12:00:00'))
>>> fh
<Mark5BStreamReader name=... offset=0
    sample_rate=32.0 MHz, samples_per_frame=5000,
    sample_shape=SampleShape(nchan=8), bps=2,
    start_time=2014-06-13T05:30:01.000000000>
>>> header0 = fh.header0    # To be used for writing, below.
>>> d = fh.read(10000)
>>> d.shape
(10000, 8)
>>> d[0, :3]
array([-3.316505, -1.      ,  1.      ], dtype=float32)
>>> fh.close()
```

When writing to file, we again need to pass in `sample_rate` and `nchan`, though time can either be passed explicitly or inferred from the header:

```
>>> fw = mark5b.open('test.m5b', 'ws', header0=header0,
...                  sample_rate=32*u.MHz, nchan=8)
>>> fw.write(d)
>>> fw.close()
>>> fh = mark5b.open('test.m5b', 'rs', sample_rate=32*u.MHz,
...                  kday=57000, nchan=8)
>>> np.all(fh.read() == d)
True
>>> fh.close()
```

6.3 Reference/API

6.3.1 baseband.mark5b Package

Mark5B VLBI data reader.

Code inspired by Walter Brisken's mark5access. See https://github.com/demorest/mark5access.

Also, for the Mark5B design, see http://www.haystack.mit.edu/tech/vlbi/mark5/mark5_memos/019.pdf

Functions

open(name[, mode])	Open Mark5B file(s) for reading or writing.

open

baseband.mark5b.**open**(*name*, *mode='rs'*, ***kwargs*)

Open Mark5B file(s) for reading or writing.

Opened as a binary file, one gets a wrapped filehandle that adds methods to read/write a frame. Opened as a stream, the handle is wrapped further, with methods such as reading and writing to the file as if it were a stream of samples.

Parameters

name
[str or filehandle, or sequence of str] File name, filehandle, or sequence of file names (see Notes).

mode
[{'rb', 'wb', 'rs', or 'ws'}, optional] Whether to open for reading or writing, and as a regular binary file or as a stream. Default: 'rs', for reading a stream.

****kwargs**
Additional arguments when opening the file as a stream.

— For reading a stream
[(see Mark5BStreamReader)]

sample_rate
[Quantity, optional] Number of complete samples per second, i.e. the rate at which each channel is sampled. If None (default), will be inferred from scanning one second of the file or, failing that, using the time difference between two consecutive frames.

kday
[int or None] Explicit thousands of MJD of the observation start time (eg. 57000 for MJD 57999), used to infer the full MJD from the header's time information. Can instead pass an approximate ref_time.

ref_time
[Time or None] Reference time within 500 days of the observation start time, used to infer the full MJD. Only used if kday is not given.

nchan
[int, optional] Number of channels. Default: 1.

bps
[int, optional] Bits per elementary sample. Default: 2.

squeeze
[bool, optional] If True (default), remove any dimensions of length unity from decoded data.

subset
[indexing object, optional] Specific channels of the complete sample to decode (after possible squeezing). If an empty tuple (default), all channels are read.

fill_value
[float or complex] Value to use for invalid or missing data. Default: 0.

verify
[bool, optional] Whether to do basic checks of frame integrity when reading. The first frame of the stream is always checked. Default: `True`.

— For writing a stream
[(see `Mark5BStreamWriter`)]

header0
[`Mark5BHeader`] Header for the first frame, holding time information, etc. Can instead give keyword arguments to construct a header (see `**kwargs`).

sample_rate
[`Quantity`] Number of complete samples per second, i.e. the rate at which each channel is sampled. Needed to calculate header timestamps.

nchan
[int, optional] Number of channels. Default: 1.

bps
[int, optional] Bits per elementary sample. Default: 2.

squeeze
[bool, optional] If `True` (default), writer accepts squeezed arrays as input, and adds channel and thread dimensions if they have length unity.

file_size
[int or None, optional] When writing to a sequence of files, the maximum size of one file in bytes. If `None` (default), the file size is unlimited, and only the first file will be written to.

****kwargs**
If no header is given, an attempt is made to construct one with any further keyword arguments. See `Mark5BStreamWriter`.

Returns

Filehandle
`Mark5BFileReader` or `Mark5BFileWriter` (binary), or `Mark5BStreamReader` or `Mark5BStreamWriter` (stream).

Notes

One can also pass to `name` a list, tuple, or subclass of `FileNameSequencer`. For writing to multiple files, the `file_size` keyword must be passed or only the first file will be written to. One may also pass in a `sequentialfile` object (opened in 'rb' mode for reading or 'w+b' for writing), though for typical use cases it is practically identical to passing in a list or template.

Classes

`Mark5BFrame`(header, payload[, valid, verify])	Representation of a Mark 5B frame, consisting of a header and payload.
`Mark5BHeader`(words[, kday, ref_time, verify])	Decoder/encoder of a Mark5B Frame Header.
`Mark5BPayload`(words[, nchan, bps, complex_data])	Container for decoding and encoding VDIF payloads.

Mark5BFrame

class baseband.mark5b.**Mark5BFrame**(*header*, *payload*, *valid=None*, *verify=True*)

Bases: `baseband.vlbi_base.frame.VLBIFrameBase`

Representation of a Mark 5B frame, consisting of a header and payload.

Parameters

header
[`Mark5BHeader`] Wrapper around the encoded header words, providing access to the header information.

payload
[`Mark5BPayload`] Wrapper around the payload, provding mechanisms to decode it.

valid
[bool or None] Whether the data are valid. If `None` (default), the validity will be determined by checking whether the payload consists of the fill pattern 0x11223344.

verify
[bool] Whether to do basic verification of integrity (default: `True`)

Notes

The Frame can also be read instantiated using class methods:

fromfile : read header and payload from a filehandle

fromdata : encode data as payload

Of course, one can also do the opposite:

tofile : method to write header and payload to filehandle

data : property that yields full decoded payload

A number of properties are defined: `shape`, `dtype` and `size` are the shape, type and number of complete samples of the data array, and `nbytes` the frame size in bytes. Furthermore, the frame acts as a dictionary, with keys those of the header. Any attribute that is not defined on the frame itself, such as `.time` will be looked up on the header as well.

Attributes Summary

`data`	Full decoded frame.
`dtype`	Numeric type of the frame data.
`fill_value`	Value to replace invalid data in the frame.
`nbytes`	Size of the encoded frame in bytes.
`ndim`	Number of dimensions of the frame data.
`sample_shape`	Shape of a sample in the frame (nchan,).
`shape`	Shape of the frame data.
`size`	Total number of component samples in the frame data.
`valid`	Whether frame contains valid data.

Methods Summary

`fromdata`(data[, header, bps, valid, verify])	Construct frame from data and header.
`fromfile`(fh[, kday, ref_time, nchan, bps, . . .])	Read a frame from a filehandle.
`keys`(self)	
`tofile`(self, fh)	Write encoded frame to filehandle.
`verify`(self)	Simple verification.

Attributes Documentation

`data`
Full decoded frame.

`dtype`
Numeric type of the frame data.

`fill_value`
Value to replace invalid data in the frame.

`nbytes`
Size of the encoded frame in bytes.

`ndim`
Number of dimensions of the frame data.

`sample_shape`
Shape of a sample in the frame (nchan,).

`shape`
Shape of the frame data.

`size`
Total number of component samples in the frame data.

`valid`
Whether frame contains valid data.

Methods Documentation

`classmethod fromdata`(*data*, *header=None*, *bps=2*, *valid=True*, *verify=True*, ***kwargs*)
Construct frame from data and header.

Parameters

data
[`ndarray`] Array holding data to be encoded.

header
[`Mark5BHeader` or None] If not given, will attempt to generate one using the keywords.

bps
[int] Bits per elementary sample. Default: 2.

valid
[bool] Whether the data are valid (default: `True`). If not, the payload will be set to a fill pattern.

verify
[bool] Whether to do basic checks of frame integrity (default: `True`).

classmethod fromfile(*fh*, *kday=None*, *ref_time=None*, *nchan=1*, *bps=3*, *valid=None*, *verify=True*)
Read a frame from a filehandle.

Parameters

fh
[filehandle] To read the header and payload from.

kday
[int or None] Explicit thousands of MJD of the observation time. Can instead pass an approximate `ref_time`.

ref_time
[`Time` or None] Reference time within 500 days of the observation time, used to infer the full MJD. Used only if `kday` is not given.

nchan
[int, optional] Number of channels. Default: 1.

bps
[int, optional] Bits per elementary sample. Default: 2.

verify
[bool] Whether to do basic checks of frame integrity (default: `True`).

keys(*self*)

tofile(*self*, *fh*)
Write encoded frame to filehandle.

verify(*self*)
Simple verification. To be added to by subclasses.

Mark5BHeader

class baseband.mark5b.**Mark5BHeader**(*words*, *kday=None*, *ref_time=None*, *verify=True*, ***kwargs*)
Bases: `baseband.vlbi_base.header.VLBIHeaderBase`

Decoder/encoder of a Mark5B Frame Header.

See page 15 of http://www.haystack.edu/tech/vlbi/mark5/docs/Mark%205B%20users%20manual.pdf

Parameters

words
[tuple of int, or None] Four 32-bit unsigned int header words. If `None`, set to a tuple of zeros for later initialisation.

kday
[int or None] Explicit thousands of MJD of the observation time (needed to remove ambiguity in the Mark 5B time stamp). Can instead pass an approximate `ref_time`.

ref_time
[`Time` or None] Reference time within 500 days of the observation time, used to infer the full MJD. Used only if `kday` is not given.

verify
[bool, optional] Whether to do basic verification of integrity. Default: `True`.

Returns

header
[`Mark5BHeader`]

Attributes Summary

`fraction`	Fractional seconds (decoded from 'bcd_fraction').
`frame_nbytes`	Size of the frame in bytes.
`jday`	Last three digits of MJD (decoded from 'bcd_jday').
`kday`	
`mutable`	Whether the header can be modified.
`nbytes`	Size of the header in bytes.
`payload_nbytes`	Size of the payload in bytes.
`seconds`	Integer seconds on day (decoded from 'bcd_seconds').
`time`	Convert year, BCD time code to Time object.

Methods Summary

`copy`(self, **kwargs)	Create a mutable and independent copy of the header.
`fromfile`(fh, *args, **kwargs)	Read VLBI Header from file.
`fromkeys`(*args, **kwargs)	Initialise a header from parsed values.
`fromvalues`(*[, verify])	Initialise a header from parsed values.
`get_time`(self[, frame_rate])	Convert year, BCD time code to Time object.
`infer_kday`(self, ref_time)	Uses a reference time to set a header's kday.
`keys`(self)	
`set_time`(self, time[, frame_rate])	Convert Time object to BCD timestamp elements and 'frame_nr'.
`tofile`(self, fh)	Write VLBI frame header to filehandle.
`update`(self, *[, crc, verify])	Update the header by setting keywords or properties.
`verify`(self)	Verify header integrity.

Attributes Documentation

`fraction`
Fractional seconds (decoded from 'bcd_fraction').

The fraction is stored to 0.1 ms accuracy. Following mark5access, this is "unrounded" to give the exact time of the start of the frame for any total bit rate below 512 Mbps. For rates above this value, it is no longer guaranteed that subsequent frames have unique rates.

Note to the above: since a Mark5B frame contains 80000 bits, the total bit rate for which times can be unique would in principle be 800 Mbps. However, standard VLBI only uses bit rates that are powers of 2 in MHz.

`frame_nbytes`
Size of the frame in bytes.

`jday`
Last three digits of MJD (decoded from 'bcd_jday').

`kday = None`

`mutable`
Whether the header can be modified.

`nbytes`
Size of the header in bytes.

`payload_nbytes`
Size of the payload in bytes.

`seconds`
Integer seconds on day (decoded from 'bcd_seconds').

`time`
Convert year, BCD time code to Time object.

Calculate time using `jday`, `seconds`, and `fraction` properties (which reflect the bcd-encoded 'bcd_jday', 'bcd_seconds' and 'bcd_fraction' header items), plus `kday` from the initialisation. See http://www.haystack.edu/tech/vlbi/mark5/docs/Mark%205B%20users%20manual.pdf

Note that some non-compliant files do not have 'bcd_fraction' set. For those, the time can still be calculated using the header's 'frame_nr' by passing in a frame rate.

Furthermore, fractional seconds are stored only to 0.1 ms accuracy. In the code, this is "unrounded" to give the exact time of the start of the frame for any total bit rate below 512 Mbps. For higher rates, it is no longer guaranteed that subsequent frames have unique `fraction`, and one should pass in an explicit frame rate instead.

Parameters

frame_rate
[`Quantity`, optional] Used to calculate the fractional second from the frame number instead of from the header's `fraction`.

Returns

`Time`

Methods Documentation

`copy`(*self*, ***kwargs*)
Create a mutable and independent copy of the header.

Keyword arguments can be passed on as needed by possible subclasses.

`classmethod fromfile`(*fh*, **args*, ***kwargs*)
Read VLBI Header from file.

Arguments are the same as for class initialisation. The header constructed will be immutable.

`classmethod fromkeys`(**args*, ***kwargs*)
Initialise a header from parsed values.

Like fromvalues, but without any interpretation of keywords.

Raises

KeyError
[if not all keys required are present in kwargs]

classmethod fromvalues(**, verify=True, **kwargs*)
Initialise a header from parsed values.

Here, the parsed values must be given as keyword arguments, i.e., for any `header = cls(<data>)`, `cls.fromvalues(**header) == header`.

However, unlike for the `Mark5BHeader.fromkeys()` class method, data can also be set using arguments named after methods, such as `jday` and `seconds`.

Given defaults:

sync_pattern : 0xABADDEED

Values set by other keyword arguments (if present):

bcd_jday : from `jday` or `time` bcd_seconds : from `seconds` or `time` bcd_fraction : from `fraction` or `time` (may need `frame_rate`) frame_nr : from `time` (may need `frame_rate`)

get_time(*self, frame_rate=None*)
Convert year, BCD time code to Time object.

Calculate time using `jday`, `seconds`, and `fraction` properties (which reflect the bcd-encoded 'bcd_jday', 'bcd_seconds' and 'bcd_fraction' header items), plus `kday` from the initialisation. See http://www.haystack.edu/tech/vlbi/mark5/docs/Mark%205B%20users%20manual.pdf

Note that some non-compliant files do not have 'bcd_fraction' set. For those, the time can still be calculated using the header's 'frame_nr' by passing in a frame rate.

Furthermore, fractional seconds are stored only to 0.1 ms accuracy. In the code, this is "unrounded" to give the exact time of the start of the frame for any total bit rate below 512 Mbps. For higher rates, it is no longer guaranteed that subsequent frames have unique `fraction`, and one should pass in an explicit frame rate instead.

Parameters

frame_rate
[`Quantity`, optional] Used to calculate the fractional second from the frame number instead of from the header's `fraction`.

Returns

`Time`

infer_kday(*self, ref_time*)
Uses a reference time to set a header's kday.

Parameters

ref_time
[`Time`] Reference time within 500 days of the observation time.

keys(*self*)

set_time(*self*, *time*, *frame_rate=None*)
Convert Time object to BCD timestamp elements and 'frame_nr'.

For non-integer seconds, the frame number will be calculated if not given explicitly. Doing so requires the frame rate.

Parameters

time
[Time] The time to use for this header.

frame_rate
[Quantity, optional] For calculating 'frame_nr' from the fractional seconds.

tofile(*self*, *fh*)
Write VLBI frame header to filehandle.

update(*self*, ***, *crc=None*, *verify=True*, ***kwargs*)
Update the header by setting keywords or properties.

Here, any keywords matching header keys are applied first, and any remaining ones are used to set header properties, in the order set by the class (in `_properties`).

Parameters

crc
[int or None, optional] If `None` (default), recalculate the CRC after updating.

verify
[bool, optional] If `True` (default), verify integrity after updating.

****kwargs**
Arguments used to set keywords and properties.

verify(*self*)
Verify header integrity.

Mark5BPayload

class baseband.mark5b.**Mark5BPayload**(*words*, *nchan=1*, *bps=2*, *complex_data=False*)
Bases: `baseband.vlbi_base.payload.VLBIPayloadBase`

Container for decoding and encoding VDIF payloads.

Parameters

words
[ndarray] Array containg LSB unsigned words (with the right size) that encode the payload.

nchan
[int, optional] Number of channels. Default: 1.

bps
[int, optional] Bits per elementary sample. Default: 2.

Attributes Summary

`data`	Full decoded payload.
`dtype`	Numeric type of the decoded data array.
`nbytes`	Size of the payload in bytes.
`ndim`	Number of dimensions of the decoded data array.
`shape`	Shape of the decoded data array.
`size`	Total number of component samples in the decoded data array.

Methods Summary

`fromdata`(data[, bps])	Encode data as payload, using a given number of bits per sample.
`fromfile`(fh, *args[, payload_nbytes])	Read payload from filehandle and decode it into data.
`tofile`(self, fh)	Write payload to filehandle.

Attributes Documentation

`data`
Full decoded payload.

`dtype`
Numeric type of the decoded data array.

`nbytes`
Size of the payload in bytes.

`ndim`
Number of dimensions of the decoded data array.

`shape`
Shape of the decoded data array.

`size`
Total number of component samples in the decoded data array.

Methods Documentation

`classmethod fromdata`(*data*, *bps=2*)
Encode data as payload, using a given number of bits per sample.

It is assumed that the last dimension is the number of channels.

`classmethod fromfile`(*fh*, **args*, *payload_nbytes=None*, ***kwargs*)
Read payload from filehandle and decode it into data.

Parameters

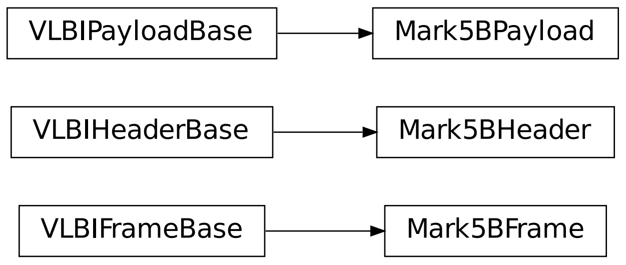
fh
[filehandle] From which data is read.

payload_nbytes
[int] Number of bytes to read (default: as given in `cls._nbytes`).

Any other (keyword) arguments are passed on to the class initialiser.

tofile(*self*, *fh*)
Write payload to filehandle.

Class Inheritance Diagram



6.3.2 baseband.mark5b.header Module

Definitions for VLBI Mark5B Headers.

Implements a Mark5BHeader class used to store header words, and decode/encode the information therein.

For the specification, see http://www.haystack.edu/tech/vlbi/mark5/docs/Mark%205B%20users%20manual.pdf

Classes

`Mark5BHeader`(words[, kday, ref_time, verify])	Decoder/encoder of a Mark5B Frame Header.

Mark5BHeader

class `baseband.mark5b.header.`**`Mark5BHeader`**(*words*, *kday=None*, *ref_time=None*, *verify=True*, ***kwargs*)

Bases: `baseband.vlbi_base.header.VLBIHeaderBase`

Decoder/encoder of a Mark5B Frame Header.

See page 15 of http://www.haystack.edu/tech/vlbi/mark5/docs/Mark%205B%20users%20manual.pdf

Parameters

words
[tuple of int, or None] Four 32-bit unsigned int header words. If `None`, set to a tuple of zeros for later initialisation.

kday
[int or None] Explicit thousands of MJD of the observation time (needed to remove ambiguity in the Mark 5B time stamp). Can instead pass an approximate `ref_time`.

ref_time
[`Time` or None] Reference time within 500 days of the observation time, used to infer the full MJD. Used only if kday is not given.

verify
[bool, optional] Whether to do basic verification of integrity. Default: `True`.

Returns

header
[`Mark5BHeader`]

Attributes Summary

`fraction`	Fractional seconds (decoded from 'bcd_fraction').
`frame_nbytes`	Size of the frame in bytes.
`jday`	Last three digits of MJD (decoded from 'bcd_jday').
`kday`	
`mutable`	Whether the header can be modified.
`nbytes`	Size of the header in bytes.
`payload_nbytes`	Size of the payload in bytes.
`seconds`	Integer seconds on day (decoded from 'bcd_seconds').
`time`	Convert year, BCD time code to Time object.

Methods Summary

`copy`(self, **kwargs)	Create a mutable and independent copy of the header.
`fromfile`(fh, *args, **kwargs)	Read VLBI Header from file.
`fromkeys`(*args, **kwargs)	Initialise a header from parsed values.
`fromvalues`(*[, verify])	Initialise a header from parsed values.
`get_time`(self[, frame_rate])	Convert year, BCD time code to Time object.
`infer_kday`(self, ref_time)	Uses a reference time to set a header's kday.
`keys`(self)	
`set_time`(self, time[, frame_rate])	Convert Time object to BCD timestamp elements and 'frame_nr'.
`tofile`(self, fh)	Write VLBI frame header to filehandle.
`update`(self, *[, crc, verify])	Update the header by setting keywords or properties.
`verify`(self)	Verify header integrity.

Attributes Documentation

`fraction`
Fractional seconds (decoded from 'bcd_fraction').

The fraction is stored to 0.1 ms accuracy. Following mark5access, this is "unrounded" to give the exact time of the start of the frame for any total bit rate below 512 Mbps. For rates above this value, it is no longer guaranteed that subsequent frames have unique rates.

Note to the above: since a Mark5B frame contains 80000 bits, the total bit rate for which times can be unique would in principle be 800 Mbps. However, standard VLBI only uses bit rates that are powers of 2 in MHz.

`frame_nbytes`
Size of the frame in bytes.

`jday`
Last three digits of MJD (decoded from 'bcd_jday').

`kday = None`

`mutable`
Whether the header can be modified.

`nbytes`
Size of the header in bytes.

`payload_nbytes`
Size of the payload in bytes.

`seconds`
Integer seconds on day (decoded from 'bcd_seconds').

`time`
Convert year, BCD time code to Time object.

Calculate time using `jday`, `seconds`, and `fraction` properties (which reflect the bcd-encoded 'bcd_jday', 'bcd_seconds' and 'bcd_fraction' header items), plus `kday` from the initialisation. See http://www.haystack.edu/tech/vlbi/mark5/docs/Mark%205B%20users%20manual.pdf

Note that some non-compliant files do not have 'bcd_fraction' set. For those, the time can still be calculated using the header's 'frame_nr' by passing in a frame rate.

Furthermore, fractional seconds are stored only to 0.1 ms accuracy. In the code, this is "unrounded" to give the exact time of the start of the frame for any total bit rate below 512 Mbps. For higher rates, it is no longer guaranteed that subsequent frames have unique `fraction`, and one should pass in an explicit frame rate instead.

Parameters

frame_rate
[`Quantity`, optional] Used to calculate the fractional second from the frame number instead of from the header's `fraction`.

Returns

`Time`

Methods Documentation

`copy`(*self*, ***kwargs*)
Create a mutable and independent copy of the header.

Keyword arguments can be passed on as needed by possible subclasses.

`classmethod fromfile`(*fh*, **args*, ***kwargs*)
Read VLBI Header from file.

Arguments are the same as for class initialisation. The header constructed will be immutable.

classmethod fromkeys(**args*, ***kwargs*)

Initialise a header from parsed values.

Like fromvalues, but without any interpretation of keywords.

Raises

KeyError

[if not all keys required are present in `kwargs`]

classmethod fromvalues(*, *verify=True*, ***kwargs*)

Initialise a header from parsed values.

Here, the parsed values must be given as keyword arguments, i.e., for any `header = cls(<data>)`, `cls.fromvalues(**header) == header`.

However, unlike for the `Mark5BHeader.fromkeys()` class method, data can also be set using arguments named after methods, such as `jday` and `seconds`.

Given defaults:

sync_pattern : 0xABADDEED

Values set by other keyword arguments (if present):

bcd_jday : from `jday` or `time` bcd_seconds : from `seconds` or `time` bcd_fraction : from `fraction` or `time` (may need `frame_rate`) frame_nr : from `time` (may need `frame_rate`)

get_time(*self*, *frame_rate=None*)

Convert year, BCD time code to Time object.

Calculate time using `jday`, `seconds`, and `fraction` properties (which reflect the bcd-encoded 'bcd_jday', 'bcd_seconds' and 'bcd_fraction' header items), plus `kday` from the initialisation. See http://www.haystack.edu/tech/vlbi/mark5/docs/Mark%205B%20users%20manual.pdf

Note that some non-compliant files do not have 'bcd_fraction' set. For those, the time can still be calculated using the header's 'frame_nr' by passing in a frame rate.

Furthermore, fractional seconds are stored only to 0.1 ms accuracy. In the code, this is "unrounded" to give the exact time of the start of the frame for any total bit rate below 512 Mbps. For higher rates, it is no longer guaranteed that subsequent frames have unique `fraction`, and one should pass in an explicit frame rate instead.

Parameters

frame_rate

[`Quantity`, optional] Used to calculate the fractional second from the frame number instead of from the header's `fraction`.

Returns

`Time`

infer_kday(*self*, *ref_time*)

Uses a reference time to set a header's `kday`.

Parameters

ref_time
[Time] Reference time within 500 days of the observation time.

keys(*self*)

set_time(*self*, *time*, *frame_rate=None*)
Convert Time object to BCD timestamp elements and 'frame_nr'.

For non-integer seconds, the frame number will be calculated if not given explicitly. Doing so requires the frame rate.

Parameters

time
[Time] The time to use for this header.

frame_rate
[Quantity, optional] For calculating 'frame_nr' from the fractional seconds.

tofile(*self*, *fh*)
Write VLBI frame header to filehandle.

update(*self*, **, *crc=None*, *verify=True*, ***kwargs*)
Update the header by setting keywords or properties.

Here, any keywords matching header keys are applied first, and any remaining ones are used to set header properties, in the order set by the class (in `_properties`).

Parameters

crc
[int or None, optional] If `None` (default), recalculate the CRC after updating.

verify
[bool, optional] If `True` (default), verify integrity after updating.

****kwargs**
Arguments used to set keywords and properties.

verify(*self*)
Verify header integrity.

Variables

`CRC16`	CRC polynomial used for Mark 5B Headers, as a check on the time code.
`crc16`(stream)	Cyclic Redundancy Check for a bitstream.

CRC16

`baseband.mark5b.header.`**`CRC16 = 98309`**
CRC polynomial used for Mark 5B Headers, as a check on the time code.

x^16 + x^15 + x^2 + 1, i.e., 0x18005. See page 11 of http://www.haystack.mit.edu/tech/vlbi/mark5/docs/230.3.pdf (defined there for VLBA headers).

This is also CRC-16-IBM mentioned in https://en.wikipedia.org/wiki/Cyclic_redundancy_check

crc16

baseband.mark5b.header.**crc16**(*stream*) = **<baseband.vlbi_base.utils.CRC object>**

Cyclic Redundancy Check for a bitstream.

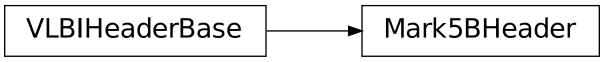
See https://en.wikipedia.org/wiki/Cyclic_redundancy_check

Once initialised, the instance can be used as a function that calculates the CRC, or one can use the check method to verify that the CRC at the end of a stream is correct.

Parameters

polynomial
[int] Binary encoded CRC divisor. For instance, that used by Mark 4 headers is 0x180f, or x^12 + x^11 + x^3 + x^2 + x + 1.

Class Inheritance Diagram



6.3.3 baseband.mark5b.payload Module

Definitions for VLBI Mark 5B payloads.

Implements a Mark5BPayload class used to store payload words, and decode to or encode from a data array.

For the specification, see http://www.haystack.edu/tech/vlbi/mark5/docs/Mark%205B%20users%20manual.pdf

Functions

init_luts()	Set up the look-up tables for levels as a function of input byte.
decode_1bit(words)	
decode_2bit(words)	
encode_1bit(values)	Encodes values using 1 bit per sample, packing the result into bytes.
encode_2bit(values)	Generic encoder for data stored using two bits.

init_luts

baseband.mark5b.payload.**init_luts**()

Set up the look-up tables for levels as a function of input byte.

For 1-bit mode, one has just the sign bit:

s	value
0	+1
1	-1

For 2-bit mode, there is a sign and a magnitude, which encode:

m	s	value	s*2+m
0	0	-Hi	0
0	1	+1	2
1	0	-1	1
1	1	+Hi	3

Note that the sign bit is flipped for 1-bit mode from what one might expect from the 2-bit encodings (at least, as implemented in mark5access; the docs are rather unclear). For more details, see Table 13 in http://library.nrao.edu/public/memos/vlba/up/VLBASU_13.pdf and http://www.haystack.edu/tech/vlbi/mark5/docs/Mark%205B%20users%20manual.pdf Appendix A: sign always on even bit stream (0, 2, 4, . . .), and magnitude on adjacent odd stream (1, 3, 5, . . .).

In the above table, the last column is the index in the linearly increasing table of levels (`decoder_levels[2]`).

decode_1bit

`baseband.mark5b.payload.`**`decode_1bit`**`(`*words*`)`

decode_2bit

`baseband.mark5b.payload.`**`decode_2bit`**`(`*words*`)`

encode_1bit

`baseband.mark5b.payload.`**`encode_1bit`**`(`*values*`)`

Encodes values using 1 bit per sample, packing the result into bytes.

encode_2bit

`baseband.mark5b.payload.`**`encode_2bit`**`(`*values*`)`

Generic encoder for data stored using two bits.

This returns an unsigned integer array containing encoded sample values that range from 0 to 3. The conversion from floating point sample value to unsigned int is given below, with `lv = TWO_BIT_1_SIGMA = 2.1745`:

Input range	Output
value < -lv	0
-lv < value < 0.	2
0. < value < lv	1
lv < value	3

This does not pack the samples into bytes.

Classes

`Mark5BPayload`(words[, nchan, bps, complex_data])	Container for decoding and encoding VDIF payloads.

Mark5BPayload

class `baseband.mark5b.payload.`**`Mark5BPayload`**(*words*, *nchan=1*, *bps=2*, *complex_data=False*)

Bases: `baseband.vlbi_base.payload.VLBIPayloadBase`

Container for decoding and encoding VDIF payloads.

Parameters

words
[`ndarray`] Array containg LSB unsigned words (with the right size) that encode the payload.

nchan
[int, optional] Number of channels. Default: 1.

bps
[int, optional] Bits per elementary sample. Default: 2.

Attributes Summary

`data`	Full decoded payload.
`dtype`	Numeric type of the decoded data array.
`nbytes`	Size of the payload in bytes.
`ndim`	Number of dimensions of the decoded data array.
`shape`	Shape of the decoded data array.
`size`	Total number of component samples in the decoded data array.

Methods Summary

`fromdata`(data[, bps])	Encode data as payload, using a given number of bits per sample.
`fromfile`(fh, *args[, payload_nbytes])	Read payload from filehandle and decode it into data.

Continued on next page

Table 16 – continued from previous page

tofile(self, fh)	Write payload to filehandle.

Attributes Documentation

data
Full decoded payload.

dtype
Numeric type of the decoded data array.

nbytes
Size of the payload in bytes.

ndim
Number of dimensions of the decoded data array.

shape
Shape of the decoded data array.

size
Total number of component samples in the decoded data array.

Methods Documentation

classmethod fromdata(*data*, *bps=2*)
Encode data as payload, using a given number of bits per sample.

It is assumed that the last dimension is the number of channels.

classmethod fromfile(*fh*, **args*, *payload_nbytes=None*, ***kwargs*)
Read payload from filehandle and decode it into data.

Parameters

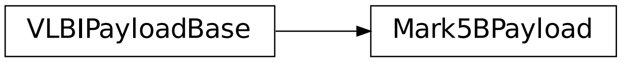
fh
[filehandle] From which data is read.

payload_nbytes
[int] Number of bytes to read (default: as given in `cls._nbytes`).

Any other (keyword) arguments are passed on to the class initialiser.

tofile(*self*, *fh*)
Write payload to filehandle.

Class Inheritance Diagram



6.3.4 baseband.mark5b.frame Module

Definitions for VLBI Mark 5B frames.

Implements a Mark5BFrame class that can be used to hold a header and a payload, providing access to the values encoded in both.

For the specification, see http://www.haystack.edu/tech/vlbi/mark5/docs/Mark%205B%20users%20manual.pdf

Classes

`Mark5BFrame`(header, payload[, valid, verify])	Representation of a Mark 5B frame, consisting of a header and payload.

Mark5BFrame

class `baseband.mark5b.frame.`**`Mark5BFrame`**(*header*, *payload*, *valid=None*, *verify=True*)

Bases: `baseband.vlbi_base.frame.VLBIFrameBase`

Representation of a Mark 5B frame, consisting of a header and payload.

Parameters

header
[`Mark5BHeader`] Wrapper around the encoded header words, providing access to the header information.

payload
[`Mark5BPayload`] Wrapper around the payload, provding mechanisms to decode it.

valid
[bool or None] Whether the data are valid. If `None` (default), the validity will be determined by checking whether the payload consists of the fill pattern 0x11223344.

verify
[bool] Whether to do basic verification of integrity (default: `True`)

Notes

The Frame can also be read instantiated using class methods:

fromfile : read header and payload from a filehandle

fromdata : encode data as payload

Of course, one can also do the opposite:

tofile : method to write header and payload to filehandle

data : property that yields full decoded payload

A number of properties are defined: `shape`, `dtype` and `size` are the shape, type and number of complete samples of the data array, and `nbytes` the frame size in bytes. Furthermore, the frame acts as a dictionary, with keys those of the header. Any attribute that is not defined on the frame itself, such as `.time` will be looked up on the header as well.

Attributes Summary

`data`	Full decoded frame.
`dtype`	Numeric type of the frame data.
`fill_value`	Value to replace invalid data in the frame.
`nbytes`	Size of the encoded frame in bytes.
`ndim`	Number of dimensions of the frame data.
`sample_shape`	Shape of a sample in the frame (nchan,).
`shape`	Shape of the frame data.
`size`	Total number of component samples in the frame data.
`valid`	Whether frame contains valid data.

Methods Summary

`fromdata`(data[, header, bps, valid, verify])	Construct frame from data and header.
`fromfile`(fh[, kday, ref_time, nchan, bps, . . .])	Read a frame from a filehandle.
`keys`(self)	
`tofile`(self, fh)	Write encoded frame to filehandle.
`verify`(self)	Simple verification.

Attributes Documentation

data
Full decoded frame.

dtype
Numeric type of the frame data.

fill_value
Value to replace invalid data in the frame.

nbytes
Size of the encoded frame in bytes.

ndim
Number of dimensions of the frame data.

sample_shape
Shape of a sample in the frame (nchan,).

shape
Shape of the frame data.

size
Total number of component samples in the frame data.

valid
Whether frame contains valid data.

Methods Documentation

classmethod fromdata(*data*, *header=None*, *bps=2*, *valid=True*, *verify=True*, ***kwargs*)
Construct frame from data and header.

Parameters

data
[`ndarray`] Array holding data to be encoded.

header
[`Mark5BHeader` or None] If not given, will attempt to generate one using the keywords.

bps
[int] Bits per elementary sample. Default: 2.

valid
[bool] Whether the data are valid (default: `True`). If not, the payload will be set to a fill pattern.

verify
[bool] Whether to do basic checks of frame integrity (default: `True`).

classmethod fromfile(*fh*, *kday=None*, *ref_time=None*, *nchan=1*, *bps=3*, *valid=None*, *verify=True*)
Read a frame from a filehandle.

Parameters

fh
[filehandle] To read the header and payload from.

kday
[int or None] Explicit thousands of MJD of the observation time. Can instead pass an approximate `ref_time`.

ref_time
[`Time` or None] Reference time within 500 days of the observation time, used to infer the full MJD. Used only if `kday` is not given.

nchan
[int, optional] Number of channels. Default: 1.

bps
[int, optional] Bits per elementary sample. Default: 2.

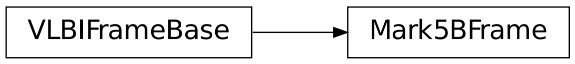
verify
[bool] Whether to do basic checks of frame integrity (default: `True`).

keys(*self*)

tofile(*self*, *fh*)
Write encoded frame to filehandle.

verify(*self*)
Simple verification. To be added to by subclasses.

Class Inheritance Diagram



6.3.5 baseband.mark5b.base Module

Functions

open(name[, mode])	Open Mark5B file(s) for reading or writing.

open

baseband.mark5b.base.**open**(*name*, *mode='rs'*, ***kwargs*)

Open Mark5B file(s) for reading or writing.

Opened as a binary file, one gets a wrapped filehandle that adds methods to read/write a frame. Opened as a stream, the handle is wrapped further, with methods such as reading and writing to the file as if it were a stream of samples.

Parameters

name
[str or filehandle, or sequence of str] File name, filehandle, or sequence of file names (see Notes).

mode
[{'rb', 'wb', 'rs', or 'ws'}, optional] Whether to open for reading or writing, and as a regular binary file or as a stream. Default: 'rs', for reading a stream.

****kwargs**
Additional arguments when opening the file as a stream.

— For reading a stream
[(see `Mark5BStreamReader`)]

sample_rate
[`Quantity`, optional] Number of complete samples per second, i.e. the rate at which each channel is sampled. If `None` (default), will be inferred from scanning one second of the file or, failing that, using the time difference between two consecutive frames.

kday
[int or None] Explicit thousands of MJD of the observation start time (eg. `57000` for MJD 57999), used to infer the full MJD from the header's time information. Can instead pass an approximate `ref_time`.

ref_time
[`Time` or None] Reference time within 500 days of the observation start time, used to infer

the full MJD. Only used if kday is not given.

nchan
[int, optional] Number of channels. Default: 1.

bps
[int, optional] Bits per elementary sample. Default: 2.

squeeze
[bool, optional] If True (default), remove any dimensions of length unity from decoded data.

subset
[indexing object, optional] Specific channels of the complete sample to decode (after possible squeezing). If an empty tuple (default), all channels are read.

fill_value
[float or complex] Value to use for invalid or missing data. Default: 0.

verify
[bool, optional] Whether to do basic checks of frame integrity when reading. The first frame of the stream is always checked. Default: True.

— For writing a stream
[(see Mark5BStreamWriter)]

header0
[Mark5BHeader] Header for the first frame, holding time information, etc. Can instead give keyword arguments to construct a header (see **kwargs).

sample_rate
[Quantity] Number of complete samples per second, i.e. the rate at which each channel is sampled. Needed to calculate header timestamps.

nchan
[int, optional] Number of channels. Default: 1.

bps
[int, optional] Bits per elementary sample. Default: 2.

squeeze
[bool, optional] If True (default), writer accepts squeezed arrays as input, and adds channel and thread dimensions if they have length unity.

file_size
[int or None, optional] When writing to a sequence of files, the maximum size of one file in bytes. If None (default), the file size is unlimited, and only the first file will be written to.

****kwargs**
If no header is given, an attempt is made to construct one with any further keyword arguments. See Mark5BStreamWriter.

Returns

Filehandle
Mark5BFileReader or Mark5BFileWriter (binary), or Mark5BStreamReader or Mark5BStreamWriter (stream).

Notes

One can also pass to `name` a list, tuple, or subclass of `FileNameSequencer`. For writing to multiple files, the `file_size` keyword must be passed or only the first file will be written to. One may also pass in a `sequentialfile` object (opened in 'rb' mode for reading or 'w+b' for writing), though for typical use cases it is practically identical to passing in a list or template.

Classes

`Mark5BFileReader`(fh_raw[, kday, ref_time, . . .])	Simple reader for Mark 5B files.
`Mark5BFileWriter`(fh_raw)	Simple writer for Mark 5B files.
`Mark5BStreamBase`(fh_raw, header0[, . . .])	Base for Mark 5B streams.
`Mark5BStreamReader`(fh_raw[, sample_rate, . . .])	VLBI Mark 5B format reader.
`Mark5BStreamWriter`(fh_raw[, header0, . . .])	VLBI Mark 5B format writer.

Mark5BFileReader

class baseband.mark5b.base.**Mark5BFileReader**(*fh_raw*, *kday=None*, *ref_time=None*, *nchan=None*, *bps=2*)

Bases: `baseband.vlbi_base.base.VLBIFileReaderBase`

Simple reader for Mark 5B files.

Wraps a binary filehandle, providing methods to help interpret the data, such as `read_frame` and `get_frame_rate`.

Parameters

fh_raw
[filehandle] Filehandle of the raw binary data file.

kday
[int or None] Explicit thousands of MJD of the observation time. Can instead pass an approximate `ref_time`.

ref_time
[`Time` or None] Reference time within 500 days of the observation time, used to infer the full MJD. Used only if kday is not given.

nchan
[int, optional] Number of channels. Default: 1.

bps
[int, optional] Bits per elementary sample. Default: 2.

Attributes Summary

`info`()

Methods Summary

close(self)	
find_header(self[, forward, maximum])	Find the nearest header from the current position.
get_frame_rate(self)	Determine the number of frames per second.
read_frame(self[, verify])	Read a single frame (header plus payload).
read_header(self)	Read a single header from the file.
temporary_offset(self)	Context manager for temporarily seeking to another file position.

Attributes Documentation

info

Methods Documentation

close(*self*)

find_header(*self*, *forward=True*, *maximum=None*)

Find the nearest header from the current position.

If successful, the file pointer is left at the start of the header.

Parameters

forward
[bool, optional] Seek forward if `True` (default), backward if `False`.

maximum
[int, optional] Maximum number of bytes to search through. Default: twice the frame size of 10016 bytes.

Returns

header
[`Mark5BHeader` or None] Retrieved Mark 5B header, or `None` if nothing found.

get_frame_rate(*self*)

Determine the number of frames per second.

This method first tries to determine the frame rate by looking for the highest frame number in the first second of data. If that fails, it uses the time difference between two consecutive frames. This can fail if the headers do not store fractional seconds, or if the data rate is above 512 Mbps.

Returns

frame_rate
[`Quantity`] Frames per second.

read_frame(*self*, *verify=True*)

Read a single frame (header plus payload).

Returns

frame
[Mark5BFrame] With header and data properties that return the Mark5BHeader and data encoded in the frame, respectively.

verify
[bool, optional] Whether to do basic checks of frame integrity. Default: True.

read_header(*self*)
Read a single header from the file.

Returns

header
[Mark5BHeader]

temporary_offset(*self*)
Context manager for temporarily seeking to another file position.

To be used as part of a with statement:

```
with fh_raw.temporary_offset() [as fh_raw]:
    with-block
```

On exiting the with-block, the file pointer is moved back to its original position.

Mark5BFileWriter

class baseband.mark5b.base.**Mark5BFileWriter**(*fh_raw*)
Bases: baseband.vlbi_base.base.VLBIFileBase

Simple writer for Mark 5B files.

Adds write_frame method to the VLBI binary file wrapper.

Methods Summary

close(self)	
temporary_offset(self)	Context manager for temporarily seeking to another file position.
write_frame(self, data[, header, bps, valid])	Write a single frame (header plus payload).

Methods Documentation

close(*self*)

temporary_offset(*self*)
Context manager for temporarily seeking to another file position.

To be used as part of a with statement:

```
with fh_raw.temporary_offset() [as fh_raw]:
    with-block
```

On exiting the with-block, the file pointer is moved back to its original position.

write_frame(*self*, *data*, *header=None*, *bps=2*, *valid=True*, ***kwargs*)
Write a single frame (header plus payload).

Parameters

data
[ndarray or :Mark5BFrame] If an array, header should be given, which will be used to get the information needed to encode the array, and to construct the Mark 5B frame.

header
[Mark5BHeader] Can instead give keyword arguments to construct a header. Ignored if data is a Mark5BFrame instance.

bps
[int, optional] Bits per elementary sample, to use when encoding the payload. Ignored if data is a Mark5BFrame instance. Default: 2.

valid
[bool, optional] Whether the data are valid; if False, a payload filled with an appropriate pattern will be crated. Ignored if data is a Mark5BFrame instance. Default: True.

****kwargs**
If header is not given, these are used to initialize one.

Mark5BStreamBase

class baseband.mark5b.base.**Mark5BStreamBase**(*fh_raw*, *header0*, *sample_rate=None*, *nchan=1*, *bps=2*, *squeeze=True*, *subset=()*, *fill_value=0.0*, *verify=True*)
Bases: baseband.vlbi_base.base.VLBIStreamBase

Base for Mark 5B streams.

Attributes Summary

bps	Bits per elementary sample.
complex_data	Whether the data are complex.
header0	First header of the file.
sample_rate	Number of complete samples per second.
sample_shape	Shape of a complete sample (possibly subset or squeezed).
samples_per_frame	Number of complete samples per frame.
squeeze	Whether data arrays have dimensions with length unity removed.
start_time	Start time of the file.
subset	Specific components of the complete sample to decode.
time	Time of the sample pointer's current offset in file.
verify	Whether to do consistency checks on frames being read.

Methods Summary

close(self)	
tell(self[, unit])	Current offset in the file.

Attributes Documentation

bps
Bits per elementary sample.

complex_data
Whether the data are complex.

header0
First header of the file.

sample_rate
Number of complete samples per second.

sample_shape
Shape of a complete sample (possibly subset or squeezed).

samples_per_frame
Number of complete samples per frame.

squeeze
Whether data arrays have dimensions with length unity removed.

If `True`, data read out has such dimensions removed, and data passed in for writing has them inserted.

start_time
Start time of the file.

See also `time` for the time of the sample pointer's current offset.

subset
Specific components of the complete sample to decode.

The order of dimensions is the same as for `sample_shape`. Set by the class initializer.

time
Time of the sample pointer's current offset in file.

See also `start_time` for the start time of the file.

verify
Whether to do consistency checks on frames being read.

Methods Documentation

close(*self*)

tell(*self*, *unit=None*)
Current offset in the file.

Parameters

unit
[`Unit` or str, optional] Time unit the offset should be returned in. By default, no unit is used, i.e., an integer enumerating samples is returned. For the special string 'time', the absolute time is calculated.

Returns

offset
[int, `Quantity`, or `Time`] Offset in current file (or time at current position).

Mark5BStreamReader

class `baseband.mark5b.base.`**`Mark5BStreamReader`**(*fh_raw*, *sample_rate=None*, *kday=None*, *ref_time=None*, *nchan=None*, *bps=2*, *squeeze=True*, *subset=()*, *fill_value=0.0*, *verify=True*)

Bases: `baseband.mark5b.base.Mark5BStreamBase`, `baseband.vlbi_base.base.VLBIStreamReaderBase`

VLBI Mark 5B format reader.

Allows access a Mark 5B file as a continues series of samples.

Parameters

fh_raw
[filehandle] Filehandle of the raw Mark 5B stream.

sample_rate
[`Quantity`, optional] Number of complete samples per second, i.e. the rate at which each channel is sampled. If `None` (default), will be inferred from scanning one second of the file or, failing that, using the time difference between two consecutive frames.

kday
[int or None] Explicit thousands of MJD of the observation start time (eg. `57000` for MJD 57999), used to infer the full MJD from the header's time information. Can instead pass an approximate `ref_time`.

ref_time
[`Time` or None] Reference time within 500 days of the observation start time, used to infer the full MJD. Only used if `kday` is not given.

nchan
[int] Number of channels. Needs to be explicitly passed in.

bps
[int, optional] Bits per elementary sample. Default: 2.

squeeze
[bool, optional] If `True` (default), remove any dimensions of length unity from decoded data.

subset
[indexing object, optional] Specific channels of the complete sample to decode (after possible squeezing). If an empty tuple (default), all channels are read.

fill_value
[float or complex] Value to use for invalid or missing data. Default: 0.

verify
[bool, optional] Whether to do basic checks of frame integrity when reading. The first frame of the stream is always checked. Default: `True`.

Attributes Summary

bps	Bits per elementary sample.
complex_data	Whether the data are complex.
dtype	
fill_value	Value to use for invalid or missing data.
header0	First header of the file.
info()	Standardized information on stream readers.
ndim	Number of dimensions of the (squeezed/subset) stream data.
sample_rate	Number of complete samples per second.
sample_shape	Shape of a complete sample (possibly subset or squeezed).
samples_per_frame	Number of complete samples per frame.
shape	Shape of the (squeezed/subset) stream data.
size	Total number of component samples in the (squeezed/subset) stream data.
squeeze	Whether data arrays have dimensions with length unity removed.
start_time	Start time of the file.
stop_time	Time at the end of the file, just after the last sample.
subset	Specific components of the complete sample to decode.
time	Time of the sample pointer's current offset in file.
verify	Whether to do consistency checks on frames being read.

Methods Summary

close(self)	
read(self[, count, out])	Read a number of complete (or subset) samples.
readable(self)	Whether the file can be read and decoded.
seek(self, offset[, whence])	Change the stream position.
tell(self[, unit])	Current offset in the file.

Attributes Documentation

bps
Bits per elementary sample.

complex_data
Whether the data are complex.

dtype

fill_value
Value to use for invalid or missing data. Default: 0.

header0
First header of the file.

info
Standardized information on stream readers.

The `info` descriptor provides a few standard attributes, all of which can also be accessed directly on the stream filehandle. More detailed information on the underlying file is stored in its info, accessible via `info.file_info`.

Attributes

start_time
[`Time`] Time of the first complete sample.

stop_time
[`Time`] Time of the complete sample just beyond the end of the file.

sample_rate
[`Quantity`] Complete samples per unit of time.

shape
[tuple] Equivalent shape of the whole file, i.e., combining the number of complete samples and the shape of those samples.

bps
[int] Number of bits used to encode each elementary sample.

complex_data
[bool] Whether the data are complex.

readable
[bool] Whether the first sample could be read and decoded.

`ndim`
Number of dimensions of the (squeezed/subset) stream data.

`sample_rate`
Number of complete samples per second.

`sample_shape`
Shape of a complete sample (possibly subset or squeezed).

`samples_per_frame`
Number of complete samples per frame.

`shape`
Shape of the (squeezed/subset) stream data.

`size`
Total number of component samples in the (squeezed/subset) stream data.

`squeeze`
Whether data arrays have dimensions with length unity removed.

If `True`, data read out has such dimensions removed, and data passed in for writing has them inserted.

`start_time`
Start time of the file.

See also `time` for the time of the sample pointer's current offset, and (if available) `stop_time` for the time at the end of the file.

`stop_time`
Time at the end of the file, just after the last sample.

See also `start_time` for the start time of the file, and `time` for the time of the sample pointer's current offset.

subset
Specific components of the complete sample to decode.

The order of dimensions is the same as for `sample_shape`. Set by the class initializer.

time
Time of the sample pointer's current offset in file.

See also `start_time` for the start time, and (if available) `stop_time` for the end time, of the file.

verify
Whether to do consistency checks on frames being read.

Methods Documentation

close(*self*)

read(*self*, *count=None*, *out=None*)
Read a number of complete (or subset) samples.

The range retrieved can span multiple frames.

Parameters

count
[int or None, optional] Number of complete/subset samples to read. If `None` (default) or negative, the whole file is read. Ignored if `out` is given.

out
[None or array, optional] Array to store the data in. If given, `count` will be inferred from the first dimension; the other dimension should equal `sample_shape`.

Returns

out
[`ndarray` of float or complex] The first dimension is sample-time, and the remainder given by `sample_shape`.

readable(*self*)
Whether the file can be read and decoded.

seek(*self*, *offset*, *whence=0*)
Change the stream position.

This works like a normal filehandle seek, but the offset is in samples (or a relative or absolute time).

Parameters

offset
[int, `Quantity`, or `Time`] Offset to move to. Can be an (integer) number of samples, an offset in time units, or an absolute time.

whence
[{0, 1, 2, 'start', 'current', or 'end'}, optional] Like regular seek, the offset is taken to be from the start if `whence=0` (default), from the current position if 1, and from the end if 2. One can alternativey use 'start', 'current', or 'end' for 0, 1, or 2, respectively. Ignored if `offset` is a time.

tell(*self*, *unit=None*)

Current offset in the file.

Parameters

unit
[Unit or str, optional] Time unit the offset should be returned in. By default, no unit is used, i.e., an integer enumerating samples is returned. For the special string 'time', the absolute time is calculated.

Returns

offset
[int, Quantity, or Time] Offset in current file (or time at current position).

Mark5BStreamWriter

class baseband.mark5b.base.**Mark5BStreamWriter**(*fh_raw*, *header0=None*, *sample_rate=None*, *nchan=1*, *bps=2*, *squeeze=True*, ***kwargs*)

Bases: `baseband.mark5b.base.Mark5BStreamBase`, `baseband.vlbi_base.base.VLBIStreamWriterBase`

VLBI Mark 5B format writer.

Encodes and writes sequences of samples to file.

Parameters

fh_raw
[filehandle] For writing filled sets of frames to storage.

header0
[Mark5BHeader] Header for the first frame, holding time information, etc. Can instead give keyword arguments to construct a header (see `**kwargs`).

sample_rate
[Quantity] Number of complete samples per second, i.e. the rate at which each channel is sampled. Needed to calculate header timestamps.

nchan
[int, optional] Number of channels. Default: 1.

bps
[int, optional] Bits per elementary sample. Default: 2.

squeeze
[bool, optional] If `True` (default), `write` accepts squeezed arrays as input, and adds any dimensions of length unity.

****kwargs**
If no header is given, an attempt is made to construct one from these. For a standard header, the following suffices.

— Header kwargs
[(see `fromvalues()`)]

time
[Time] Start time of the file. Sets bcd-encoded unit day, hour, minute, second, and fraction, as well as the frame number, in the header.

Attributes Summary

`bps`	Bits per elementary sample.
`complex_data`	Whether the data are complex.
`header0`	First header of the file.
`sample_rate`	Number of complete samples per second.
`sample_shape`	Shape of a complete sample (possibly subset or squeezed).
`samples_per_frame`	Number of complete samples per frame.
`squeeze`	Whether data arrays have dimensions with length unity removed.
`start_time`	Start time of the file.
`subset`	Specific components of the complete sample to decode.
`time`	Time of the sample pointer's current offset in file.
`verify`	Whether to do consistency checks on frames being read.

Methods Summary

`close`(self)	
`tell`(self[, unit])	Current offset in the file.
`write`(self, data[, valid])	Write data, buffering by frames as needed.

Attributes Documentation

bps
Bits per elementary sample.

complex_data
Whether the data are complex.

header0
First header of the file.

sample_rate
Number of complete samples per second.

sample_shape
Shape of a complete sample (possibly subset or squeezed).

samples_per_frame
Number of complete samples per frame.

squeeze
Whether data arrays have dimensions with length unity removed.

If `True`, data read out has such dimensions removed, and data passed in for writing has them inserted.

start_time
Start time of the file.

See also `time` for the time of the sample pointer's current offset.

subset
Specific components of the complete sample to decode.

The order of dimensions is the same as for `sample_shape`. Set by the class initializer.

`time`
Time of the sample pointer's current offset in file.

See also `start_time` for the start time of the file.

`verify`
Whether to do consistency checks on frames being read.

Methods Documentation

`close`(*self*)

`tell`(*self*, *unit=None*)
Current offset in the file.

Parameters

unit
[`Unit` or str, optional] Time unit the offset should be returned in. By default, no unit is used, i.e., an integer enumerating samples is returned. For the special string 'time', the absolute time is calculated.

Returns

offset
[int, `Quantity`, or `Time`] Offset in current file (or time at current position).

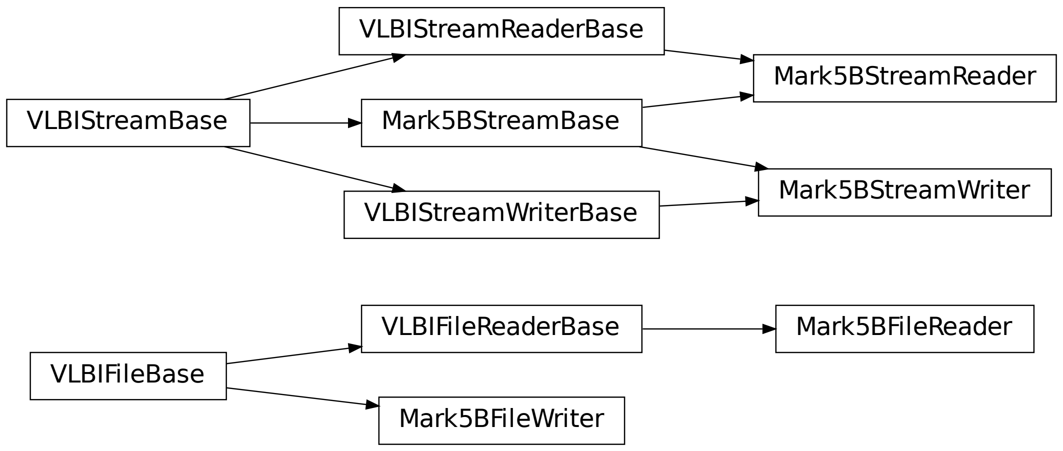
`write`(*self*, *data*, *valid=True*)
Write data, buffering by frames as needed.

Parameters

data
[`ndarray`] Piece of data to be written, with sample dimensions as given by `sample_shape`. This should be properly scaled to make best use of the dynamic range delivered by the encoding.

valid
[bool, optional] Whether the current data are valid. Default: `True`.

Class Inheritance Diagram



CHAPTER

SEVEN

MARK 4

The Mark 4 format is the output format of the MIT Haystack Observatory's Mark 4 VLBI magnetic tape-based data acquisition system, and one output format of its successor, the Mark 5A hard drive-based system. The format's specification is in the Mark IIIA/IV/VLBA design specifications.

Baseband currently only supports files that have been parity-stripped and corrected for barrel roll and data modulation.

7.1 File Structure

Mark 4 files contain up to 64 concurrent data "tracks". Tracks are divided into 22500-bit "tape frames", each of which consists of a 160-bit *header* followed by a 19840-bit *payload*. The header includes a timestamp (accurate to 1.25 ms), track ID, sideband, and fan-out/in factor (see below); the details of these can be found in 2.1.1 - 2.1.3 in the design specifications. The payload consists of a 1-bit *stream*. When recording 2-bit *elementary samples*, the data is split into two tracks, with one carrying the sign bit, and the other the magnitude bit.

The header takes the place of the first 160 bits of payload data, so that the first sample occurs `fanout * 160` sample times after the header time. This means that a Mark 4 stream is not contiguous in time. The length of one frame ranges from 1.25 ms to 160 ms in octave steps (which ensures an integer number of frames falls within 1 minute), setting the maximum sample rate per track to 18 megabits/track/s.

Data from a single *channel* may be distributed to multiple tracks - "fan-out" - or multiple channels fed to one track - "fan-in". Fan-out is used when sampling at rates higher than 18 megabits/track/s. Baseband currently only supports tracks using fan-out ("longitudinal data format").

Baseband reconstructs the tracks into channels (reconstituting 2-bit data from two tracks into a single channel if necessary) and combines tape frame headers into a single *data frame* header.

7.2 Usage

This section covers reading and writing Mark 4 files with Baseband; general usage can be found under the *Using Baseband* section. For situations in which one is unsure of a file's format, Baseband features the general `baseband.open` and `baseband.file_info` functions, which are also discussed in *Using Baseband*. The examples below use the small sample file `baseband/data/sample.m4`, and the `numpy`, `astropy.units`, `astropy.time.Time`, and `baseband.mark4` modules:

```
>>> import numpy as np
>>> import astropy.units as u
>>> from astropy.time import Time
>>> from baseband import mark4
>>> from baseband.data import SAMPLE_MARK4
```

Opening a Mark 4 file with open in binary mode provides a normal file reader but extended with methods to read a Mark4Frame. Mark 4 files generally **do not start (or end) at a frame boundary**, so in binary mode one has to seek the first frame using locate_frame (which will also determine the number of Mark 4 tracks, if not given explicitly). Since Mark 4 files do not store the full time information, one must pass either the the decade the data was taken, or an equivalent reference Time object:

```
>>> fb = mark4.open(SAMPLE_MARK4, 'rb', decade=2010)
>>> fb.locate_frame()  # Locate first frame.
2696
>>> frame = fb.read_frame()
>>> frame.shape
(80000, 8)
>>> fb.close()
```

Opening in stream mode automatically seeks for the first frame, and wraps the low-level routines such that reading and writing is in units of samples. It also provides access to header information. Here we pass a reference Time object within 4 years of the observation start time to `ref_time`, rather than a decade:

```
>>> fh = mark4.open(SAMPLE_MARK4, 'rs', ref_time=Time('2013:100:23:00:00'))
>>> fh
<Mark4StreamReader name=... offset=0
    sample_rate=32.0 MHz, samples_per_frame=80000,
    sample_shape=SampleShape(nchan=8), bps=2,
    start_time=2014-06-16T07:38:12.47500>
>>> d = fh.read(6400)
>>> d.shape
(6400, 8)
>>> d[635:645, 0].astype(int)  # first channel
array([ 0,  0,  0,  0,  0, -1,  1,  3,  1, -1])
>>> fh.close()
```

As mentioned in the *File Structure* section, because the header takes the place of the first 160 samples of each track, the first payload sample occurs `fanout * 160` sample times after the header time. The stream reader includes these overwritten samples as invalid data (zeros, by default):

```
>>> np.array_equal(d[:640], np.zeros((640,) + d.shape[1:]))
True
```

When writing to file, we need to pass in the sample rate in addition to decade. The number of tracks can be inferred from the header:

```
>>> fw = mark4.open('sample_mark4_segment.m4', 'ws', header0=frame.header,
...                 sample_rate=32*u.MHz, decade=2010)
>>> fw.write(frame.data)
>>> fw.close()
>>> fh = mark4.open('sample_mark4_segment.m4', 'rs',
...                 sample_rate=32.*u.MHz, decade=2010)
>>> np.all(fh.read(80000) == frame.data)
True
>>> fh.close()
```

Note that above we had to pass in the sample rate even when opening the file for reading; this is because there is only a single frame in the file, and hence the sample rate cannot be inferred automatically.

7.3 Reference/API

7.3.1 baseband.mark4 Package

Mark 4 VLBI data reader.

Code inspired by Walter Brisken's mark5access. See https://github.com/demorest/mark5access.

The format itself is described in detail in http://www.haystack.mit.edu/tech/vlbi/mark5/docs/230.3.pdf

Functions

`open`(name[, mode])	Open Mark4 file(s) for reading or writing.

open

`baseband.mark4.`**`open`**(*name*, *mode='rs'*, ***kwargs*)

Open Mark4 file(s) for reading or writing.

Opened as a binary file, one gets a wrapped filehandle that adds methods to read/write a frame. Opened as a stream, the handle is wrapped further, with methods such as reading and writing to the file as if it were a stream of samples.

Parameters

name
[str or filehandle, or sequence of str] File name, filehandle, or sequence of file names (see Notes).

mode
[{'rb', 'wb', 'rs', or 'ws'}, optional] Whether to open for reading or writing, and as a regular binary file or as a stream. Default: 'rs', for reading a stream.

****kwargs**
Additional arguments when opening the file as a stream.

— For reading a stream
[(see `Mark4StreamReader`)]

sample_rate
[`Quantity`, optional] Number of complete samples per second, i.e. the rate at which each channel is sampled. If not given, will be inferred from scanning two frames of the file.

ntrack
[int, optional] Number of Mark 4 bitstreams. If `None` (default), will attempt to automatically detect it by scanning the file.

decade
[int or None] Decade of the observation start time (eg. `2010` for 2018), needed to remove ambiguity in the Mark 4 time stamp (default: `None`). Can instead pass an approximate `ref_time`.

ref_time
[`Time` or None] Reference time within 4 years of the start time of the observations. Used only if decade is not given.

squeeze
[bool, optional] If True (default), remove any dimensions of length unity from decoded data.

subset
[indexing object, optional] Specific channels of the complete sample to decode (after possible squeezing). If an empty tuple (default), all channels are read.

fill_value
[float or complex, optional] Value to use for invalid or missing data. Default: 0.

verify
[bool, optional] Whether to do basic checks of frame integrity when reading. The first frame of the stream is always checked. Default: True.

— For writing a stream
[(see Mark4StreamWriter)]

header0
[Mark4Header] Header for the first frame, holding time information, etc. Can instead give keyword arguments to construct a header (see `**kwargs`).

sample_rate
[Quantity] Number of complete samples per second, i.e. the rate at which each channel is sampled. Needed to calculate header timestamps.

squeeze
[bool, optional] If True (default), writer accepts squeezed arrays as input, and adds any dimensions of length unity.

file_size
[int or None, optional] When writing to a sequence of files, the maximum size of one file in bytes. If None (default), the file size is unlimited, and only the first file will be written to.

****kwargs**
If the header is not given, an attempt will be made to construct one with any further keyword arguments. See Mark4StreamWriter.

Returns

Filehandle
Mark4FileReader or Mark4FileWriter (binary), or Mark4StreamReader or Mark4StreamWriter (stream)

Notes

Although it is not generally expected to be useful for Mark 4, like for other formats one can also pass to `name` a list, tuple, or subclass of FileNameSequencer. For writing to multiple files, the `file_size` keyword must be passed or only the first file will be written to. One may also pass in a sequentialfile object (opened in 'rb' mode for reading or 'w+b' for writing), though for typical use cases it is practically identical to passing in a list or template.

Classes

Mark4Frame(header, payload[, valid, verify])	Representation of a Mark 4 frame, consisting of a header and payload.

Continued on next page

Table 2 – continued from previous page

Mark4Header(words[, ntrack, decade, . . .])	Decoder/encoder of a Mark 4 Header, containing all streams.
Mark4Payload(words[, header, nchan, bps, fanout])	Container for decoding and encoding Mark 4 payloads.

Mark4Frame

class baseband.mark4.**Mark4Frame**(*header*, *payload*, *valid=None*, *verify=True*)

Bases: `baseband.vlbi_base.frame.VLBIFrameBase`

Representation of a Mark 4 frame, consisting of a header and payload.

Parameters

header
[Mark4Header] Wrapper around the encoded header words, providing access to the header information.

payload
[Mark4Payload] Wrapper around the payload, provding mechanisms to decode it.

valid
[bool or None, optional] Whether the data are valid. If `None` (default), inferred from header. Note that `header` is updated in-place if `True` or `False`.

verify
[bool, optional] Whether or not to do basic assertions that check the integrity (e.g., that channel information and number of tracks are consistent between header and data). Default: `True`.

Notes

The Frame can also be read instantiated using class methods:

fromfile : read header and payload from a filehandle

fromdata : encode data as payload

Of course, one can also do the opposite:

tofile : method to write header and payload to filehandle

data : property that yields full decoded payload

One can decode part of the payload by indexing or slicing the frame. If the frame does not contain valid data, all values returned are set to `self.fill_value`.

A number of properties are defined: `shape`, `dtype` and `size` are the shape, type and number of complete samples of the data array, and `nbytes` the frame size in bytes. Furthermore, the frame acts as a dictionary, with keys those of the header. Any attribute that is not defined on the frame itself, such as `.time` will be looked up on the header as well.

Attributes Summary

data	Full decoded frame, with header part filled in.
dtype	Numeric type of the frame data.

Continued on next page

Table 3 – continued from previous page

fill_value	Value to replace invalid data in the frame.
nbytes	Size of the encoded frame in bytes.
ndim	Number of dimensions of the frame data.
sample_shape	Shape of a sample in the frame (nchan,).
shape	Shape of the frame data.
size	Total number of component samples in the frame data.
valid	Whether frame contains valid data.

Methods Summary

fromdata(data[, header, verify])	Construct frame from data and header.
fromfile(fh, ntrack[, decade, ref_time, verify])	Read a frame from a filehandle.
keys(self)	
tofile(self, fh)	Write encoded frame to filehandle.
verify(self)	Simple verification.

Attributes Documentation

data
Full decoded frame, with header part filled in.

dtype
Numeric type of the frame data.

fill_value
Value to replace invalid data in the frame.

nbytes
Size of the encoded frame in bytes.

ndim
Number of dimensions of the frame data.

sample_shape
Shape of a sample in the frame (nchan,).

shape
Shape of the frame data.

size
Total number of component samples in the frame data.

valid
Whether frame contains valid data.

None of the error flags are set.

Methods Documentation

classmethod fromdata(*data*, *header=None*, *verify=True*, ***kwargs*)
Construct frame from data and header.

Parameters

data
[`ndarray`] Array holding complex or real data to be encoded. This should have the full size of a data frame, even though the part covered by the header will be ignored.

header
[`Mark4Header` or None] If not given, will attempt to generate one using the keywords.

verify
[bool, optional] Whether to do basic checks of frame integrity (default: `True`).

classmethod fromfile(*fh*, *ntrack*, *decade=None*, *ref_time=None*, *verify=True*)
Read a frame from a filehandle.

Parameters

fh
[filehandle] To read header from.

ntrack
[int] Number of Mark 4 bitstreams.

decade
[int or None] Decade in which the observations were taken. Can instead pass an approximate `ref_time`.

ref_time
[`Time` or None] Reference time within 4 years of the observation time. Used only if `decade` is not given.

verify
[bool, optional] Whether to do basic verification of integrity. Default: `True`.

keys(*self*)

tofile(*self*, *fh*)
Write encoded frame to filehandle.

verify(*self*)
Simple verification. To be added to by subclasses.

Mark4Header

class baseband.mark4.**Mark4Header**(*words*, *ntrack=None*, *decade=None*, *ref_time=None*, *verify=True*)
Bases: `baseband.mark4.header.Mark4TrackHeader`

Decoder/encoder of a Mark 4 Header, containing all streams.

See http://www.haystack.mit.edu/tech/vlbi/mark5/docs/230.3.pdf

Parameters

words
[`ndarray` of int, or None] Shape should be (5, number-of-tracks), and dtype np.uint32. If `None`, `ntrack` should be given and words will be initialized to 0.

ntrack
[None or int] Number of Mark 4 bitstreams, to help initialize `words` if needed.

decade
[int or None] Decade in which the observations were taken (needed to remove ambiguity in the Mark 4 time stamp). Can instead pass an approximate `ref_time`.

ref_time
[`Time` or None] Reference time within 4 years of the observation time, used to infer the full Mark 4 timestamp. Used only if decade is not given.

verify
[bool, optional] Whether to do basic verification of integrity. Default: `True`.

Returns

header
[`Mark4Header`]

Attributes Summary

`bps`	Bits per elementary sample (either 1 or 2).
`converters`	Converted ID and sideband used for each channel.
`decade`	
`fanout`	Number of samples stored in one payload item of size ntrack.
`fraction`	Fractional seconds (decoded from 'bcd_fraction').
`frame_nbytes`	Size of the frame in bytes.
`mutable`	Whether the header can be modified.
`nbytes`	Size of the header in bytes.
`nchan`	Number of channels (`ntrack * fanout`) in the frame.
`nsb`	Number of side bands used.
`ntrack`	Number of Mark 4 bitstreams.
`payload_nbytes`	Size of the payload in bytes.
`samples_per_frame`	Number of complete samples in the frame.
`stream_dtype`	Stream dtype required to hold this header's number of tracks.
`time`	Convert BCD time code to Time object for all tracks.
`track_assignment`	Assignments of tracks to channels and fanout items.
`track_id`	

Methods Summary

`copy`(self, **kwargs)	Create a mutable and independent copy of the header.
`fromfile`(fh, ntrack[, decade, ref_time, verify])	Read Mark 4 header from file.
`fromkeys`(*args, **kwargs)	Initialise a header from parsed values.
`fromvalues`(ntrack[, decade, ref_time])	Initialise a header from parsed values.
`get_time`(self)	Convert BCD time code to Time object for all tracks.
`infer_decade`(self, ref_time)	Uses a reference time to set a header's decade.
`keys`(self)	
`set_time`(self, time)	
`tofile`(self, fh)	Write VLBI frame header to filehandle.
`update`(self[, crc, verify])	Update the header by setting keywords or properties.

Continued on next page

Table 6 – continued from previous page

verify(self)	Verify header integrity.

Attributes Documentation

bps
Bits per elementary sample (either 1 or 2).

If set, combined with fanout and ntrack to update 'magnitude_bit' for all tracks.

converters
Converted ID and sideband used for each channel.

Returns a structured array with numerical 'converter' and boolean 'lsb' entries (where True means lower sideband).

Can be set with a similar structured array or a dict; if just an an array is passed in, it will be assumed that the sideband has been set beforehand (e.g., by setting nsb) and that the array holds the converter IDs.

decade = None

fanout
Number of samples stored in one payload item of size ntrack.

If set, will update 'fan_out' for each track.

fraction
Fractional seconds (decoded from 'bcd_fraction').

frame_nbytes
Size of the frame in bytes.

mutable
Whether the header can be modified.

nbytes
Size of the header in bytes.

nchan
Number of channels (`ntrack * fanout`) in the frame.

If set, it is combined with ntrack and fanout to infer bps.

nsb
Number of side bands used.

If set, assumes all converters are upper sideband for 1, and that converter IDs alternate between upper and lower sideband for 2.

ntrack
Number of Mark 4 bitstreams.

payload_nbytes
Size of the payload in bytes.

Note that the payloads miss pieces overwritten by the header.

samples_per_frame
Number of complete samples in the frame.

If set, this uses the number of tracks to infer and set fanout.

stream_dtype
Stream dtype required to hold this header's number of tracks.

time
Convert BCD time code to Time object for all tracks.

If all tracks have the same fractional seconds, only a single Time instance is returned.

Uses bcd-encoded 'unit_year', 'day', 'hour', 'minute', 'second' and 'frac_sec', plus `decade` from the initialisation to calculate the time. See http://www.haystack.mit.edu/tech/vlbi/mark5/docs/230.3.pdf

track_assignment
Assignments of tracks to channels and fanout items.

The assignments are inferred from tables 10-14 in http://www.haystack.mit.edu/tech/vlbi/mark5/docs/230.3.pdf except that 2 has been subtracted so that tracks start at 0, and that for 64 tracks the arrays are suitably enlarged by adding another set of channels.

The returned array has shape `(fanout, nchan, bps)`.

track_id

Methods Documentation

copy(*self*, ***kwargs*)
Create a mutable and independent copy of the header.

Keyword arguments can be passed on as needed by possible subclasses.

classmethod fromfile(*fh*, *ntrack*, *decade=None*, *ref_time=None*, *verify=True*)
Read Mark 4 header from file.

Parameters

fh
[filehandle] To read header from.

ntrack
[int] Number of Mark 4 bitstreams.

decade
[int or None] Decade in which the observations were taken. Can instead pass an approximate `ref_time`.

ref_time
[`Time` or None] Reference time within 4 years of the observation time. Used only if `decade` is not given.

verify
[bool, optional] Whether to do basic verification of integrity. Default: `True`.

classmethod fromkeys(**args*, ***kwargs*)
Initialise a header from parsed values.

Like fromvalues, but without any interpretation of keywords.

Raises

KeyError
[if not all keys required are present in `kwargs`]

classmethod fromvalues(*ntrack*, *decade=None*, *ref_time=None*, ***kwargs*)

Initialise a header from parsed values.

Here, the parsed values must be given as keyword arguments, i.e., for any `header = cls(<words>)`, `cls.fromvalues(**header) == header`.

However, unlike for the `fromkeys` class method, data can also be set using arguments named after header methods, such as `time`.

Parameters

ntrack
[int] Number of Mark 4 bitstreams.

decade
[int or None, optional] Decade in which the observations were taken. Can instead pass an approximate `ref_time`. Not needed if `time` is given.

ref_time
[`Time` or None, optional] Reference time within 4 years of the observation time. Used only if decade is not given, and not needed if `time` is given.

****kwargs :**
Values used to initialize header keys or methods.

— Header keywords
[(minimum for a complete header)]

time
[`Time` instance] Time of the first sample.

bps
[int] Bits per elementary sample.

fanout
[int] Number of tracks over which a given channel is spread out.

get_time(*self*)

Convert BCD time code to Time object for all tracks.

If all tracks have the same fractional seconds, only a single Time instance is returned.

Uses bcd-encoded 'unit_year', 'day', 'hour', 'minute', 'second' and 'frac_sec', plus `decade` from the initialisation to calculate the time. See http://www.haystack.mit.edu/tech/vlbi/mark5/docs/230.3.pdf

infer_decade(*self*, *ref_time*)

Uses a reference time to set a header's `decade`.

Parameters

ref_time
[`Time`] Reference time within 5 years of the observation time.

keys(*self*)

set_time(*self*, *time*)

tofile(*self*, *fh*)

Write VLBI frame header to filehandle.

update(*self*, *crc=None*, *verify=True*, ***kwargs*)
Update the header by setting keywords or properties.

Here, any keywords matching header keys are applied first, and any remaining ones are used to set header properties, in the order set by the class (in `_properties`).

Parameters

crc
[int or None, optional] If `None` (default), recalculate the CRC after updating.

verify
[bool, optional] If `True` (default), verify integrity after updating.

****kwargs**
Arguments used to set keywords and properties.

verify(*self*)
Verify header integrity.

Mark4Payload

class baseband.mark4.**Mark4Payload**(*words*, *header=None*, *nchan=1*, *bps=2*, *fanout=1*)
Bases: `baseband.vlbi_base.payload.VLBIPayloadBase`

Container for decoding and encoding Mark 4 payloads.

Parameters

words
[`ndarray`] Array containg LSB unsigned words (with the right size) that encode the payload.

header
[`Mark4Header`, optional] If given, used to infer the number of channels, bps, and fanout.

nchan
[int, optional] Number of channels, used if `header` is not given. Default: 1.

bps
[int, optional] Number of bits per sample, used if `header` is not given. Default: 2.

fanout
[int, optional] Number of tracks every bit stream is spread over, used if `header` is not given. Default: 1.

Notes

The total number of tracks is `nchan * bps * fanout`.

Attributes Summary

`data`	Full decoded payload.
`dtype`	Numeric type of the decoded data array.
`nbytes`	Size of the payload in bytes.

Continued on next page

Table 7 – continued from previous page

ndim	Number of dimensions of the decoded data array.
shape	Shape of the decoded data array.
size	Total number of component samples in the decoded data array.

Methods Summary

fromdata(data, header)	Encode data as payload, using header information.
fromfile(fh, header)	Read payload from filehandle and decode it into data.
tofile(self, fh)	Write payload to filehandle.

Attributes Documentation

data
Full decoded payload.

dtype
Numeric type of the decoded data array.

nbytes
Size of the payload in bytes.

ndim
Number of dimensions of the decoded data array.

shape
Shape of the decoded data array.

size
Total number of component samples in the decoded data array.

Methods Documentation

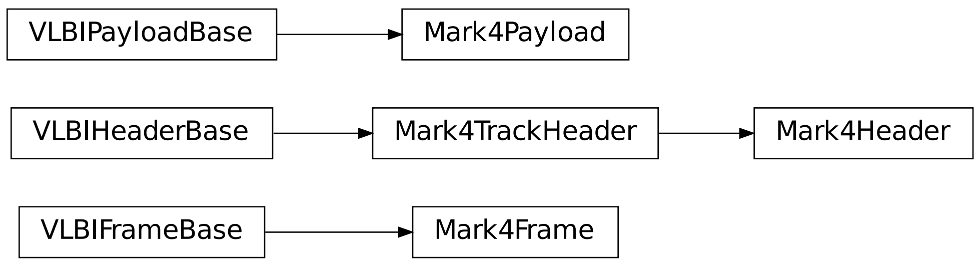
classmethod fromdata(*data*, *header*)
Encode data as payload, using header information.

classmethod fromfile(*fh*, *header*)
Read payload from filehandle and decode it into data.

The payload_nbytes, number of channels, bits per sample, and fanout ratio are all taken from the header.

tofile(*self*, *fh*)
Write payload to filehandle.

Class Inheritance Diagram



7.3.2 baseband.mark4.header Module

Definitions for VLBI Mark 4 Headers.

Implements a Mark4Header class used to store header words, and decode/encode the information therein.

For the specification of tape Mark 4 format, see http://www.haystack.mit.edu/tech/vlbi/mark5/docs/230.3.pdf

A little bit on the disk representation is at http://adsabs.harvard.edu/abs/2003ASPC..306..123W

Functions

`stream2words`(stream[, track])	Convert a stream of integers to uint32 header words.
`words2stream`(words)	Convert a set of uint32 header words to a stream of integers.

stream2words

`baseband.mark4.header.`**`stream2words`**(*stream*, *track=None*)

Convert a stream of integers to uint32 header words.

Parameters

stream
[`array` of int] For each int, every bit corresponds to a particular track.

track
[int, array, or None, optional] The track to extract. If `None` (default), extract all tracks that the type of int in the stream can hold.

words2stream

`baseband.mark4.header.`**`words2stream`**(*words*)

Convert a set of uint32 header words to a stream of integers.

Parameters

words
[array of uint32]

Returns

stream
[array of int] For each int, every bit corresponds to a particular track.

Classes

Mark4TrackHeader(words[, decade, ref_time, . . .])	Decoder/encoder of a Mark 4 Track Header.
Mark4Header(words[, ntrack, decade, . . .])	Decoder/encoder of a Mark 4 Header, containing all streams.

Mark4TrackHeader

class baseband.mark4.header.**Mark4TrackHeader**(*words*, *decade=None*, *ref_time=None*, *verify=True*)

Bases: baseband.vlbi_base.header.VLBIHeaderBase

Decoder/encoder of a Mark 4 Track Header.

See http://www.haystack.mit.edu/tech/vlbi/mark5/docs/230.3.pdf

Parameters

words
[tuple of int, or None] Five 32-bit unsigned int header words. If None, set to a list of zeros for later initialisation.

decade
[int or None] Decade in which the observations were taken (needed to remove ambiguity in the Mark 4 time stamp). Can instead pass an approximate `ref_time`.

ref_time
[Time or None] Reference time within 4 years of the observation time, used to infer the full Mark 4 timestamp. Used only if decade is not given.

verify
[bool, optional] Whether to do basic verification of integrity. Default: True.

Returns

header
[Mark4TrackHeader]

Attributes Summary

decade	
fraction	Fractional seconds (decoded from 'bcd_fraction').

Continued on next page

Table 11 – continued from previous page

`mutable`	Whether the header can be modified.
`nbytes`	Size of the header in bytes.
`time`	Convert BCD time code to Time object.
`track_id`	

Methods Summary

`copy`(self, **kwargs)	Create a mutable and independent copy of the header.
`fromfile`(fh, *args, **kwargs)	Read VLBI Header from file.
`fromkeys`(*args, **kwargs)	Initialise a header from parsed values.
`fromvalues`(*args, **kwargs)	Initialise a header from parsed values.
`get_time`(self)	Convert BCD time code to Time object.
`infer_decade`(self, ref_time)	Uses a reference time to set a header's `decade`.
`keys`(self)	
`set_time`(self, time)	
`tofile`(self, fh)	Write VLBI frame header to filehandle.
`update`(self, *[, verify])	Update the header by setting keywords or properties.
`verify`(self)	Verify header integrity.

Attributes Documentation

decade = None

fraction
Fractional seconds (decoded from 'bcd_fraction').

mutable
Whether the header can be modified.

nbytes
Size of the header in bytes.

time
Convert BCD time code to Time object.

Calculate time using bcd-encoded 'bcd_unit_year', 'bcd_day', 'bcd_hour', 'bcd_minute', 'bcd_second' header items, as well as the `fraction` property (inferred from 'bcd_fraction') and `decade` from the initialisation. See See http://www.haystack.mit.edu/tech/vlbi/mark5/docs/230.3.pdf

track_id

Methods Documentation

copy(*self*, ***kwargs*)
Create a mutable and independent copy of the header.

Keyword arguments can be passed on as needed by possible subclasses.

classmethod fromfile(*fh*, **args*, ***kwargs*)
Read VLBI Header from file.

Arguments are the same as for class initialisation. The header constructed will be immutable.

classmethod fromkeys(**args*, ***kwargs*)

Initialise a header from parsed values.

Like fromvalues, but without any interpretation of keywords.

Raises

KeyError
[if not all keys required are present in `kwargs`]

classmethod fromvalues(**args*, ***kwargs*)

Initialise a header from parsed values.

Here, the parsed values must be given as keyword arguments, i.e., for any `header = cls(<words>)`, `cls.fromvalues(**header) == header`.

However, unlike for the `fromkeys` class method, data can also be set using arguments named after header methods, such as `time`.

Parameters

***args**
Possible arguments required to initialize an empty header.

****kwargs**
Values used to initialize header keys or methods.

get_time(*self*)

Convert BCD time code to Time object.

Calculate time using bcd-encoded 'bcd_unit_year', 'bcd_day', 'bcd_hour', 'bcd_minute', 'bcd_second' header items, as well as the `fraction` property (inferred from 'bcd_fraction') and `decade` from the initialisation. See See http://www.haystack.mit.edu/tech/vlbi/mark5/docs/230.3.pdf

infer_decade(*self*, *ref_time*)

Uses a reference time to set a header's `decade`.

Parameters

ref_time
[`Time`] Reference time within 5 years of the observation time.

keys(*self*)

set_time(*self*, *time*)

tofile(*self*, *fh*)

Write VLBI frame header to filehandle.

update(*self*, ***, *verify=True*, ***kwargs*)

Update the header by setting keywords or properties.

Here, any keywords matching header keys are applied first, and any remaining ones are used to set header properties, in the order set by the class (in `_properties`).

Parameters

verify
[bool, optional] If `True` (default), verify integrity after updating.

****kwargs**
Arguments used to set keywords and properties.

`verify`(*self*)
Verify header integrity.

Mark4Header

class `baseband.mark4.header.`**`Mark4Header`**(*words*, *ntrack=None*, *decade=None*, *ref_time=None*, *verify=True*)

Bases: `baseband.mark4.header.Mark4TrackHeader`

Decoder/encoder of a Mark 4 Header, containing all streams.

See http://www.haystack.mit.edu/tech/vlbi/mark5/docs/230.3.pdf

Parameters

words
[`ndarray` of int, or None] Shape should be (5, number-of-tracks), and dtype np.uint32. If `None`, `ntrack` should be given and words will be initialized to 0.

ntrack
[None or int] Number of Mark 4 bitstreams, to help initialize `words` if needed.

decade
[int or None] Decade in which the observations were taken (needed to remove ambiguity in the Mark 4 time stamp). Can instead pass an approximate `ref_time`.

ref_time
[`Time` or None] Reference time within 4 years of the observation time, used to infer the full Mark 4 timestamp. Used only if `decade` is not given.

verify
[bool, optional] Whether to do basic verification of integrity. Default: `True`.

Returns

header
[`Mark4Header`]

Attributes Summary

`bps`	Bits per elementary sample (either 1 or 2).
`converters`	Converted ID and sideband used for each channel.
`decade`	
`fanout`	Number of samples stored in one payload item of size ntrack.
`fraction`	Fractional seconds (decoded from 'bcd_fraction').
`frame_nbytes`	Size of the frame in bytes.
`mutable`	Whether the header can be modified.

Continued on next page

Table 13 – continued from previous page

nbytes	Size of the header in bytes.
nchan	Number of channels (ntrack * fanout) in the frame.
nsb	Number of side bands used.
ntrack	Number of Mark 4 bitstreams.
payload_nbytes	Size of the payload in bytes.
samples_per_frame	Number of complete samples in the frame.
stream_dtype	Stream dtype required to hold this header's number of tracks.
time	Convert BCD time code to Time object for all tracks.
track_assignment	Assignments of tracks to channels and fanout items.
track_id	

Methods Summary

copy(self, **kwargs)	Create a mutable and independent copy of the header.
fromfile(fh, ntrack[, decade, ref_time, verify])	Read Mark 4 header from file.
fromkeys(*args, **kwargs)	Initialise a header from parsed values.
fromvalues(ntrack[, decade, ref_time])	Initialise a header from parsed values.
get_time(self)	Convert BCD time code to Time object for all tracks.
infer_decade(self, ref_time)	Uses a reference time to set a header's decade.
keys(self)	
set_time(self, time)	
tofile(self, fh)	Write VLBI frame header to filehandle.
update(self[, crc, verify])	Update the header by setting keywords or properties.
verify(self)	Verify header integrity.

Attributes Documentation

bps

Bits per elementary sample (either 1 or 2).

If set, combined with `fanout` and `ntrack` to update 'magnitude_bit' for all tracks.

converters

Converted ID and sideband used for each channel.

Returns a structured array with numerical 'converter' and boolean 'lsb' entries (where `True` means lower sideband).

Can be set with a similar structured array or a `dict`; if just an an array is passed in, it will be assumed that the sideband has been set beforehand (e.g., by setting `nsb`) and that the array holds the converter IDs.

decade = None

fanout

Number of samples stored in one payload item of size ntrack.

If set, will update 'fan_out' for each track.

fraction

Fractional seconds (decoded from 'bcd_fraction').

frame_nbytes
Size of the frame in bytes.

mutable
Whether the header can be modified.

nbytes
Size of the header in bytes.

nchan
Number of channels (`ntrack * fanout`) in the frame.

If set, it is combined with `ntrack` and `fanout` to infer `bps`.

nsb
Number of side bands used.

If set, assumes all converters are upper sideband for 1, and that converter IDs alternate between upper and lower sideband for 2.

ntrack
Number of Mark 4 bitstreams.

payload_nbytes
Size of the payload in bytes.

Note that the payloads miss pieces overwritten by the header.

samples_per_frame
Number of complete samples in the frame.

If set, this uses the number of tracks to infer and set `fanout`.

stream_dtype
Stream dtype required to hold this header's number of tracks.

time
Convert BCD time code to Time object for all tracks.

If all tracks have the same fractional seconds, only a single Time instance is returned.

Uses bcd-encoded 'unit_year', 'day', 'hour', 'minute', 'second' and 'frac_sec', plus `decade` from the initialisation to calculate the time. See http://www.haystack.mit.edu/tech/vlbi/mark5/docs/230.3.pdf

track_assignment
Assignments of tracks to channels and fanout items.

The assignments are inferred from tables 10-14 in http://www.haystack.mit.edu/tech/vlbi/mark5/docs/230.3.pdf except that 2 has been subtracted so that tracks start at 0, and that for 64 tracks the arrays are suitably enlarged by adding another set of channels.

The returned array has shape `(fanout, nchan, bps)`.

track_id

Methods Documentation

copy(*self*, ***kwargs*)
Create a mutable and independent copy of the header.

Keyword arguments can be passed on as needed by possible subclasses.

classmethod fromfile(*fh*, *ntrack*, *decade=None*, *ref_time=None*, *verify=True*)

Read Mark 4 header from file.

Parameters

fh
[filehandle] To read header from.

ntrack
[int] Number of Mark 4 bitstreams.

decade
[int or None] Decade in which the observations were taken. Can instead pass an approximate `ref_time`.

ref_time
[`Time` or None] Reference time within 4 years of the observation time. Used only if `decade` is not given.

verify
[bool, optional] Whether to do basic verification of integrity. Default: `True`.

classmethod fromkeys(**args*, ***kwargs*)

Initialise a header from parsed values.

Like fromvalues, but without any interpretation of keywords.

Raises

KeyError
[if not all keys required are present in `kwargs`]

classmethod fromvalues(*ntrack*, *decade=None*, *ref_time=None*, ***kwargs*)

Initialise a header from parsed values.

Here, the parsed values must be given as keyword arguments, i.e., for any `header = cls(<words>)`, `cls.fromvalues(**header) == header`.

However, unlike for the `fromkeys` class method, data can also be set using arguments named after header methods, such as `time`.

Parameters

ntrack
[int] Number of Mark 4 bitstreams.

decade
[int or None, optional] Decade in which the observations were taken. Can instead pass an approximate `ref_time`. Not needed if `time` is given.

ref_time
[`Time` or None, optional] Reference time within 4 years of the observation time. Used only if `decade` is not given, and not needed if `time` is given.

****kwargs :**
Values used to initialize header keys or methods.

— Header keywords
[(minimum for a complete header)]

time
[`Time` instance] Time of the first sample.

bps
[int] Bits per elementary sample.

fanout
[int] Number of tracks over which a given channel is spread out.

`get_time`(*self*)
Convert BCD time code to Time object for all tracks.

If all tracks have the same fractional seconds, only a single Time instance is returned.

Uses bcd-encoded 'unit_year', 'day', 'hour', 'minute', 'second' and 'frac_sec', plus `decade` from the initialisation to calculate the time. See http://www.haystack.mit.edu/tech/vlbi/mark5/docs/230.3.pdf

`infer_decade`(*self*, *ref_time*)
Uses a reference time to set a header's `decade`.

Parameters

ref_time
[`Time`] Reference time within 5 years of the observation time.

`keys`(*self*)

`set_time`(*self*, *time*)

`tofile`(*self*, *fh*)
Write VLBI frame header to filehandle.

`update`(*self*, *crc=None*, *verify=True*, ***kwargs*)
Update the header by setting keywords or properties.

Here, any keywords matching header keys are applied first, and any remaining ones are used to set header properties, in the order set by the class (in `_properties`).

Parameters

crc
[int or None, optional] If `None` (default), recalculate the CRC after updating.

verify
[bool, optional] If `True` (default), verify integrity after updating.

****kwargs**
Arguments used to set keywords and properties.

`verify`(*self*)
Verify header integrity.

Variables

`CRC12`	CRC polynomial used for Mark 4 Headers.
`crc12`(stream)	Cyclic Redundancy Check for a bitstream.

CRC12

`baseband.mark4.header.CRC12 = 6159`

CRC polynomial used for Mark 4 Headers.

x^12 + x^11 + x^3 + x^2 + x + 1, i.e., 0x180f. See page 4 of http://www.haystack.mit.edu/tech/vlbi/mark5/docs/230.3.pdf

This is also a 'standard' CRC-12 mentioned in https://en.wikipedia.org/wiki/Cyclic_redundancy_check

crc12

`baseband.mark4.header.crc12(stream) = <baseband.vlbi_base.utils.CRC object>`

Cyclic Redundancy Check for a bitstream.

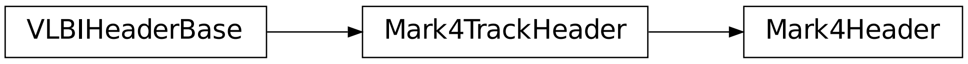
See https://en.wikipedia.org/wiki/Cyclic_redundancy_check

Once initialised, the instance can be used as a function that calculates the CRC, or one can use the check method to verify that the CRC at the end of a stream is correct.

Parameters

polynomial
[int] Binary encoded CRC divisor. For instance, that used by Mark 4 headers is 0x180f, or x^12 + x^11 + x^3 + x^2 + x + 1.

Class Inheritance Diagram



7.3.3 baseband.mark4.payload Module

Definitions for VLBI Mark 4 payloads.

Implements a Mark4Payload class used to store payload words, and decode to or encode from a data array.

For the specification, see http://www.haystack.mit.edu/tech/vlbi/mark5/docs/230.3.pdf

Functions

`reorder32`(x)	Reorder 32-track bits to bring signs & magnitudes together.
`reorder64`(x)	Reorder 64-track bits to bring signs & magnitudes together.

Continued on next page

Table 16 – continued from previous page

`init_luts`()	Set up the look-up tables for levels as a function of input byte.
`decode_8chan_2bit_fanout4`(frame)	Decode payload for 8 channels using 2 bits, fan-out 4 (64 tracks).
`encode_8chan_2bit_fanout4`(values)	Encode payload for 8 channels using 2 bits, fan-out 4 (64 tracks).

reorder32

baseband.mark4.payload.**reorder32**(*x*)

Reorder 32-track bits to bring signs & magnitudes together.

reorder64

baseband.mark4.payload.**reorder64**(*x*)

Reorder 64-track bits to bring signs & magnitudes together.

init_luts

baseband.mark4.payload.**init_luts**()

Set up the look-up tables for levels as a function of input byte.

decode_8chan_2bit_fanout4

baseband.mark4.payload.**decode_8chan_2bit_fanout4**(*frame*)

Decode payload for 8 channels using 2 bits, fan-out 4 (64 tracks).

encode_8chan_2bit_fanout4

baseband.mark4.payload.**encode_8chan_2bit_fanout4**(*values*)

Encode payload for 8 channels using 2 bits, fan-out 4 (64 tracks).

Classes

`Mark4Payload`(words[, header, nchan, bps, fanout])	Container for decoding and encoding Mark 4 payloads.

Mark4Payload

class baseband.mark4.payload.**Mark4Payload**(*words*, *header=None*, *nchan=1*, *bps=2*, *fanout=1*)

Bases: `baseband.vlbi_base.payload.VLBIPayloadBase`

Container for decoding and encoding Mark 4 payloads.

Parameters

words
[`ndarray`] Array containg LSB unsigned words (with the right size) that encode the payload.

header
[Mark4Header, optional] If given, used to infer the number of channels, bps, and fanout.

nchan
[int, optional] Number of channels, used if `header` is not given. Default: 1.

bps
[int, optional] Number of bits per sample, used if `header` is not given. Default: 2.

fanout
[int, optional] Number of tracks every bit stream is spread over, used if `header` is not given. Default: 1.

Notes

The total number of tracks is `nchan * bps * fanout`.

Attributes Summary

`data`	Full decoded payload.
`dtype`	Numeric type of the decoded data array.
`nbytes`	Size of the payload in bytes.
`ndim`	Number of dimensions of the decoded data array.
`shape`	Shape of the decoded data array.
`size`	Total number of component samples in the decoded data array.

Methods Summary

`fromdata`(data, header)	Encode data as payload, using header information.
`fromfile`(fh, header)	Read payload from filehandle and decode it into data.
`tofile`(self, fh)	Write payload to filehandle.

Attributes Documentation

`data`
Full decoded payload.

`dtype`
Numeric type of the decoded data array.

`nbytes`
Size of the payload in bytes.

`ndim`
Number of dimensions of the decoded data array.

`shape`
Shape of the decoded data array.

`size`
Total number of component samples in the decoded data array.

Methods Documentation

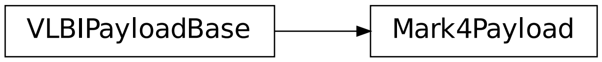
classmethod fromdata(*data*, *header*)
Encode data as payload, using header information.

classmethod fromfile(*fh*, *header*)
Read payload from filehandle and decode it into data.

The payload_nbytes, number of channels, bits per sample, and fanout ratio are all taken from the header.

tofile(*self*, *fh*)
Write payload to filehandle.

Class Inheritance Diagram



7.3.4 baseband.mark4.frame Module

Definitions for VLBI Mark 4 payloads.

Implements a Mark4Payload class used to store payload words, and decode to or encode from a data array.

For the specification, see http://www.haystack.mit.edu/tech/vlbi/mark5/docs/230.3.pdf

Classes

`Mark4Frame`(header, payload[, valid, verify])	Representation of a Mark 4 frame, consisting of a header and payload.

Mark4Frame

class `baseband.mark4.frame.`**`Mark4Frame`**(*header*, *payload*, *valid=None*, *verify=True*)
Bases: `baseband.vlbi_base.frame.VLBIFrameBase`

Representation of a Mark 4 frame, consisting of a header and payload.

Parameters

header
[`Mark4Header`] Wrapper around the encoded header words, providing access to the header information.

payload
[`Mark4Payload`] Wrapper around the payload, provding mechanisms to decode it.

valid
[bool or None, optional] Whether the data are valid. If `None` (default), inferred from header. Note that `header` is updated in-place if `True` or `False`.

verify
[bool, optional] Whether or not to do basic assertions that check the integrity (e.g., that channel information and number of tracks are consistent between header and data). Default: `True`.

Notes

The Frame can also be read instantiated using class methods:

fromfile : read header and payload from a filehandle

fromdata : encode data as payload

Of course, one can also do the opposite:

tofile : method to write header and payload to filehandle

data : property that yields full decoded payload

One can decode part of the payload by indexing or slicing the frame. If the frame does not contain valid data, all values returned are set to `self.fill_value`.

A number of properties are defined: `shape`, `dtype` and `size` are the shape, type and number of complete samples of the data array, and `nbytes` the frame size in bytes. Furthermore, the frame acts as a dictionary, with keys those of the header. Any attribute that is not defined on the frame itself, such as `.time` will be looked up on the header as well.

Attributes Summary

`data`	Full decoded frame, with header part filled in.
`dtype`	Numeric type of the frame data.
`fill_value`	Value to replace invalid data in the frame.
`nbytes`	Size of the encoded frame in bytes.
`ndim`	Number of dimensions of the frame data.
`sample_shape`	Shape of a sample in the frame (nchan,).
`shape`	Shape of the frame data.
`size`	Total number of component samples in the frame data.
`valid`	Whether frame contains valid data.

Methods Summary

`fromdata`(data[, header, verify])	Construct frame from data and header.
`fromfile`(fh, ntrack[, decade, ref_time, verify])	Read a frame from a filehandle.
`keys`(self)	
`tofile`(self, fh)	Write encoded frame to filehandle.
`verify`(self)	Simple verification.

Attributes Documentation

data
Full decoded frame, with header part filled in.

dtype
Numeric type of the frame data.

fill_value
Value to replace invalid data in the frame.

nbytes
Size of the encoded frame in bytes.

ndim
Number of dimensions of the frame data.

sample_shape
Shape of a sample in the frame (nchan,).

shape
Shape of the frame data.

size
Total number of component samples in the frame data.

valid
Whether frame contains valid data.

None of the error flags are set.

Methods Documentation

classmethod fromdata(*data*, *header=None*, *verify=True*, ***kwargs*)
Construct frame from data and header.

Parameters

data
[`ndarray`] Array holding complex or real data to be encoded. This should have the full size of a data frame, even though the part covered by the header will be ignored.

header
[`Mark4Header` or None] If not given, will attempt to generate one using the keywords.

verify
[bool, optional] Whether to do basic checks of frame integrity (default: `True`).

classmethod fromfile(*fh*, *ntrack*, *decade=None*, *ref_time=None*, *verify=True*)
Read a frame from a filehandle.

Parameters

fh
[filehandle] To read header from.

ntrack
[int] Number of Mark 4 bitstreams.

decade
[int or None] Decade in which the observations were taken. Can instead pass an approximate `ref_time`.

ref_time
[`Time` or None] Reference time within 4 years of the observation time. Used only if `decade` is not given.

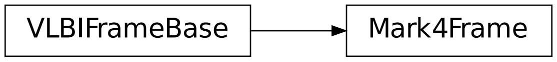
verify
[bool, optional] Whether to do basic verification of integrity. Default: `True`.

keys(*self*)

tofile(*self*, *fh*)
Write encoded frame to filehandle.

verify(*self*)
Simple verification. To be added to by subclasses.

Class Inheritance Diagram



7.3.5 baseband.mark4.file_info Module

Classes

`Mark4FileReaderInfo`	Standardized information on Mark 4 file readers.

Mark4FileReaderInfo

class baseband.mark4.file_info.**Mark4FileReaderInfo**
Bases: `baseband.vlbi_base.file_info.VLBIFileReaderInfo`

Standardized information on Mark 4 file readers.

The `info` descriptor has a number of standard attributes, which are determined from arguments passed in opening the file, from the first header (`info.header0`) and from possibly scanning the file to determine the duration of frames. This class has two additional attributes specific to Mark 4 files (`ntrack` and `offset0`, see below).

Examples

The most common use is simply to print information:

```
>>> from baseband.data import SAMPLE_MARK4
>>> from baseband import mark4
>>> fh = mark4.open(SAMPLE_MARK4, 'rb')
>>> fh.info
File information:
format = mark4
frame_rate = 400.0 Hz
sample_rate = 32.0 MHz
samples_per_frame = 80000
sample_shape = (8,)
bps = 2
complex_data = False
readable = True
offset0 = 2696

missing:  decade, ref_time: needed to infer full times.

errors:  start_time: unsupported operand type(s) for //: 'NoneType' and 'int'
>>> fh.close()

>>> fh = mark4.open(SAMPLE_MARK4, 'rb', decade=2010)
>>> fh.info
File information:
format = mark4
frame_rate = 400.0 Hz
sample_rate = 32.0 MHz
samples_per_frame = 80000
sample_shape = (8,)
bps = 2
complex_data = False
start_time = 2014-06-16T07:38:12.475000000
readable = True
offset0 = 2696
>>> fh.close()
```

Attributes

format
[str or `None`] File format, or `None` if the underlying file cannot be parsed.

frame_rate
[`Quantity`] Number of data frames per unit of time.

sample_rate
[`Quantity`] Complete samples per unit of time.

samples_per_frame
[int] Number of complete samples in each frame.

sample_shape
[tuple] Dimensions of each complete sample (e.g., `(nchan,)`).

bps
[int] Number of bits used to encode each elementary sample.

complex_data
[bool] Whether the data are complex.

start_time
[Time] Time of the first complete sample.

ntrack
[int] Number of "tape tracks" simulated in the disk file.

offset0
[int] Offset in bytes from the start of the file to the location of the first header.

readable
[bool] Whether the first sample could be read and decoded.

missing
[dict] Entries are keyed by names of arguments that should be passed to the file reader to obtain full information. The associated entries explain why these arguments are needed. For Mark 4, the possible entries are `decade` and `ref_time`.

errors
[dict] Any exceptions raised while trying to determine attributes. Keyed by the attributes.

Attributes Summary

`attr_names`
`bps`
`complex_data`
`format`
`frame_rate`
`ntrack`
`offset0`
`readable`
`sample_rate`
`sample_shape`
`samples_per_frame`
`start_time`

Methods Summary

`__call__`(self)	Create a dict with file information, including missing pieces.

Attributes Documentation

attr_names = ('format', 'frame_rate', 'sample_rate', 'samples_per_frame', 'sample_shape', 'bps', 'comple

bps = None

complex_data = None

format = None

frame_rate = None

`ntrack = None`

`offset0 = None`

`readable = None`

`sample_rate = None`

`sample_shape = None`

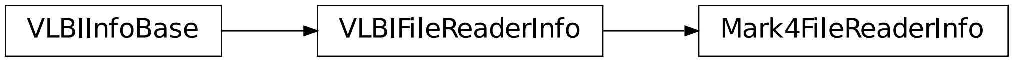
`samples_per_frame = None`

`start_time = None`

Methods Documentation

`__call__`(*self*)
Create a dict with file information, including missing pieces.

Class Inheritance Diagram



7.3.6 baseband.mark4.base Module

Functions

open(name[, mode])	Open Mark4 file(s) for reading or writing.

open

`baseband.mark4.base.`**`open`**(*name*, *mode='rs'*, ***kwargs*)
Open Mark4 file(s) for reading or writing.

Opened as a binary file, one gets a wrapped filehandle that adds methods to read/write a frame. Opened as a stream, the handle is wrapped further, with methods such as reading and writing to the file as if it were a stream of samples.

Parameters

name
[str or filehandle, or sequence of str] File name, filehandle, or sequence of file names (see Notes).

mode
[{'rb', 'wb', 'rs', or 'ws'}, optional] Whether to open for reading or writing, and as a regular binary file or as a stream. Default: 'rs', for reading a stream.

****kwargs**
Additional arguments when opening the file as a stream.

— For reading a stream
[(see `Mark4StreamReader`)]

sample_rate
[`Quantity`, optional] Number of complete samples per second, i.e. the rate at which each channel is sampled. If not given, will be inferred from scanning two frames of the file.

ntrack
[int, optional] Number of Mark 4 bitstreams. If `None` (default), will attempt to automatically detect it by scanning the file.

decade
[int or None] Decade of the observation start time (eg. `2010` for 2018), needed to remove ambiguity in the Mark 4 time stamp (default: `None`). Can instead pass an approximate `ref_time`.

ref_time
[`Time` or None] Reference time within 4 years of the start time of the observations. Used only if `decade` is not given.

squeeze
[bool, optional] If `True` (default), remove any dimensions of length unity from decoded data.

subset
[indexing object, optional] Specific channels of the complete sample to decode (after possible squeezing). If an empty tuple (default), all channels are read.

fill_value
[float or complex, optional] Value to use for invalid or missing data. Default: 0.

verify
[bool, optional] Whether to do basic checks of frame integrity when reading. The first frame of the stream is always checked. Default: `True`.

— For writing a stream
[(see `Mark4StreamWriter`)]

header0
[`Mark4Header`] Header for the first frame, holding time information, etc. Can instead give keyword arguments to construct a header (see `**kwargs`).

sample_rate
[`Quantity`] Number of complete samples per second, i.e. the rate at which each channel is sampled. Needed to calculate header timestamps.

squeeze
[bool, optional] If `True` (default), writer accepts squeezed arrays as input, and adds any dimensions of length unity.

file_size
[int or None, optional] When writing to a sequence of files, the maximum size of one file in bytes. If `None` (default), the file size is unlimited, and only the first file will be written to.

****kwargs**
If the header is not given, an attempt will be made to construct one with any further keyword arguments. See `Mark4StreamWriter`.

Returns

Filehandle
`Mark4FileReader` or `Mark4FileWriter` (binary), or `Mark4StreamReader` or `Mark4StreamWriter` (stream)

Notes

Although it is not generally expected to be useful for Mark 4, like for other formats one can also pass to `name` a list, tuple, or subclass of `FileNameSequencer`. For writing to multiple files, the `file_size` keyword must be passed or only the first file will be written to. One may also pass in a `sequentialfile` object (opened in 'rb' mode for reading or 'w+b' for writing), though for typical use cases it is practically identical to passing in a list or template.

Classes

`Mark4FileReader`(fh_raw[, ntrack, decade, ...])	Simple reader for Mark 4 files.
`Mark4FileWriter`(fh_raw)	Simple writer for Mark 4 files.
`Mark4StreamBase`(fh_raw, header0[, ...])	Base for Mark 4 streams.
`Mark4StreamReader`(fh_raw[, sample_rate, ...])	VLBI Mark 4 format reader.
`Mark4StreamWriter`(fh_raw[, header0, ...])	VLBI Mark 4 format writer.

Mark4FileReader

class `baseband.mark4.base.`**`Mark4FileReader`**(*fh_raw*, *ntrack=None*, *decade=None*, *ref_time=None*)
Bases: `baseband.vlbi_base.base.VLBIFileReaderBase`

Simple reader for Mark 4 files.

Wraps a binary filehandle, providing methods to help interpret the data, such as `locate_frame`, `read_frame` and `get_frame_rate`.

Parameters

fh_raw
[filehandle] Filehandle of the raw binary data file.

ntrack
[int or None, optional.] Number of Mark 4 bitstreams. Can be determined automatically as part of locating the first frame.

decade
[int or None] Decade in which the observations were taken. Can instead pass an approximate `ref_time`.

ref_time
[Time or None] Reference time within 4 years of the observation time. Used only if decade is not given.

Attributes Summary

info()	Standardized information on Mark 4 file readers.

Methods Summary

close(self)	
determine_ntrack(self[, maximum])	Determines the number of tracks, by seeking the next frame.
find_header(self[, forward, maximum])	Find the nearest header from the current position.
get_frame_rate(self)	Determine the number of frames per second.
locate_frame(self[, forward, maximum])	Locate the frame nearest the current position.
read_frame(self[, verify])	Read a single frame (header plus payload).
read_header(self)	Read a single header from the file.
temporary_offset(self)	Context manager for temporarily seeking to another file position.

Attributes Documentation

info
Standardized information on Mark 4 file readers.

The info descriptor has a number of standard attributes, which are determined from arguments passed in opening the file, from the first header (info.header0) and from possibly scanning the file to determine the duration of frames. This class has two additional attributes specific to Mark 4 files (ntrack and offset0, see below).

Examples

The most common use is simply to print information:

```
>>> from baseband.data import SAMPLE_MARK4
>>> from baseband import mark4
>>> fh = mark4.open(SAMPLE_MARK4, 'rb')
>>> fh.info
File information:
format = mark4
frame_rate = 400.0 Hz
sample_rate = 32.0 MHz
samples_per_frame = 80000
sample_shape = (8,)
bps = 2
complex_data = False
readable = True
offset0 = 2696

missing:  decade, ref_time: needed to infer full times.
```

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```
errors:  start_time: unsupported operand type(s) for //: 'NoneType' and 'int'
>>> fh.close()

>>> fh = mark4.open(SAMPLE_MARK4, 'rb', decade=2010)
>>> fh.info
File information:
format = mark4
frame_rate = 400.0 Hz
sample_rate = 32.0 MHz
samples_per_frame = 80000
sample_shape = (8,)
bps = 2
complex_data = False
start_time = 2014-06-16T07:38:12.475000000
readable = True
offset0 = 2696
>>> fh.close()
```

Attributes

format
[str or None] File format, or None if the underlying file cannot be parsed.

frame_rate
[Quantity] Number of data frames per unit of time.

sample_rate
[Quantity] Complete samples per unit of time.

samples_per_frame
[int] Number of complete samples in each frame.

sample_shape
[tuple] Dimensions of each complete sample (e.g., (nchan,)).

bps
[int] Number of bits used to encode each elementary sample.

complex_data
[bool] Whether the data are complex.

start_time
[Time] Time of the first complete sample.

ntrack
[int] Number of “tape tracks” simulated in the disk file.

offset0
[int] Offset in bytes from the start of the file to the location of the first header.

readable
[bool] Whether the first sample could be read and decoded.

missing
[dict] Entries are keyed by names of arguments that should be passed to the file reader to obtain full information. The associated entries explain why these arguments are needed. For Mark 4, the possible entries are decade and ref_time.

errors
[dict] Any exceptions raised while trying to determine attributes. Keyed by the attributes.

Methods Documentation

`close`(*self*)

`determine_ntrack`(*self*, *maximum=None*)
Determines the number of tracks, by seeking the next frame.

Uses `locate_frame` to look for the first occurrence of a frame from the current position for all supported `ntrack` values. Returns the first `ntrack` for which `locate_frame` is successful, setting the file's `ntrack` property appropriately, and leaving the file pointer at the start of the frame.

Parameters

maximum
[int, optional] Maximum number of bytes forward to search through. Default: twice the frame size (`20000 * ntrack // 8`).

Returns

ntrack
[int or None] Number of Mark 4 bitstreams. `None` if no frame was found.

`find_header`(*self*, *forward=True*, *maximum=None*)
Find the nearest header from the current position.

If successful, the file pointer is left at the start of the header.

Parameters

forward
[bool, optional] Seek forward if `True` (default), backward if `False`.

maximum
[int, optional] Maximum number of bytes forward to search through. Default: twice the frame size (`20000 * ntrack // 8`).

Returns

header
[`Mark4Header` or None] Retrieved Mark 4 header, or `None` if nothing found.

`get_frame_rate`(*self*)
Determine the number of frames per second.

The frame rate is calculated from the time elapsed between the first two frames, as inferred from their time stamps.

Returns

frame_rate
[`Quantity`] Frames per second.

locate_frame(*self*, *forward=True*, *maximum=None*)

Locate the frame nearest the current position.

The search is for the following pattern:

- 32*tracks bits set at offset bytes
- 1*tracks bits unset before offset
- 32*tracks bits set at offset+2500*tracks bytes

This reflects 'sync_pattern' of 0xffffffff for a given header and one a frame ahead, which is in word 2, plus the lsb of word 1, which is 'system_id'.

If the file does not have ntrack is set, it will be auto-determined.

Parameters

forward
[bool, optional] Whether to search forwards or backwards. Default: `True`.

maximum
[int, optional] Maximum number of bytes forward to search through. Default: twice the frame size (`20000 * ntrack // 8`).

Returns

offset
[int or `None`] Byte offset of the next frame. `None` if the search was not successful.

read_frame(*self*, *verify=True*)

Read a single frame (header plus payload).

Returns

frame
[`Mark4Frame`] With `.header` and `.data` properties that return the `Mark4Header` and data encoded in the frame, respectively.

verify
[bool, optional] Whether to do basic checks of frame integrity. Default: `True`.

read_header(*self*)

Read a single header from the file.

Returns

header
[`Mark4Header`]

temporary_offset(*self*)

Context manager for temporarily seeking to another file position.

To be used as part of a `with` statement:

```
with fh_raw.temporary_offset() [as fh_raw]:
    with-block
```

On exiting the `with-block`, the file pointer is moved back to its original position.

Mark4FileWriter

class baseband.mark4.base.**Mark4FileWriter**(*fh_raw*)

Bases: baseband.vlbi_base.base.VLBIFileBase

Simple writer for Mark 4 files.

Adds write_frame method to the VLBI binary file wrapper.

Methods Summary

close(self)	
temporary_offset(self)	Context manager for temporarily seeking to another file position.
write_frame(self, data[, header])	Write a single frame (header plus payload).

Methods Documentation

close(*self*)

temporary_offset(*self*)

Context manager for temporarily seeking to another file position.

To be used as part of a with statement:

```
with fh_raw.temporary_offset() [as fh_raw]:
    with-block
```

On exiting the with-block, the file pointer is moved back to its original position.

write_frame(*self*, *data*, *header=None*, ***kwargs*)

Write a single frame (header plus payload).

Parameters

data
[ndarray or Mark4Frame] If an array, a header should be given, which will be used to get the information needed to encode the array, and to construct the Mark 4 frame.

header
[Mark4Header] Can instead give keyword arguments to construct a header. Ignored if payload is a Mark4Frame instance.

****kwargs :**
If header is not given, these are used to initialize one.

Mark4StreamBase

class baseband.mark4.base.**Mark4StreamBase**(*fh_raw*, *header0*, *sample_rate=None*, *squeeze=True*, *subset=()*, *fill_value=0.0*, *verify=True*)

Bases: baseband.vlbi_base.base.VLBIStreamBase

Base for Mark 4 streams.

Attributes Summary

`bps`	Bits per elementary sample.
`complex_data`	Whether the data are complex.
`header0`	First header of the file.
`sample_rate`	Number of complete samples per second.
`sample_shape`	Shape of a complete sample (possibly subset or squeezed).
`samples_per_frame`	Number of complete samples per frame.
`squeeze`	Whether data arrays have dimensions with length unity removed.
`start_time`	Start time of the file.
`subset`	Specific components of the complete sample to decode.
`time`	Time of the sample pointer's current offset in file.
`verify`	Whether to do consistency checks on frames being read.

Methods Summary

`close`(self)	
`tell`(self[, unit])	Current offset in the file.

Attributes Documentation

`bps`
Bits per elementary sample.

`complex_data`
Whether the data are complex.

`header0`
First header of the file.

`sample_rate`
Number of complete samples per second.

`sample_shape`
Shape of a complete sample (possibly subset or squeezed).

`samples_per_frame`
Number of complete samples per frame.

`squeeze`
Whether data arrays have dimensions with length unity removed.

If `True`, data read out has such dimensions removed, and data passed in for writing has them inserted.

`start_time`
Start time of the file.

See also `time` for the time of the sample pointer's current offset.

`subset`
Specific components of the complete sample to decode.

The order of dimensions is the same as for `sample_shape`. Set by the class initializer.

`time`
: Time of the sample pointer's current offset in file.

  See also `start_time` for the start time of the file.

`verify`
: Whether to do consistency checks on frames being read.

Methods Documentation

`close`(*self*)

`tell`(*self*, *unit=None*)
: Current offset in the file.

  Parameters

  unit
  [`Unit` or str, optional] Time unit the offset should be returned in. By default, no unit is used, i.e., an integer enumerating samples is returned. For the special string 'time', the absolute time is calculated.

  Returns

  offset
  [int, `Quantity`, or `Time`] Offset in current file (or time at current position).

Mark4StreamReader

class baseband.mark4.base.**Mark4StreamReader**(*fh_raw*, *sample_rate=None*, *ntrack=None*, *decade=None*, *ref_time=None*, *squeeze=True*, *subset=()*, *fill_value=0.0*, *verify=True*)

Bases: `baseband.mark4.base.Mark4StreamBase`, `baseband.vlbi_base.base.VLBIStreamReaderBase`

VLBI Mark 4 format reader.

Allows access to a Mark 4 file as a continuous series of samples. Parts of the data stream replaced by header values are filled in.

Parameters

fh_raw
[filehandle] Filehandle of the raw Mark 4 stream.

sample_rate
[`Quantity`, optional] Number of complete samples per second, i.e. the rate at which each channel is sampled. If `None`, will be inferred from scanning two frames of the file.

ntrack
[int or None, optional] Number of Mark 4 bitstreams. If `None` (default), will attempt to automatically detect it by scanning the file.

decade
[int or None] Decade of the observation start time (eg. `2010` for 2018), needed to remove ambiguity in the Mark 4 time stamp. Can instead pass an approximate `ref_time`.

ref_time
[Time or None] Reference time within 4 years of the start time of the observations. Used only if decade is not given.

squeeze
[bool, optional] If True (default), remove any dimensions of length unity from decoded data.

subset
[indexing object, optional] Specific channels of the complete sample to decode (after possible squeezing). If an empty tuple (default), all channels are read.

fill_value
[float or complex, optional] Value to use for invalid or missing data. Default: 0.

verify
[bool, optional] Whether to do basic checks of frame integrity when reading. The first frame of the stream is always checked. Default: True.

Attributes Summary

bps	Bits per elementary sample.
complex_data	Whether the data are complex.
dtype	
fill_value	Value to use for invalid or missing data.
header0	First header of the file.
info()	Standardized information on stream readers.
ndim	Number of dimensions of the (squeezed/subset) stream data.
sample_rate	Number of complete samples per second.
sample_shape	Shape of a complete sample (possibly subset or squeezed).
samples_per_frame	Number of complete samples per frame.
shape	Shape of the (squeezed/subset) stream data.
size	Total number of component samples in the (squeezed/subset) stream data.
squeeze	Whether data arrays have dimensions with length unity removed.
start_time	Start time of the file.
stop_time	Time at the end of the file, just after the last sample.
subset	Specific components of the complete sample to decode.
time	Time of the sample pointer's current offset in file.
verify	Whether to do consistency checks on frames being read.

Methods Summary

close(self)	
read(self[, count, out])	Read a number of complete (or subset) samples.
readable(self)	Whether the file can be read and decoded.
seek(self, offset[, whence])	Change the stream position.
tell(self[, unit])	Current offset in the file.

Attributes Documentation

bps
Bits per elementary sample.

complex_data
Whether the data are complex.

dtype

fill_value
Value to use for invalid or missing data. Default: 0.

header0
First header of the file.

info
Standardized information on stream readers.

The `info` descriptor provides a few standard attributes, all of which can also be accessed directly on the stream filehandle. More detailed information on the underlying file is stored in its info, accessible via `info.file_info`.

Attributes

start_time
[`Time`] Time of the first complete sample.

stop_time
[`Time`] Time of the complete sample just beyond the end of the file.

sample_rate
[`Quantity`] Complete samples per unit of time.

shape
[tuple] Equivalent shape of the whole file, i.e., combining the number of complete samples and the shape of those samples.

bps
[int] Number of bits used to encode each elementary sample.

complex_data
[bool] Whether the data are complex.

readable
[bool] Whether the first sample could be read and decoded.

ndim
Number of dimensions of the (squeezed/subset) stream data.

sample_rate
Number of complete samples per second.

sample_shape
Shape of a complete sample (possibly subset or squeezed).

samples_per_frame
Number of complete samples per frame.

shape
Shape of the (squeezed/subset) stream data.

size
Total number of component samples in the (squeezed/subset) stream data.

squeeze
Whether data arrays have dimensions with length unity removed.

If `True`, data read out has such dimensions removed, and data passed in for writing has them inserted.

start_time
Start time of the file.

See also `time` for the time of the sample pointer's current offset, and (if available) `stop_time` for the time at the end of the file.

stop_time
Time at the end of the file, just after the last sample.

See also `start_time` for the start time of the file, and `time` for the time of the sample pointer's current offset.

subset
Specific components of the complete sample to decode.

The order of dimensions is the same as for `sample_shape`. Set by the class initializer.

time
Time of the sample pointer's current offset in file.

See also `start_time` for the start time, and (if available) `stop_time` for the end time, of the file.

verify
Whether to do consistency checks on frames being read.

Methods Documentation

close(*self*)

read(*self*, *count=None*, *out=None*)
Read a number of complete (or subset) samples.

The range retrieved can span multiple frames.

Parameters

count
[int or None, optional] Number of complete/subset samples to read. If `None` (default) or negative, the whole file is read. Ignored if `out` is given.

out
[None or array, optional] Array to store the data in. If given, `count` will be inferred from the first dimension; the other dimension should equal `sample_shape`.

Returns

out
[`ndarray` of float or complex] The first dimension is sample-time, and the remainder given by `sample_shape`.

readable(*self*)
Whether the file can be read and decoded.

seek(*self*, *offset*, *whence=0*)
Change the stream position.

This works like a normal filehandle seek, but the offset is in samples (or a relative or absolute time).

Parameters

offset
[int, `Quantity`, or `Time`] Offset to move to. Can be an (integer) number of samples, an offset in time units, or an absolute time.

whence
[{0, 1, 2, 'start', 'current', or 'end'}, optional] Like regular seek, the offset is taken to be from the start if `whence=0` (default), from the current position if 1, and from the end if 2. One can alternativey use 'start', 'current', or 'end' for 0, 1, or 2, respectively. Ignored if `offset` is a time.

tell(*self*, *unit=None*)
Current offset in the file.

Parameters

unit
[`Unit` or str, optional] Time unit the offset should be returned in. By default, no unit is used, i.e., an integer enumerating samples is returned. For the special string 'time', the absolute time is calculated.

Returns

offset
[int, `Quantity`, or `Time`] Offset in current file (or time at current position).

Mark4StreamWriter

class baseband.mark4.base.**Mark4StreamWriter**(*fh_raw*, *header0=None*, *sample_rate=None*, *squeeze=True*, ***kwargs*)
Bases: `baseband.mark4.base.Mark4StreamBase`, `baseband.vlbi_base.base.VLBIStreamWriterBase`

VLBI Mark 4 format writer.

Encodes and writes sequences of samples to file.

Parameters

raw
[filehandle] Which will write filled sets of frames to storage.

header0
[`Mark4Header`] Header for the first frame, holding time information, etc. Can instead give keyword arguments to construct a header (see `**kwargs`).

sample_rate
[`Quantity`] Number of complete samples per second, i.e. the rate at which each channel is sampled. Needed to calculate header timestamps.

squeeze
[bool, optional] If `True` (default), `write` accepts squeezed arrays as input, and adds any dimensions of length unity.

****kwargs**
If no header is given, an attempt is made to construct one from these. For a standard header, this would include the following.

— Header keywords
[(see `fromvalues()`)]

time
[`Time`] Start time of the file. Sets bcd-encoded unit year, day, hour, minute, second in the header.

ntrack
[int] Number of Mark 4 bitstreams (equal to number of channels times `fanout` times `bps`)

bps
[int] Bits per elementary sample.

fanout
[int] Number of tracks over which a given channel is spread out.

Attributes Summary

`bps`	Bits per elementary sample.
`complex_data`	Whether the data are complex.
`header0`	First header of the file.
`sample_rate`	Number of complete samples per second.
`sample_shape`	Shape of a complete sample (possibly subset or squeezed).
`samples_per_frame`	Number of complete samples per frame.
`squeeze`	Whether data arrays have dimensions with length unity removed.
`start_time`	Start time of the file.
`subset`	Specific components of the complete sample to decode.
`time`	Time of the sample pointer's current offset in file.
`verify`	Whether to do consistency checks on frames being read.

Methods Summary

`close`(self)	
`tell`(self[, unit])	Current offset in the file.
`write`(self, data[, valid])	Write data, buffering by frames as needed.

Attributes Documentation

`bps`
Bits per elementary sample.

`complex_data`

Whether the data are complex.

`header0`
First header of the file.

`sample_rate`
Number of complete samples per second.

`sample_shape`
Shape of a complete sample (possibly subset or squeezed).

`samples_per_frame`
Number of complete samples per frame.

`squeeze`
Whether data arrays have dimensions with length unity removed.

If `True`, data read out has such dimensions removed, and data passed in for writing has them inserted.

`start_time`
Start time of the file.

See also `time` for the time of the sample pointer's current offset.

`subset`
Specific components of the complete sample to decode.

The order of dimensions is the same as for `sample_shape`. Set by the class initializer.

`time`
Time of the sample pointer's current offset in file.

See also `start_time` for the start time of the file.

`verify`
Whether to do consistency checks on frames being read.

Methods Documentation

`close`(*self*)

`tell`(*self*, *unit=None*)
Current offset in the file.

Parameters

unit
[`Unit` or str, optional] Time unit the offset should be returned in. By default, no unit is used, i.e., an integer enumerating samples is returned. For the special string 'time', the absolute time is calculated.

Returns

offset
[int, `Quantity`, or `Time`] Offset in current file (or time at current position).

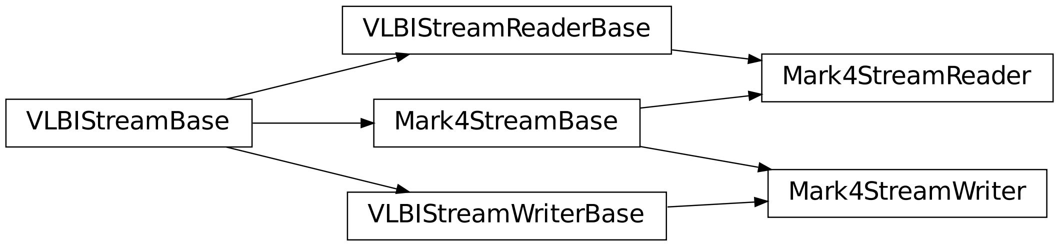
`write`(*self*, *data*, *valid=True*)
Write data, buffering by frames as needed.

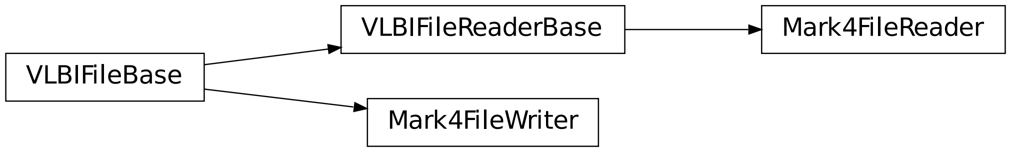
Parameters

data
[ndarray] Piece of data to be written, with sample dimensions as given by sample_shape. This should be properly scaled to make best use of the dynamic range delivered by the encoding.

valid
[bool, optional] Whether the current data are valid. Default: True.

Class Inheritance Diagram





CHAPTER

EIGHT

DADA

Distributed Acquisition and Data Analysis (DADA) format data files contain a single *data frame* consisting of an ASCII *header* of typically 4096 bytes followed by a *payload*.

8.1 Usage

This section covers reading and writing DADA files with Baseband; general usage is covered in the *Using Baseband* section. For situations in which one is unsure of a file's format, Baseband features the general `baseband.open` and `baseband.file_info` functions, which are also discussed in *Using Baseband*. The examples below use the sample file `baseband/data/sample.dada`, and the the `astropy.units` and `baseband.dada` modules:

```
>>> from baseband import dada
>>> import astropy.units as u
>>> from baseband.data import SAMPLE_DADA
```

Single files can be opened with `open` in binary mode. DADA files typically consist of just a single header and payload, and can be read into a single `DADAFrame`.

```
>>> fb = dada.open(SAMPLE_DADA, 'rb')
>>> frame = fb.read_frame()
>>> frame.shape
(16000, 2, 1)
>>> frame[:3].squeeze()
array([[ -38.-38.j,  -38.-38.j],
       [ -38.-38.j,  -40. +0.j],
       [-105.+60.j,   85.-15.j]], dtype=complex64)
>>> fb.close()
```

Since the files can be quite large, the payload is mapped (with `numpy.memmap`), so that if one accesses part of the data, only the corresponding parts of the encoded payload are loaded into memory (since the sample file is encoded using 8 bits, the above example thus loads 12 bytes into memory).

Opening in stream mode wraps the low-level routines such that reading and writing is in units of samples, and provides access to header information:

```
>>> fh = dada.open(SAMPLE_DADA, 'rs')
>>> fh
<DADAStreamReader name=... offset=0
    sample_rate=16.0 MHz, samples_per_frame=16000,
    sample_shape=SampleShape(npol=2), bps=8,
    start_time=2013-07-02T01:39:20.000>
>>> d = fh.read(10000)
```

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```
>>> d.shape
(10000, 2)
>>> d[:3]
array([[ -38.-38.j,  -38.-38.j],
       [ -38.-38.j,  -40. +0.j],
       [-105.+60.j,   85.-15.j]], dtype=complex64)
>>> fh.close()
```

To set up a file for writing as a stream is possible as well:

```
>>> from astropy.time import Time
>>> fw = dada.open('{utc_start}.{obs_offset:016d}.000000.dada', 'ws',
...                  sample_rate=16*u.MHz, samples_per_frame=5000,
...                  npol=2, nchan=1, bps=8, complex_data=True,
...                  time=Time('2013-07-02T01:39:20.000'))
>>> fw.write(d)
>>> fw.close()
>>> import os
>>> [f for f in sorted(os.listdir('.')) if f.startswith('2013')]
['2013-07-02-01:39:20.0000000000000000.000000.dada',
 '2013-07-02-01:39:20.0000000000020000.000000.dada']
>>> fr = dada.open('2013-07-02-01:39:20.{obs_offset:016d}.000000.dada', 'rs')
>>> d2 = fr.read()
>>> (d == d2).all()
True
>>> fr.close()
```

Here, we have used an even smaller size of the payload, to show how one can define multiple files. DADA data are typically stored in sequences of files. If one passes a time-ordered list or tuple of filenames to `open`, it uses `sequentialfile.open` to access the sequence. If, as above, one passes a template string, `open` uses `DADAFileNameSequencer` to create and use a filename sequencer. (See API links for further details.)

8.2 Reference/API

8.2.1 baseband.dada Package

Distributed Acquisition and Data Analysis (DADA) format reader/writer.

Functions

open(name[, mode])	Open DADA file(s) for reading or writing.

open

`baseband.dada.`**`open`**(*name*, *mode='rs'*, ***kwargs*)

Open DADA file(s) for reading or writing.

Opened as a binary file, one gets a wrapped filehandle that adds methods to read/write a frame. Opened as a stream, the handle is wrapped further, with methods such as reading and writing to the file as if it were a stream of samples.

Parameters

name
[str or filehandle, or sequence of str] File name, filehandle, or sequence of file names (see Notes).

mode
[{'rb', 'wb', 'rs', or 'ws'}, optional] Whether to open for reading or writing, and as a regular binary file or as a stream. Default: 'rs', for reading a stream.

****kwargs**
Additional arguments when opening the file as a stream.

— For reading a stream
[(see `DADAStreamReader`)]

squeeze
[bool, optional] If `True` (default), remove any dimensions of length unity from decoded data.

subset
[indexing object or tuple of objects, optional] Specific components of the complete sample to decode (after possibly squeezing). If a single indexing object is passed, it selects polarizations. With a tuple, the first selects polarizations and the second selects channels. If the tuple is empty (default), all components are read.

— For writing a stream
[(see `DADAStreamWriter`)]

header0
[`DADAHeader`] Header for the first frame, holding time information, etc. Can instead give keyword arguments to construct a header (see `**kwargs`).

squeeze
[bool, optional] If `True` (default), writer accepts squeezed arrays as input, and adds any dimensions of length unity.

****kwargs**
If the header is not given, an attempt will be made to construct one with any further keyword arguments.

— Header keywords
[(see `fromvalues()`)]

time
[`Time`] Start time of the file.

samples_per_frame
[int,] Number of complete samples per frame.

sample_rate
[`Quantity`] Number of complete samples per second, i.e. the rate at which each channel of each polarization is sampled.

offset
[`Quantity` or `TimeDelta`, optional] Time offset from the start of the whole observation (default: 0).

npol
[int, optional] Number of polarizations (default: 1).

nchan
[int, optional] Number of channels (default: 1).

complex_data
[bool, optional] Whether data are complex (default: `False`).

bps
[int, optional] Bits per elementary sample, i.e. per real or imaginary component for complex data (default: 8).

Returns

Filehandle
`DADAFileReader` or `DADAFileWriter` (binary), or `DADAStreamReader` or `DADAStreamWriter` (stream).

Notes

For streams, one can also pass to `name` a list of files, or a template string that can be formatted using 'frame_nr', 'obs_offset', and other header keywords (by `DADAFileNameSequencer`).

For writing, one can mimic what is done at quite a few telescopes by using the template '{utc_start}_{obs_offset:016d}.000000.dada'. Unlike for the VLBI openers, `file_size` is set to the size of one frame as given by the header.

For reading, to read series such as the above, use something like '2013-07-02-01:37:40_{obs_offset:016d}.000000.dada'. Note that here we have to pass in the date explicitly, since the template is used to get the first file name, before any header is read, and therefore the only keywords available are 'frame_nr', 'file_nr', and 'obs_offset', all of which are assumed to be zero for the first file. To avoid this restriction, pass in keyword arguments with values appropriate for the first file.

One may also pass in a `sequentialfile` object (opened in 'rb' mode for reading or 'w+b' for writing), though for typical use cases it is practically identical to passing in a list or template.

Classes

`DADAFrame`(header, payload[, valid, verify])	Representation of a DADA file, consisting of a header and payload.
`DADAHeader`(*args[, verify, mutable])	DADA baseband file format header.
`DADAPayload`(words[, header, sample_shape, . . .])	Container for decoding and encoding DADA payloads.

DADAFrame

class baseband.dada.**DADAFrame**(*header*, *payload*, *valid=True*, *verify=True*)
Bases: `baseband.vlbi_base.frame.VLBIFrameBase`

Representation of a DADA file, consisting of a header and payload.

Parameters

header
[`DADAHeader`] Wrapper around the header lines, providing access to the values.

payload
[`DADAPayload`] Wrapper around the payload, provding mechanisms to decode it.

valid

[bool, optional] Whether the data are valid. Default: `True`.

verify
[bool, optional] Whether to do basic verification of integrity. Default: `True`.

Notes

DADA files do not support storing whether data are valid or not on disk. Hence, this has to be determined independently. If `valid=False`, any decoded data are set to `cls.fill_value` (by default, 0).

The Frame can also be instantiated using class methods:

fromfile : read header and map or read payload from a filehandle

fromdata : encode data as payload

Of course, one can also do the opposite:

tofile : method to write header and payload to filehandle

data : property that yields full decoded payload

One can decode part of the payload by indexing or slicing the frame.

A number of properties are defined: `shape`, `dtype` and `size` are the shape, type and number of complete samples of the data array, and `nbytes` the frame size in bytes. Furthermore, the frame acts as a dictionary, with keys those of the header. Any attribute that is not defined on the frame itself, such as `.time` will be looked up on the header as well.

Attributes Summary

`data`	Full decoded frame.
`dtype`	Numeric type of the frame data.
`fill_value`	Value to replace invalid data in the frame.
`nbytes`	Size of the encoded frame in bytes.
`ndim`	Number of dimensions of the frame data.
`sample_shape`	Shape of a sample in the frame (nchan,).
`shape`	Shape of the frame data.
`size`	Total number of component samples in the frame data.
`valid`	Whether frame contains valid data.

Methods Summary

`fromdata`(data[, header, valid, verify])	Construct frame from data and header.
`fromfile`(fh[, memmap, valid, verify])	Read a frame from a filehandle, possible mapping the payload.
`keys`(self)	
`tofile`(self, fh)	Write encoded frame to filehandle.
`verify`(self)	Simple verification.

Attributes Documentation

`data`
Full decoded frame.

dtype
Numeric type of the frame data.

fill_value
Value to replace invalid data in the frame.

nbytes
Size of the encoded frame in bytes.

ndim
Number of dimensions of the frame data.

sample_shape
Shape of a sample in the frame (nchan,).

shape
Shape of the frame data.

size
Total number of component samples in the frame data.

valid
Whether frame contains valid data.

Methods Documentation

classmethod fromdata(*data*, *header=None*, *valid=True*, *verify=True*, ***kwargs*)
Construct frame from data and header.

Note that since DADA files are generally very large, one would normally map the file, and then set pieces of it by assigning to slices of the frame. See `memmap_frame`.

Parameters

data
[`ndarray`] Array holding complex or real data to be encoded.

header
[`DADAHeader` or None] If not given, will attempt to generate one using the keywords.

valid
[bool, optional] Whether the data are valid (default: `True`). Note that this information cannot be written to disk.

verify
[bool, optional] Whether or not to do basic assertions that check the integrity. Default: `True`.

****kwargs**
If `header` is not given, these are used to initialize one.

classmethod fromfile(*fh*, *memmap=True*, *valid=True*, *verify=True*)
Read a frame from a filehandle, possible mapping the payload.

Parameters

fh
[filehandle] To read header from.

memmap
[bool, optional] If True (default), use memmap to map the payload. If False, just read it from disk.

valid
[bool, optional] Whether the data are valid (default: True). Note that this cannot be inferred from the header or payload itself. If False, any data read will be set to `cls.fill_value`.

verify
[bool, optional] Whether to do basic verification of integrity. Default: True.

keys(*self*)

tofile(*self*, *fh*)
Write encoded frame to filehandle.

verify(*self*)
Simple verification. To be added to by subclasses.

DADAHeader

class baseband.dada.**DADAHeader**(**args*, *verify=True*, *mutable=True*, ***kwargs*)
Bases: collections.OrderedDict

DADA baseband file format header.

Defines a number of routines common to all baseband format headers.

Parameters

***args**
[str or iterable] If a string, parsed as a DADA header from a file, otherwise as for the OrderedDict baseclass.

verify
[bool, optional] Whether to do minimal verification that the header is consistent with the DADA standard. Default: True.

mutable
[bool, optional] Whether to allow the header to be changed after initialisation. Default: True.

****kwargs**
Any further header keywords to be set. If any value is a 2-item tuple, the second one will be considered a comment.

Notes

Like OrderedDict, in order to ensure keywords are kept in the right order, one should pass on values as a tuple, not as a dict. E.g., to copy a header, one should not do `DADAHeader(**header)`, but rather:

```
DADAHeader(((key, header[key]) for key in header))
```

or, to also keep the comments:

```
DADAHeader(((key, (header[key], header.comments[key]))
          for key in header))
```

Attributes Summary

bps	Bits per elementary sample.
complex_data	Whether the data are complex.
frame_nbytes	Size of the frame in bytes.
nbytes	Size of the header in bytes.
offset	Offset from start of observation in units of time.
payload_nbytes	Size of the payload in bytes.
sample_rate	Number of complete samples per second.
sample_shape	Shape of a sample in the payload (npol, nchan).
samples_per_frame	Number of complete samples in the frame.
sideband	True if upper sideband.
start_time	Start time of the observation.
time	Start time of the part of the observation covered by this header.

Methods Summary

clear()	
copy(self)	Create a mutable and independent copy of the header.
fromfile(fh[, verify])	Reads in DADA header block from a file.
fromkeys(*args, **kwargs)	Initialise a header from keyword values.
fromvalues(**kwargs)	Initialise a header from parsed values.
get(self, key[, default])	Return the value for key if key is in the dictionary, else default.
items()	
keys()	
move_to_end(self, /, key[, last])	Move an existing element to the end (or beginning if last is false).
pop()	value.
popitem(self, /[, last])	Remove and return a (key, value) pair from the dictionary.
setdefault(self, /, key[, default])	Insert key with a value of default if key is not in the dictionary.
tofile(self, fh)	Write DADA file header to filehandle.
update(self, *[, verify])	Update the header with new values.
values()	
verify(self)	Basic check of integrity.

Attributes Documentation

bps

Bits per elementary sample.

complex_data

Whether the data are complex.

`frame_nbytes`
Size of the frame in bytes.

`nbytes`
Size of the header in bytes.

`offset`
Offset from start of observation in units of time.

`payload_nbytes`
Size of the payload in bytes.

`sample_rate`
Number of complete samples per second.

Can be set with a negative quantity to set `sideband`.

`sample_shape`
Shape of a sample in the payload (npol, nchan).

`samples_per_frame`
Number of complete samples in the frame.

`sideband`
True if upper sideband.

`start_time`
Start time of the observation.

`time`
Start time of the part of the observation covered by this header.

Methods Documentation

`clear`()

`copy`(*self*)
Create a mutable and independent copy of the header.

`classmethod fromfile`(*fh*, *verify=True*)
Reads in DADA header block from a file.

The file pointer should be at the start.

Parameters

fh
[filehandle] To read data from.

verify: bool, optional
Whether to do basic checks on whether the header is valid. Default: `True`.

`classmethod fromkeys`(**args*, ***kwargs*)
Initialise a header from keyword values.

Like fromvalues, but without any interpretation of keywords.

This just calls the class initializer; it is present for compatibility with other header classes only.

classmethod fromvalues(***kwargs*)
Initialise a header from parsed values.

Here, the parsed values must be given as keyword arguments, i.e., for any `header`, `cls.fromvalues(**header) == header`.

However, unlike for the `fromkeys` class method, data can also be set using arguments named after header methods, such as `time`.

Furthermore, some header defaults are set in `DADAHeader._defaults`.

get(*self*, *key*, *default=None*, */*)
Return the value for key if key is in the dictionary, else default.

items()

keys()

move_to_end(*self*, */*, *key*, *last=True*)
Move an existing element to the end (or beginning if last is false).

Raise KeyError if the element does not exist.

pop()
value. If key is not found, d is returned if given, otherwise KeyError is raised.

popitem(*self*, */*, *last=True*)
Remove and return a (key, value) pair from the dictionary.

Pairs are returned in LIFO order if last is true or FIFO order if false.

setdefault(*self*, */*, *key*, *default=None*)
Insert key with a value of default if key is not in the dictionary.

Return the value for key if key is in the dictionary, else default.

tofile(*self*, *fh*)
Write DADA file header to filehandle.

Parts of the header beyond the ascii lines are filled with 0x00. Note that file should in principle be at the start, but we don't check for that since that would break SequentialFileWriter.

update(*self*, ***, *verify=True*, ***kwargs*)
Update the header with new values.

Here, any keywords matching properties are processed as well, in the order set by the class (in `_properties`), and after all other keywords have been processed.

Parameters

verify
[bool, optional] If `True` (default), verify integrity after updating.

****kwargs**
Arguments used to set keywords and properties.

values()

verify(*self*)
Basic check of integrity.

DADAPayload

class baseband.dada.**DADAPayload**(*words*, *header=None*, *sample_shape=()*, *bps=8*, *complex_data=False*)

Bases: `baseband.vlbi_base.payload.VLBIPayloadBase`

Container for decoding and encoding DADA payloads.

Parameters

words
[`ndarray`] Array containg LSB unsigned words (with the right size) that encode the payload.

header
[`DADAHeader`] Header that provides information about how the payload is encoded. If not given, the following arguments have to be passed in.

bps
[int, optional] Number of bits per sample part (i.e., per channel and per real or imaginary component). Default: 8.

sample_shape
[tuple, optional] Shape of the samples; e.g., (nchan,). Default: ().

complex_data
[bool, optional] Whether data are complex. Default: `False`.

Attributes Summary

`data`	Full decoded payload.
`dtype`	Numeric type of the decoded data array.
`nbytes`	Size of the payload in bytes.
`ndim`	Number of dimensions of the decoded data array.
`shape`	Shape of the decoded data array.
`size`	Total number of component samples in the decoded data array.

Methods Summary

`fromdata`(data[, header, bps])	Encode data as a payload.
`fromfile`(fh[, header, memmap, payload_nbytes])	Read or map encoded data in file.
`tofile`(self, fh)	Write payload to filehandle.

Attributes Documentation

data
Full decoded payload.

dtype
Numeric type of the decoded data array.

nbytes
Size of the payload in bytes.

ndim

Number of dimensions of the decoded data array.

`shape`
Shape of the decoded data array.

`size`
Total number of component samples in the decoded data array.

Methods Documentation

classmethod fromdata(*data*, *header=None*, *bps=2*)
Encode data as a payload.

Parameters

data
[`ndarray`] Data to be encoded. The last dimension is taken as the number of channels.

header
[header instance, optional] If given, used to infer the bps.

bps
[int, optional] Bits per elementary sample, i.e., per channel and per real or imaginary component, used if header is not given. Default: 2.

classmethod fromfile(*fh*, *header=None*, *memmap=False*, *payload_nbytes=None*, ***kwargs*)
Read or map encoded data in file.

Parameters

fh
[filehandle] Handle to the file which will be read or mapped.

header
[`DADAHeader`, optional] If given, used to infer `payload_nbytes`, `bps`, `sample_shape`, and `complex_data`. If not given, those have to be passed in.

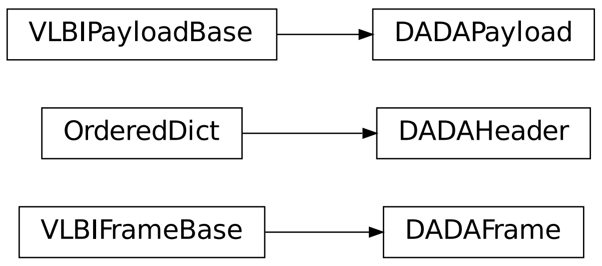
memmap
[bool, optional] If `False` (default), read from file. Otherwise, map the file in memory (see `memmap`).

payload_nbytes
[int, optional] Number of bytes to read (default: as given in `header`, `cls._nbytes`, or, for mapping, to the end of the file).

****kwargs**
Additional arguments are passed on to the class initializer. These are only needed if `header` is not given.

tofile(*self*, *fh*)
Write payload to filehandle.

Class Inheritance Diagram



8.2.2 baseband.dada.header Module

Definitions for DADA pulsar baseband headers.

Implements a DADAHeader class used to store header definitions in a FITS header, and read & write these from files.

Classes

`DADAHeader`(*args[, verify, mutable])	DADA baseband file format header.

DADAHeader

class `baseband.dada.header.`**`DADAHeader`**(**args*, *verify=True*, *mutable=True*, ***kwargs*)

Bases: `collections.OrderedDict`

DADA baseband file format header.

Defines a number of routines common to all baseband format headers.

Parameters

***args**
[str or iterable] If a string, parsed as a DADA header from a file, otherwise as for the OrderedDict baseclass.

verify
[bool, optional] Whether to do minimal verification that the header is consistent with the DADA standard. Default: `True`.

mutable
[bool, optional] Whether to allow the header to be changed after initialisation. Default: `True`.

****kwargs**
Any further header keywords to be set. If any value is a 2-item tuple, the second one will be considered a comment.

Notes

Like OrderedDict, in order to ensure keywords are kept in the right order, one should pass on values as a tuple, not as a dict. E.g., to copy a header, one should not do DADAHeader(**header), but rather:

```
DADAHeader(((key, header[key]) for key in header))
```

or, to also keep the comments:

```
DADAHeader(((key, (header[key], header.comments[key]))
          for key in header))
```

Attributes Summary

bps	Bits per elementary sample.
complex_data	Whether the data are complex.
frame_nbytes	Size of the frame in bytes.
nbytes	Size of the header in bytes.
offset	Offset from start of observation in units of time.
payload_nbytes	Size of the payload in bytes.
sample_rate	Number of complete samples per second.
sample_shape	Shape of a sample in the payload (npol, nchan).
samples_per_frame	Number of complete samples in the frame.
sideband	True if upper sideband.
start_time	Start time of the observation.
time	Start time of the part of the observation covered by this header.

Methods Summary

clear()	
copy(self)	Create a mutable and independent copy of the header.
fromfile(fh[, verify])	Reads in DADA header block from a file.
fromkeys(*args, **kwargs)	Initialise a header from keyword values.
fromvalues(**kwargs)	Initialise a header from parsed values.
get(self, key[, default])	Return the value for key if key is in the dictionary, else default.
items()	
keys()	
move_to_end(self, /, key[, last])	Move an existing element to the end (or beginning if last is false).
pop()	value.
popitem(self, /[, last])	Remove and return a (key, value) pair from the dictionary.
setdefault(self, /, key[, default])	Insert key with a value of default if key is not in the dictionary.
tofile(self, fh)	Write DADA file header to filehandle.
update(self, *[, verify])	Update the header with new values.
values()	
verify(self)	Basic check of integrity.

Attributes Documentation

`bps`
Bits per elementary sample.

`complex_data`
Whether the data are complex.

`frame_nbytes`
Size of the frame in bytes.

`nbytes`
Size of the header in bytes.

`offset`
Offset from start of observation in units of time.

`payload_nbytes`
Size of the payload in bytes.

`sample_rate`
Number of complete samples per second.

Can be set with a negative quantity to set `sideband`.

`sample_shape`
Shape of a sample in the payload (npol, nchan).

`samples_per_frame`
Number of complete samples in the frame.

`sideband`
True if upper sideband.

`start_time`
Start time of the observation.

`time`
Start time of the part of the observation covered by this header.

Methods Documentation

`clear()`

`copy(`*self*`)`
Create a mutable and independent copy of the header.

`classmethod fromfile(`*fh*, *verify=True*`)`
Reads in DADA header block from a file.

The file pointer should be at the start.

Parameters

fh
[filehandle] To read data from.

verify: bool, optional
Whether to do basic checks on whether the header is valid. Default: `True`.

classmethod fromkeys(**args*, ***kwargs*)

Initialise a header from keyword values.

Like fromvalues, but without any interpretation of keywords.

This just calls the class initializer; it is present for compatibility with other header classes only.

classmethod fromvalues(***kwargs*)

Initialise a header from parsed values.

Here, the parsed values must be given as keyword arguments, i.e., for any `header`, `cls.fromvalues(**header) == header`.

However, unlike for the `fromkeys` class method, data can also be set using arguments named after header methods, such as `time`.

Furthermore, some header defaults are set in `DADAHeader._defaults`.

get(*self*, *key*, *default=None*, */*)

Return the value for key if key is in the dictionary, else default.

items()

keys()

move_to_end(*self*, */*, *key*, *last=True*)

Move an existing element to the end (or beginning if last is false).

Raise KeyError if the element does not exist.

pop()

value. If key is not found, d is returned if given, otherwise KeyError is raised.

popitem(*self*, */*, *last=True*)

Remove and return a (key, value) pair from the dictionary.

Pairs are returned in LIFO order if last is true or FIFO order if false.

setdefault(*self*, */*, *key*, *default=None*)

Insert key with a value of default if key is not in the dictionary.

Return the value for key if key is in the dictionary, else default.

tofile(*self*, *fh*)

Write DADA file header to filehandle.

Parts of the header beyond the ascii lines are filled with 0x00. Note that file should in principle be at the start, but we don't check for that since that would break SequentialFileWriter.

update(*self*, ***, *verify=True*, ***kwargs*)

Update the header with new values.

Here, any keywords matching properties are processed as well, in the order set by the class (in `_properties`), and after all other keywords have been processed.

Parameters

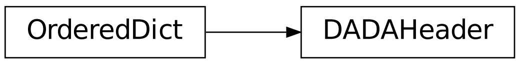
verify
[bool, optional] If `True` (default), verify integrity after updating.

****kwargs**
Arguments used to set keywords and properties.

`values()`

`verify(self)`
Basic check of integrity.

Class Inheritance Diagram



8.2.3 baseband.dada.payload Module

Payload for DADA format.

Classes

`DADAPayload`(words[, header, sample_shape, ...])	Container for decoding and encoding DADA payloads.

DADAPayload

class `baseband.dada.payload.`**`DADAPayload`**(*words*, *header=None*, *sample_shape=()*, *bps=8*, *complex_data=False*)
Bases: `baseband.vlbi_base.payload.VLBIPayloadBase`

Container for decoding and encoding DADA payloads.

Parameters

words
[`ndarray`] Array containg LSB unsigned words (with the right size) that encode the payload.

header
[`DADAHeader`] Header that provides information about how the payload is encoded. If not given, the following arguments have to be passed in.

bps
[int, optional] Number of bits per sample part (i.e., per channel and per real or imaginary component). Default: 8.

sample_shape
[tuple, optional] Shape of the samples; e.g., (nchan,). Default: ().

complex_data
[bool, optional] Whether data are complex. Default: `False`.

Attributes Summary

`data`	Full decoded payload.
`dtype`	Numeric type of the decoded data array.
`nbytes`	Size of the payload in bytes.
`ndim`	Number of dimensions of the decoded data array.
`shape`	Shape of the decoded data array.
`size`	Total number of component samples in the decoded data array.

Methods Summary

`fromdata`(data[, header, bps])	Encode data as a payload.
`fromfile`(fh[, header, memmap, payload_nbytes])	Read or map encoded data in file.
`tofile`(self, fh)	Write payload to filehandle.

Attributes Documentation

`data`
Full decoded payload.

`dtype`
Numeric type of the decoded data array.

`nbytes`
Size of the payload in bytes.

`ndim`
Number of dimensions of the decoded data array.

`shape`
Shape of the decoded data array.

`size`
Total number of component samples in the decoded data array.

Methods Documentation

`classmethod fromdata`(*data*, *header=None*, *bps=2*)
Encode data as a payload.

Parameters

data
[`ndarray`] Data to be encoded. The last dimension is taken as the number of channels.

header
[header instance, optional] If given, used to infer the bps.

bps
[int, optional] Bits per elementary sample, i.e., per channel and per real or imaginary component, used if header is not given. Default: 2.

`classmethod fromfile`(*fh*, *header=None*, *memmap=False*, *payload_nbytes=None*, ***kwargs*)
Read or map encoded data in file.

Parameters

fh
[filehandle] Handle to the file which will be read or mapped.

header
[`DADAHeader`, optional] If given, used to infer `payload_nbytes`, `bps`, `sample_shape`, and `complex_data`. If not given, those have to be passed in.

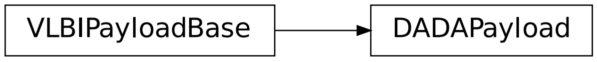
memmap
[bool, optional] If `False` (default), read from file. Otherwise, map the file in memory (see `memmap`).

payload_nbytes
[int, optional] Number of bytes to read (default: as given in `header`, `cls._nbytes`, or, for mapping, to the end of the file).

****kwargs**
Additional arguments are passed on to the class initializer. These are only needed if `header` is not given.

`tofile`(*self*, *fh*)
Write payload to filehandle.

Class Inheritance Diagram



8.2.4 baseband.dada.frame Module

Classes

`DADAFrame`(header, payload[, valid, verify])	Representation of a DADA file, consisting of a header and payload.

DADAFrame

class `baseband.dada.frame.`**`DADAFrame`**(*header*, *payload*, *valid=True*, *verify=True*)
Bases: `baseband.vlbi_base.frame.VLBIFrameBase`

Representation of a DADA file, consisting of a header and payload.

Parameters

header
[`DADAHeader`] Wrapper around the header lines, providing access to the values.

payload
[DADAPayload] Wrapper around the payload, provding mechanisms to decode it.

valid
[bool, optional] Whether the data are valid. Default: True.

verify
[bool, optional] Whether to do basic verification of integrity. Default: True.

Notes

DADA files do not support storing whether data are valid or not on disk. Hence, this has to be determined independently. If `valid=False`, any decoded data are set to `cls.fill_value` (by default, 0).

The Frame can also be instantiated using class methods:

fromfile : read header and map or read payload from a filehandle

fromdata : encode data as payload

Of course, one can also do the opposite:

tofile : method to write header and payload to filehandle

data : property that yields full decoded payload

One can decode part of the payload by indexing or slicing the frame.

A number of properties are defined: `shape`, `dtype` and `size` are the shape, type and number of complete samples of the data array, and `nbytes` the frame size in bytes. Furthermore, the frame acts as a dictionary, with keys those of the header. Any attribute that is not defined on the frame itself, such as `.time` will be looked up on the header as well.

Attributes Summary

`data`	Full decoded frame.
`dtype`	Numeric type of the frame data.
`fill_value`	Value to replace invalid data in the frame.
`nbytes`	Size of the encoded frame in bytes.
`ndim`	Number of dimensions of the frame data.
`sample_shape`	Shape of a sample in the frame (nchan,).
`shape`	Shape of the frame data.
`size`	Total number of component samples in the frame data.
`valid`	Whether frame contains valid data.

Methods Summary

`fromdata`(data[, header, valid, verify])	Construct frame from data and header.
`fromfile`(fh[, memmap, valid, verify])	Read a frame from a filehandle, possible mapping the payload.
`keys`(self)	
`tofile`(self, fh)	Write encoded frame to filehandle.
`verify`(self)	Simple verification.

Attributes Documentation

data
Full decoded frame.

dtype
Numeric type of the frame data.

fill_value
Value to replace invalid data in the frame.

nbytes
Size of the encoded frame in bytes.

ndim
Number of dimensions of the frame data.

sample_shape
Shape of a sample in the frame (nchan,).

shape
Shape of the frame data.

size
Total number of component samples in the frame data.

valid
Whether frame contains valid data.

Methods Documentation

classmethod fromdata(*data*, *header=None*, *valid=True*, *verify=True*, ***kwargs*)
Construct frame from data and header.

Note that since DADA files are generally very large, one would normally map the file, and then set pieces of it by assigning to slices of the frame. See `memmap_frame`.

Parameters

data
[`ndarray`] Array holding complex or real data to be encoded.

header
[`DADAHeader` or None] If not given, will attempt to generate one using the keywords.

valid
[bool, optional] Whether the data are valid (default: `True`). Note that this information cannot be written to disk.

verify
[bool, optional] Whether or not to do basic assertions that check the integrity. Default: `True`.

****kwargs**
If `header` is not given, these are used to initialize one.

classmethod fromfile(*fh*, *memmap=True*, *valid=True*, *verify=True*)
Read a frame from a filehandle, possible mapping the payload.

Parameters

fh
[filehandle] To read header from.

memmap
[bool, optional] If `True` (default), use `memmap` to map the payload. If `False`, just read it from disk.

valid
[bool, optional] Whether the data are valid (default: `True`). Note that this cannot be inferred from the header or payload itself. If `False`, any data read will be set to `cls.fill_value`.

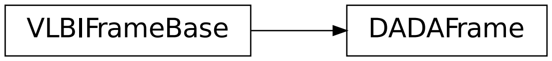
verify
[bool, optional] Whether to do basic verification of integrity. Default: `True`.

keys(*self*)

tofile(*self*, *fh*)
Write encoded frame to filehandle.

verify(*self*)
Simple verification. To be added to by subclasses.

Class Inheritance Diagram



8.2.5 baseband.dada.base Module

Functions

open(name[, mode])	Open DADA file(s) for reading or writing.

open

`baseband.dada.base.`**open**(*name*, *mode='rs'*, ***kwargs*)
Open DADA file(s) for reading or writing.

Opened as a binary file, one gets a wrapped filehandle that adds methods to read/write a frame. Opened as a stream, the handle is wrapped further, with methods such as reading and writing to the file as if it were a stream of samples.

Parameters

name
[str or filehandle, or sequence of str] File name, filehandle, or sequence of file names (see

Notes).

mode
[{'rb', 'wb', 'rs', or 'ws'}, optional] Whether to open for reading or writing, and as a regular binary file or as a stream. Default: 'rs', for reading a stream.

****kwargs**
Additional arguments when opening the file as a stream.

— For reading a stream
[(see `DADAStreamReader`)]

squeeze
[bool, optional] If `True` (default), remove any dimensions of length unity from decoded data.

subset
[indexing object or tuple of objects, optional] Specific components of the complete sample to decode (after possibly squeezing). If a single indexing object is passed, it selects polarizations. With a tuple, the first selects polarizations and the second selects channels. If the tuple is empty (default), all components are read.

— For writing a stream
[(see `DADAStreamWriter`)]

header0
[`DADAHeader`] Header for the first frame, holding time information, etc. Can instead give keyword arguments to construct a header (see `**kwargs`).

squeeze
[bool, optional] If `True` (default), writer accepts squeezed arrays as input, and adds any dimensions of length unity.

****kwargs**
If the header is not given, an attempt will be made to construct one with any further keyword arguments.

— Header keywords
[(see `fromvalues()`)]

time
[`Time`] Start time of the file.

samples_per_frame
[int,] Number of complete samples per frame.

sample_rate
[`Quantity`] Number of complete samples per second, i.e. the rate at which each channel of each polarization is sampled.

offset
[`Quantity` or `TimeDelta`, optional] Time offset from the start of the whole observation (default: 0).

npol
[int, optional] Number of polarizations (default: 1).

nchan
[int, optional] Number of channels (default: 1).

complex_data
[bool, optional] Whether data are complex (default: `False`).

bps
[int, optional] Bits per elementary sample, i.e. per real or imaginary component for complex data (default: 8).

Returns

Filehandle
`DADAFileReader` or `DADAFileWriter` (binary), or `DADAStreamReader` or `DADAStreamWriter` (stream).

Notes

For streams, one can also pass to `name` a list of files, or a template string that can be formatted using 'frame_nr', 'obs_offset', and other header keywords (by `DADAFileNameSequencer`).

For writing, one can mimic what is done at quite a few telescopes by using the template '{utc_start}_{obs_offset:016d}.000000.dada'. Unlike for the VLBI openers, `file_size` is set to the size of one frame as given by the header.

For reading, to read series such as the above, use something like '2013-07-02-01:37:40_{obs_offset:016d}.000000.dada'. Note that here we have to pass in the date explicitly, since the template is used to get the first file name, before any header is read, and therefore the only keywords available are 'frame_nr', 'file_nr', and 'obs_offset', all of which are assumed to be zero for the first file. To avoid this restriction, pass in keyword arguments with values appropriate for the first file.

One may also pass in a `sequentialfile` object (opened in 'rb' mode for reading or 'w+b' for writing), though for typical use cases it is practically identical to passing in a list or template.

Classes

`DADAFileNameSequencer`(template[, header])	List-like generator of DADA filenames using a template.
`DADAFileReader`(fh_raw)	Simple reader for DADA files.
`DADAFileWriter`(fh_raw)	Simple writer/mapper for DADA files.
`DADAStreamBase`(fh_raw, header0[, squeeze, . . .])	Base for DADA streams.
`DADAStreamReader`(fh_raw[, squeeze, subset, . . .])	DADA format reader.
`DADAStreamWriter`(fh_raw, header0[, squeeze])	DADA format writer.

DADAFileNameSequencer

class `baseband.dada.base.`**`DADAFileNameSequencer`**(*template*, *header={}*)
Bases: `baseband.helpers.sequentialfile.FileNameSequencer`

List-like generator of DADA filenames using a template.

The template is formatted, filling in any items in curly brackets with values from the header, as well as possibly a file number equal to the indexing value, indicated with '{file_nr}'. The value '{obs_offset}' is treated specially, in being calculated using `header['OBS_OFFSET'] + file_nr * header['FILE_SIZE']`, where `header['FILE_SIZE']` is the file size in bytes.

The length of the instance will be the number of files that exist that match the template for increasing values of the file number (when writing, it is the number of files that have so far been generated).

Parameters

template
[str] Template to format to get specific filenames. Curly bracket item keywords are not case-sensitive.

header
[dict-like] Structure holding key'd values that are used to fill in the format. Keys must be in all caps (eg. DATE), as with DADA header keys.

Examples

```
>>> from baseband import dada
>>> dfs = dada.base.DADAFileNameSequencer(
...     '{date}_{file_nr:03d}.dada', {'DATE': "2018-01-01"})
>>> dfs[10]
'2018-01-01_010.dada'
>>> from baseband.data import SAMPLE_DADA
>>> with open(SAMPLE_DADA, 'rb') as fh:
...     header = dada.DADAHeader.fromfile(fh)
>>> template = '{utc_start}.{obs_offset:016d}.000000.dada'
>>> dfs = dada.base.DADAFileNameSequencer(template, header)
>>> dfs[0]
'2013-07-02-01:37:40.0000006400000000.000000.dada'
>>> dfs[1]
'2013-07-02-01:37:40.0000006400064000.000000.dada'
>>> dfs[10]
'2013-07-02-01:37:40.0000006400640000.000000.dada'
```

DADAFileReader

class baseband.dada.base.**DADAFileReader**(*fh_raw*)
Bases: baseband.vlbi_base.base.VLBIFileReaderBase

Simple reader for DADA files.

Wraps a binary filehandle, providing methods to help interpret the data, such as read_frame and get_frame_rate. By default, frame payloads are mapped rather than fully read into physical memory.

Parameters

fh_raw
[filehandle] Filehandle of the raw binary data file.

Attributes Summary

info()	Standardized information on file readers.

Methods Summary

close(self)	
get_frame_rate(self)	Determine the number of frames per second.

Continued on next page

Table 21 – continued from previous page

read_frame(self[, memmap, verify])	Read the frame header and read or map the corresponding payload.
read_header(self)	Read a single header from the file.
temporary_offset(self)	Context manager for temporarily seeking to another file position.

Attributes Documentation

info

Standardized information on file readers.

The `info` descriptor has a number of standard attributes, which are determined from arguments passed in opening the file, from the first header (`info.header0`) and from possibly scanning the file to determine the duration of frames.

Examples

The most common use is simply to print information:

```
>>> from baseband.data import SAMPLE_MARK5B
>>> from baseband import mark5b
>>> fh = mark5b.open(SAMPLE_MARK5B, 'rb')
>>> fh.info
File information:
format = mark5b
frame_rate = 6400.0 Hz
bps = 2
complex_data = False
readable = False

missing:  nchan: needed to determine sample shape and rate.
          kday, ref_time: needed to infer full times.

errors:  start_time: unsupported operand type(s) for +: 'NoneType' and 'int'
         frame0: In order to read frames, the file handle should be initialized with nchan␣
↪set.

>>> fh.close()

>>> fh = mark5b.open(SAMPLE_MARK5B, 'rb', kday=56000, nchan=8)
>>> fh.info
File information:
format = mark5b
frame_rate = 6400.0 Hz
sample_rate = 32.0 MHz
samples_per_frame = 5000
sample_shape = (8,)
bps = 2
complex_data = False
start_time = 2014-06-13T05:30:01.000000000
readable = True
>>> fh.close()
```

Attributes

format
[str or `None`] File format, or `None` if the underlying file cannot be parsed.

frame_rate
[`Quantity`] Number of data frames per unit of time.

sample_rate
[`Quantity`] Complete samples per unit of time.

samples_per_frame
[int] Number of complete samples in each frame.

sample_shape
[tuple] Dimensions of each complete sample (e.g., `(nchan,)`).

bps
[int] Number of bits used to encode each elementary sample.

complex_data
[bool] Whether the data are complex.

start_time
[`Time`] Time of the first complete sample.

readable
[bool] Whether the first sample could be read and decoded.

missing
[dict] Entries are keyed by names of arguments that should be passed to the file reader to obtain full information. The associated entries explain why these arguments are needed.

errors
[dict] Any exceptions raised while trying to determine attributes. Keyed by the attributes.

Methods Documentation

`close`(*self*)

`get_frame_rate`(*self*)
Determine the number of frames per second.

The routine uses the sample rate and number of samples per frame from the first header in the file.

Returns

frame_rate
[`Quantity`] Frames per second.

`read_frame`(*self*, *memmap=True*, *verify=True*)
Read the frame header and read or map the corresponding payload.

Parameters

memmap
[bool, optional] If `True` (default), map the payload using `memmap`, so that parts are only loaded into memory as needed to access data.

verify
[bool, optional] Whether to do basic checks of frame integrity. Default: `True`.

Returns

frame
[DADAFrame] With .header and .payload properties. The .data property returns all data encoded in the frame. Since this may be too large to fit in memory, it may be better to access the parts of interest by slicing the frame.

read_header(*self*)
Read a single header from the file.

Returns

header
[DADAHeader]

temporary_offset(*self*)
Context manager for temporarily seeking to another file position.

To be used as part of a with statement:

```
with fh_raw.temporary_offset() [as fh_raw]:
    with-block
```

On exiting the with-block, the file pointer is moved back to its original position.

DADAFileWriter

class baseband.dada.base.**DADAFileWriter**(*fh_raw*)
Bases: baseband.vlbi_base.base.VLBIFileBase

Simple writer/mapper for DADA files.

Adds write_frame and memmap_frame methods to the VLBI binary file wrapper. The latter allows one to encode data in pieces, writing to disk as needed.

Methods Summary

close(self)	
memmap_frame(self[, header])	Get frame by writing the header to disk and mapping its payload.
temporary_offset(self)	Context manager for temporarily seeking to another file position.
write_frame(self, data[, header])	Write a single frame (header plus payload).

Methods Documentation

close(*self*)

memmap_frame(*self*, *header=None*, ***kwargs*)
Get frame by writing the header to disk and mapping its payload.

The header is written to disk immediately, but the payload is mapped, so that it can be filled in pieces, by setting slices of the frame.

Parameters

header
[DADAHeader] Written to disk immediately. Can instead give keyword arguments to construct a header.

****kwargs**
If header is not given, these are used to initialize one.

Returns

frame: DADAFrame
By assigning slices to data, the payload can be encoded piecewise.

temporary_offset(*self*)
Context manager for temporarily seeking to another file position.

To be used as part of a with statement:

```
with fh_raw.temporary_offset() [as fh_raw]:
    with-block
```

On exiting the with-block, the file pointer is moved back to its original position.

write_frame(*self*, *data*, *header=None*, ***kwargs*)
Write a single frame (header plus payload).

Parameters

data
[ndarray or DADAFrame] If an array, a header should be given, which will be used to get the information needed to encode the array, and to construct the DADA frame.

header
[DADAHeader] Can instead give keyword arguments to construct a header. Ignored if data is a DADAFrame instance.

****kwargs**
If header is not given, these are used to initialize one.

DADAStreamBase

class baseband.dada.base.**DADAStreamBase**(*fh_raw*, *header0*, *squeeze=True*, *subset=()*, *verify=True*)
Bases: baseband.vlbi_base.base.VLBIStreamBase

Base for DADA streams.

Attributes Summary

bps	Bits per elementary sample.
complex_data	Whether the data are complex.
header0	First header of the file.
sample_rate	Number of complete samples per second.

Continued on next page

Table 23 – continued from previous page

sample_shape	Shape of a complete sample (possibly subset or squeezed).
samples_per_frame	Number of complete samples per frame.
squeeze	Whether data arrays have dimensions with length unity removed.
start_time	Start time of the file.
subset	Specific components of the complete sample to decode.
time	Time of the sample pointer's current offset in file.
verify	Whether to do consistency checks on frames being read.

Methods Summary

close(self)	
tell(self[, unit])	Current offset in the file.

Attributes Documentation

bps
Bits per elementary sample.

complex_data
Whether the data are complex.

header0
First header of the file.

sample_rate
Number of complete samples per second.

sample_shape
Shape of a complete sample (possibly subset or squeezed).

samples_per_frame
Number of complete samples per frame.

squeeze
Whether data arrays have dimensions with length unity removed.

If `True`, data read out has such dimensions removed, and data passed in for writing has them inserted.

start_time
Start time of the file.

See also `time` for the time of the sample pointer's current offset.

subset
Specific components of the complete sample to decode.

The order of dimensions is the same as for `sample_shape`. Set by the class initializer.

time
Time of the sample pointer's current offset in file.

See also `start_time` for the start time of the file.

`verify`
Whether to do consistency checks on frames being read.

Methods Documentation

`close`(*self*)

`tell`(*self*, *unit=None*)
Current offset in the file.

Parameters

unit
[`Unit` or str, optional] Time unit the offset should be returned in. By default, no unit is used, i.e., an integer enumerating samples is returned. For the special string 'time', the absolute time is calculated.

Returns

offset
[int, `Quantity`, or `Time`] Offset in current file (or time at current position).

DADAStreamReader

class `baseband.dada.base.`**`DADAStreamReader`**(*fh_raw*, *squeeze=True*, *subset=()*, *verify=True*)
Bases: `baseband.dada.base.DADAStreamBase`, `baseband.vlbi_base.base.VLBIStreamReaderBase`

DADA format reader.

Allows access to DADA files as a continuous series of samples.

Parameters

fh_raw
[filehandle] Filehandle of the raw DADA stream.

squeeze
[bool, optional] If `True` (default), remove any dimensions of length unity from decoded data.

subset
[indexing object or tuple of objects, optional] Specific components of the complete sample to decode (after possibly squeezing). If a single indexing object is passed, it selects polarizations. With a tuple, the first selects polarizations and the second selects channels. If the tuple is empty (default), all components are read.

verify
[bool, optional] Whether to do basic checks of frame integrity when reading. The first frame of the stream is always checked, so `verify` is effective only when reading sequences of files. Default: `True`.

Attributes Summary

bps	Bits per elementary sample.
complex_data	Whether the data are complex.
dtype	
fill_value	Value to use for invalid or missing data.
header0	First header of the file.
info()	Standardized information on stream readers.
ndim	Number of dimensions of the (squeezed/subset) stream data.
sample_rate	Number of complete samples per second.
sample_shape	Shape of a complete sample (possibly subset or squeezed).
samples_per_frame	Number of complete samples per frame.
shape	Shape of the (squeezed/subset) stream data.
size	Total number of component samples in the (squeezed/subset) stream data.
squeeze	Whether data arrays have dimensions with length unity removed.
start_time	Start time of the file.
stop_time	Time at the end of the file, just after the last sample.
subset	Specific components of the complete sample to decode.
time	Time of the sample pointer's current offset in file.
verify	Whether to do consistency checks on frames being read.

Methods Summary

close(self)	
read(self[, count, out])	Read a number of complete (or subset) samples.
readable(self)	Whether the file can be read and decoded.
seek(self, offset[, whence])	Change the stream position.
tell(self[, unit])	Current offset in the file.

Attributes Documentation

bps
Bits per elementary sample.

complex_data
Whether the data are complex.

dtype

fill_value
Value to use for invalid or missing data. Default: 0.

header0
First header of the file.

info
Standardized information on stream readers.

The `info` descriptor provides a few standard attributes, all of which can also be accessed directly on the stream filehandle. More detailed information on the underlying file is stored in its info, accessible via `info.file_info`.

Attributes

start_time
[`Time`] Time of the first complete sample.

stop_time
[`Time`] Time of the complete sample just beyond the end of the file.

sample_rate
[`Quantity`] Complete samples per unit of time.

shape
[tuple] Equivalent shape of the whole file, i.e., combining the number of complete samples and the shape of those samples.

bps
[int] Number of bits used to encode each elementary sample.

complex_data
[bool] Whether the data are complex.

readable
[bool] Whether the first sample could be read and decoded.

`ndim`
Number of dimensions of the (squeezed/subset) stream data.

`sample_rate`
Number of complete samples per second.

`sample_shape`
Shape of a complete sample (possibly subset or squeezed).

`samples_per_frame`
Number of complete samples per frame.

`shape`
Shape of the (squeezed/subset) stream data.

`size`
Total number of component samples in the (squeezed/subset) stream data.

`squeeze`
Whether data arrays have dimensions with length unity removed.

If `True`, data read out has such dimensions removed, and data passed in for writing has them inserted.

`start_time`
Start time of the file.

See also `time` for the time of the sample pointer's current offset, and (if available) `stop_time` for the time at the end of the file.

`stop_time`
Time at the end of the file, just after the last sample.

See also `start_time` for the start time of the file, and `time` for the time of the sample pointer's current offset.

subset
Specific components of the complete sample to decode.

The order of dimensions is the same as for `sample_shape`. Set by the class initializer.

time
Time of the sample pointer's current offset in file.

See also `start_time` for the start time, and (if available) `stop_time` for the end time, of the file.

verify
Whether to do consistency checks on frames being read.

Methods Documentation

close(*self*)

read(*self*, *count=None*, *out=None*)
Read a number of complete (or subset) samples.

The range retrieved can span multiple frames.

Parameters

count
[int or None, optional] Number of complete/subset samples to read. If `None` (default) or negative, the whole file is read. Ignored if `out` is given.

out
[None or array, optional] Array to store the data in. If given, `count` will be inferred from the first dimension; the other dimension should equal `sample_shape`.

Returns

out
[`ndarray` of float or complex] The first dimension is sample-time, and the remainder given by `sample_shape`.

readable(*self*)
Whether the file can be read and decoded.

seek(*self*, *offset*, *whence=0*)
Change the stream position.

This works like a normal filehandle seek, but the offset is in samples (or a relative or absolute time).

Parameters

offset
[int, `Quantity`, or `Time`] Offset to move to. Can be an (integer) number of samples, an offset in time units, or an absolute time.

whence
[{0, 1, 2, 'start', 'current', or 'end'}, optional] Like regular seek, the offset is taken to be from the start if `whence=0` (default), from the current position if 1, and from the end if 2. One can alternativey use 'start', 'current', or 'end' for 0, 1, or 2, respectively. Ignored if `offset` is a time.

tell(*self*, *unit=None*)

Current offset in the file.

Parameters

unit
[Unit or str, optional] Time unit the offset should be returned in. By default, no unit is used, i.e., an integer enumerating samples is returned. For the special string 'time', the absolute time is calculated.

Returns

offset
[int, Quantity, or Time] Offset in current file (or time at current position).

DADAStreamWriter

class baseband.dada.base.**DADAStreamWriter**(*fh_raw*, *header0*, *squeeze=True*)

Bases: baseband.dada.base.DADAStreamBase, baseband.vlbi_base.base.VLBIStreamWriterBase

DADA format writer.

Encodes and writes sequences of samples to file.

Parameters

raw
[filehandle] For writing the header and raw data to storage.

header0
[DADAHeader] Header for the first frame, holding time information, etc.

squeeze
[bool, optional] If True (default), write accepts squeezed arrays as input, and adds any dimensions of length unity.

Attributes Summary

bps	Bits per elementary sample.
complex_data	Whether the data are complex.
header0	First header of the file.
sample_rate	Number of complete samples per second.
sample_shape	Shape of a complete sample (possibly subset or squeezed).
samples_per_frame	Number of complete samples per frame.
squeeze	Whether data arrays have dimensions with length unity removed.
start_time	Start time of the file.
subset	Specific components of the complete sample to decode.
time	Time of the sample pointer's current offset in file.

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verify	Whether to do consistency checks on frames being read.

Methods Summary

close(self)	
tell(self[, unit])	Current offset in the file.
write(self, data[, valid])	Write data, buffering by frames as needed.

Attributes Documentation

bps
Bits per elementary sample.

complex_data
Whether the data are complex.

header0
First header of the file.

sample_rate
Number of complete samples per second.

sample_shape
Shape of a complete sample (possibly subset or squeezed).

samples_per_frame
Number of complete samples per frame.

squeeze
Whether data arrays have dimensions with length unity removed.

If True, data read out has such dimensions removed, and data passed in for writing has them inserted.

start_time
Start time of the file.

See also time for the time of the sample pointer's current offset.

subset
Specific components of the complete sample to decode.

The order of dimensions is the same as for sample_shape. Set by the class initializer.

time
Time of the sample pointer's current offset in file.

See also start_time for the start time of the file.

verify
Whether to do consistency checks on frames being read.

Methods Documentation

close(*self*)

tell(*self*, *unit=None*)
Current offset in the file.

Parameters

unit
[Unit or str, optional] Time unit the offset should be returned in. By default, no unit is used, i.e., an integer enumerating samples is returned. For the special string 'time', the absolute time is calculated.

Returns

offset
[int, Quantity, or Time] Offset in current file (or time at current position).

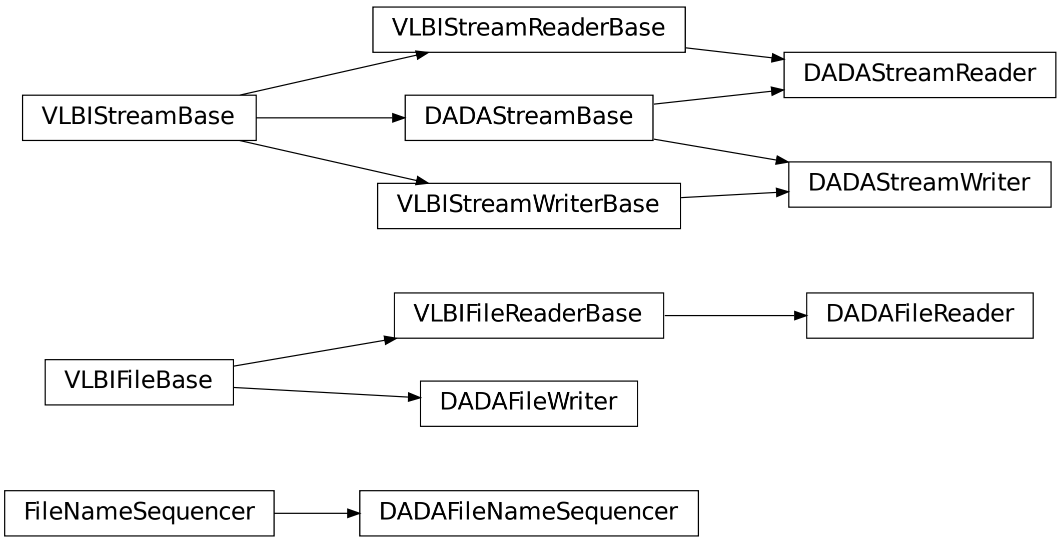
write(*self*, *data*, *valid=True*)
Write data, buffering by frames as needed.

Parameters

data
[ndarray] Piece of data to be written, with sample dimensions as given by sample_shape. This should be properly scaled to make best use of the dynamic range delivered by the encoding.

valid
[bool, optional] Whether the current data are valid. Default: True.

Class Inheritance Diagram



CHAPTER

NINE

GUPPI

The GUPPI format is the output of the Green Bank Ultimate Pulsar Processing Instrument and any clones operating at other telescopes, such as PUPPI at the Arecibo Observatory. Baseband specifically supports GUPPI data **taken in baseband mode**, and is based off of DSPSR's implementation. While general format specifications can be found at the SERA Project and on Paul Demorest's site, some of the header information could be invalid or not applicable, particularly with older files.

Baseband currently only supports 8-bit *elementary samples*.

9.1 File Structure

Each GUPPI file contains multiple (typically 128) *frames*, with each frame consisting of an ASCII *header* composed of 80-character entries, followed by a binary *payload* (or "block"). The header's length is variable, but always ends with "END" followed by 77 spaces.

How samples are stored in the payload depends on whether or not it is **channels-first**. A channels-first payload stores each channel's *stream* in a contiguous data block, while a non-channels-first one groups the *components* of a *complete sample* together (like with other formats). In either case, for each channel polarization samples from the same point in time are stored adjacent to one another. At the end of each channel's data is a section of **overlap samples** identical to the first samples in the next payload. Baseband retains these redundant samples when reading individual GUPPI frames, but removes them when reading files as a stream.

9.2 Usage

This section covers reading and writing GUPPI files with Baseband; general usage is covered in the *Using Baseband* section. For situations in which one is unsure of a file's format, Baseband features the general `baseband.open` and `baseband.file_info` functions, which are also discussed in *Using Baseband*. The examples below use the sample PUPPI file `baseband/data/sample_puppi.raw`, and the the `astropy.units` and `baseband.guppi` modules:

```
>>> from baseband import guppi
>>> import astropy.units as u
>>> from baseband.data import SAMPLE_PUPPI
```

Single files can be opened with `open` in binary mode, which provides a normal file reader, but extended with methods to read a `GUPPIFrame`:

```
>>> fb = guppi.open(SAMPLE_PUPPI, 'rb')
>>> frame = fb.read_frame()
>>> frame.shape
(1024, 2, 4)
```

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```
>>> frame[:3, 0, 1]
array([-32.-10.j, -15.-14.j,   9.-13.j], dtype=complex64)
>>> fb.close()
```

Since the files can be quite large, the payload is mapped (with `numpy.memmap`), so that if one accesses part of the data, only the corresponding parts of the encoded payload are loaded into memory (since the sample file is encoded using 8 bits, the above example thus loads 6 bytes into memory).

Opening in stream mode wraps the low-level routines such that reading and writing is in units of samples, and provides access to header information:

```
>>> fh = guppi.open(SAMPLE_PUPPI, 'rs')
>>> fh
<GUPPIStreamReader name=... offset=0
    sample_rate=250.0 Hz, samples_per_frame=960,
    sample_shape=SampleShape(npol=2, nchan=4), bps=8,
    start_time=2018-01-14T14:11:33.000>
>>> d = fh.read()
>>> d.shape
(3840, 2, 4)
>>> d[:3, 0, 1]
array([-32.-10.j, -15.-14.j,   9.-13.j], dtype=complex64)
>>> fh.close()
```

Note that `fh.samples_per_frame` represents the number of samples per frame **excluding overlap samples**, since the stream reader works on a linearly increasing sequence of samples. Frames themselves have access to the overlap, and `fh.header0.samples_per_frame` returns the number of samples per frame including overlap.

To set up a file for writing as a stream is possible as well. Overlap must be zero when writing (so we set `samples_per_frame` to its stream reader value from above):

```
>>> from astropy.time import Time
>>> fw = guppi.open('puppi_test.{file_nr:04d}.raw', 'ws',
...                 frames_per_file=2, sample_rate=250*u.Hz,
...                 samples_per_frame=960, pktsize=1024,
...                 time=Time(58132.59135416667, format='mjd'),
...                 npol=2, nchan=4)
>>> fw.write(d)
>>> fw.close()
>>> fr = guppi.open('puppi_test.{file_nr:04d}.raw', 'rs')
>>> d2 = fr.read()
>>> (d == d2).all()
True
>>> fr.close()
```

Here we show how to write a sequence of files by passing a string template to `open`, which prompts it to create and use a filename sequencer generated with `GUPPIFileNameSequencer`. One may also pass a time-ordered list or tuple of filenames to `open`. Unlike when writing DADA files, which have one frame per file, we specify the number of frames in one file using‘‘frames_per_file‘‘. Note that typically one does not have to pass `PKTSIZE`, the UDP data packet size (set by the observing mode), but the sample file has small enough frames that the default of 8192 bytes is too large. Baseband only uses `PKTSIZE` to double-check the sample offset of the frame, so `PKTSIZE` must be set to a value such that each payload, excluding overlap samples, contains an integer number of packets. (See API links for further details on how to read and write file sequences.)

9.3 Reference/API

9.3.1 baseband.guppi Package

Green Bank Ultimate Pulsar Processing Instrument (GUPPI) format reader/writer.

Functions

open(name[, mode])	Open GUPPI file(s) for reading or writing.

open

`baseband.guppi.open`(*name*, *mode='rs'*, ***kwargs*)

Open GUPPI file(s) for reading or writing.

Opened as a binary file, one gets a wrapped filehandle that adds methods to read/write a frame. Opened as a stream, the handle is wrapped further, with methods such as reading and writing to the file as if it were a stream of samples.

Parameters

name
[str or filehandle, or sequence of str] File name, filehandle, or sequence of file names (see Notes).

mode
[{'rb', 'wb', 'rs', or 'ws'}, optional] Whether to open for reading or writing, and as a regular binary file or as a stream. Default: 'rs', for reading a stream.

****kwargs**
Additional arguments when opening the file as a stream.

— For reading a stream
[(see `GUPPIStreamReader`)]

squeeze
[bool, optional] If `True` (default), remove any dimensions of length unity from decoded data.

subset
[indexing object or tuple of objects, optional] Specific components of the complete sample to decode (after possibly squeezing). If a single indexing object is passed, it selects polarizations. With a tuple, the first selects polarizations and the second selects channels. If the tuple is empty (default), all components are read.

— For writing a stream
[(see `GUPPIStreamWriter`)]

header0
[`GUPPIHeader`] Header for the first frame, holding time information, etc. Can instead give keyword arguments to construct a header (see `**kwargs`).

squeeze
[bool, optional] If `True` (default), writer accepts squeezed arrays as input, and adds any dimensions of length unity.

frames_per_file
[int, optional] When writing to a sequence of files, sets the number of frames within each file. Default: 128.

****kwargs**
If the header is not given, an attempt will be made to construct one with any further keyword arguments.

— Header keywords
[(see `fromvalues()`)]

time
[`Time`] Start time of the file. Must have an integer number of seconds.

sample_rate
[`Quantity`] Number of complete samples per second, i.e. the rate at which each channel of each polarization is sampled.

samples_per_frame
[int] Number of complete samples per frame. Can alternatively give `payload_nbytes`.

payload_nbytes
[int] Number of bytes per payload. Can alternatively give `samples_per_frame`.

offset
[`Quantity` or `TimeDelta`, optional] Time offset from the start of the whole observation (default: 0).

npol
[int, optional] Number of polarizations (default: 1).

nchan
[int, optional] Number of channels (default: 1). For GUPPI, complex data is only allowed when nchan > 1.

bps
[int, optional] Bits per elementary sample, i.e. per real or imaginary component for complex data (default: 8).

Returns

Filehandle
`GUPPIFileReader` or `GUPPIFileWriter` (binary), or `GUPPIStreamReader` or `GUPPIStreamWriter` (stream).

Notes

For streams, one can also pass to `name` a list of files, or a template string that can be formatted using ‘stt_imjd’, ‘src_name’, and other header keywords (by `GUPPIFileNameSequencer`).

For writing, one can mimic, for example, what is done at Arecibo by using the template ‘puppi_{stt_imjd}_{src_name}_{scannum}.{file_nr:04d}.raw’. GUPPI typically has 128 frames per file; to change this, use the `frames_per_file` keyword. `file_size` is set by `frames_per_file` and cannot be passed.

For reading, to read series such as the above, you will need to use something like ‘puppi_58132_J1810+1744_2176.{file_nr:04d}.raw’. Here we have to pass in the MJD, source name and scan number explicitly, since the template is used to get the first file name, before any header is read, and therefore the only keyword available is ‘file_nr’, which is assumed to be zero for the first file. To avoid this restriction, pass in keyword arguments with values appropriate for the first file.

One may also pass in a `sequentialfile` object (opened in 'rb' mode for reading or 'w+b' for writing), though for typical use cases it is practically identical to passing in a list or template.

Classes

`GUPPIFrame`(header, payload[, valid, verify])	Representation of a GUPPI file, consisting of a header and payload.
`GUPPIHeader`(*args[, verify, mutable])	GUPPI baseband file format header.
`GUPPIPayload`(words[, header, sample_shape, ...])	Container for decoding and encoding GUPPI payloads.

GUPPIFrame

class `baseband.guppi.`**`GUPPIFrame`**(*header*, *payload*, *valid=True*, *verify=True*)

Bases: `baseband.vlbi_base.frame.VLBIFrameBase`

Representation of a GUPPI file, consisting of a header and payload.

Parameters

header
[`GUPPIHeader`] Wrapper around the header lines, providing access to the values.

payload
[`GUPPIPayload`] Wrapper around the payload, provding mechanisms to decode it.

valid
[bool, optional] Whether the data are valid. Default: `True`.

verify
[bool, optional] Whether to do basic verification of integrity. Default: `True`.

Notes

GUPPI files do not support storing whether data are valid or not on disk. Hence, this has to be determined independently. If `valid=False`, any decoded data are set to `cls.fill_value` (by default, 0).

The Frame can also be instantiated using class methods:

fromfile : read header and and map or read payload from a filehandle

fromdata : encode data as payload

Of course, one can also do the opposite:

tofile : method to write header and payload to filehandle

data : property that yields full decoded payload

One can decode part of the payload by indexing or slicing the frame.

A number of properties are defined: `shape`, `dtype` and `size` are the shape, type and number of complete samples of the data array, and `nbytes` the frame size in bytes. Furthermore, the frame acts as a dictionary, with keys those of the header. Any attribute that is not defined on the frame itself, such as `.time` will be looked up on the header as well.

Attributes Summary

`data`	Full decoded frame.
`dtype`	Numeric type of the frame data.
`fill_value`	Value to replace invalid data in the frame.
`nbytes`	Size of the encoded frame in bytes.
`ndim`	Number of dimensions of the frame data.
`sample_shape`	Shape of a sample in the frame (nchan,).
`shape`	Shape of the frame data.
`size`	Total number of component samples in the frame data.
`valid`	Whether frame contains valid data.

Methods Summary

`fromdata`(data[, header, valid, verify])	Construct frame from data and header.
`fromfile`(fh[, memmap, valid, verify])	Read a frame from a filehandle, possible mapping the payload.
`keys`(self)	
`tofile`(self, fh)	Write encoded frame to filehandle.
`verify`(self)	Simple verification.

Attributes Documentation

`data`
Full decoded frame.

`dtype`
Numeric type of the frame data.

`fill_value`
Value to replace invalid data in the frame.

`nbytes`
Size of the encoded frame in bytes.

`ndim`
Number of dimensions of the frame data.

`sample_shape`
Shape of a sample in the frame (nchan,).

`shape`
Shape of the frame data.

`size`
Total number of component samples in the frame data.

`valid`
Whether frame contains valid data.

Methods Documentation

`classmethod fromdata`(*data*, *header=None*, *valid=True*, *verify=True*, ***kwargs*)
Construct frame from data and header.

Note that since GUPPI files are generally very large, one would normally map the file, and then set pieces of it by assigning to slices of the frame. See `memmap_frame`.

Parameters

data
[`ndarray`] Array holding complex or real data to be encoded.

header
[`GUPPIHeader` or None, optional] If not given, will attempt to generate one using the keywords.

valid
[bool, optional] Whether the data are valid (default: `True`). Note that this information cannot be written to disk.

verify
[bool, optional] Whether or not to do basic assertions that check the integrity. Default: `True`.

****kwargs**
If `header` is not given, these are used to initialize one.

classmethod fromfile(*fh*, *memmap=True*, *valid=True*, *verify=True*)
Read a frame from a filehandle, possible mapping the payload.

Parameters

fh
[filehandle] To read header from.

memmap
[bool, optional] If `True` (default), use `memmap` to map the payload. If `False`, just read it from disk.

valid
[bool, optional] Whether the data are valid (default: `True`). Note that this cannot be inferred from the header or payload itself. If `False`, any data read will be set to `cls.fill_value`.

verify
[bool, optional] Whether to do basic verification of integrity. Default: `True`.

keys(*self*)

tofile(*self*, *fh*)
Write encoded frame to filehandle.

verify(*self*)
Simple verification. To be added to by subclasses.

GUPPIHeader

class baseband.guppi.**GUPPIHeader**(**args*, *verify=True*, *mutable=True*, ***kwargs*)
Bases: `astropy.io.fits.Header`

GUPPI baseband file format header.

Parameters

***args**
[str or iterable] If a string, parsed as a GUPPI header from a file, otherwise as for the `astropy.io.fits.Header` baseclass.

verify
[bool, optional] Whether to do minimal verification that the header is consistent with the GUPPI standard. Default: `True`.

mutable
[bool, optional] Whether to allow the header to be changed after initialisation. Default: `True`.

****kwargs**
Any further header keywords to be set.

Notes

Like `Header`, the initialiser does not accept keyword arguments to populate an array - instead, one must pass an iterable. In order to ensure keywords are kept in the right order, one should pass on values as a tuple, not as a dict. E.g., to copy a header, one should not do `GUPPIHeader({key: header[key] for key in header})`, but rather:

```
GUPPIHeader(((key, header[key]) for key in header))
```

or, to also keep the comments:

```
GUPPIHeader(((key, (header[key], header.comments[key]))
             for key in header))
```

Attributes Summary

`bps`	Bits per elementary sample.
`cards`	The underlying physical cards that make up this Header; it can be looked at, but it should not be modified directly.
`channels_first`	True if encoded payload ordering is (nchan, nsample, npol).
`comments`	View the comments associated with each keyword, if any.
`complex_data`	Whether the data are complex.
`frame_nbytes`	Size of the frame in bytes.
`nbytes`	Size of the header in bytes.
`nchan`	Number of channels.
`npol`	Number of polarisations.
`offset`	Offset from start of observation in units of time.
`overlap`	Number of complete samples that overlap with the next frame.
`payload_nbytes`	Size of the payload in bytes.
`sample_rate`	Number of complete samples per second.

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Table 5 – continued from previous page

sample_shape	Shape of a sample in the payload (npol, nchan).
samples_per_frame	Number of complete samples in the frame, including overlap.
sideband	True if upper sideband.
start_time	Start time of the observation.
time	Start time of the part of the observation covered by this header.

Methods Summary

add_blank(self[, value, before, after])	Add a blank card.
add_comment(self, value[, before, after])	Add a COMMENT card.
add_history(self, value[, before, after])	Add a HISTORY card.
append(self[, card, useblanks, bottom, end])	Appends a new keyword+value card to the end of the Header, similar to list.append.
clear(self)	Remove all cards from the header.
copy(self)	Create a mutable and independent copy of the header.
count(self, keyword)	Returns the count of the given keyword in the header, similar to list.count if the Header object is treated as a list of keywords.
extend(self, cards[, strip, unique, update, . . .])	Appends multiple keyword+value cards to the end of the header, similar to list.extend.
fromfile(fh[, verify])	Reads in GUPPI header block from a file.
fromkeys(*args[, verify, mutable])	Initialise a header from keyword values.
fromstring(data[, sep])	Creates an HDU header from a byte string containing the entire header data.
fromtextfile(fileobj[, endcard])	Read a header from a simple text file or file-like object.
fromvalues(**kwargs)	Initialise a header from parsed values.
get(self, key[, default])	Similar to dict.get()–returns the value associated with keyword in the header, or a default value if the keyword is not found.
index(self, keyword[, start, stop])	Returns the index if the first instance of the given keyword in the header, similar to list.index if the Header object is treated as a list of keywords.
insert(self, key, card[, useblanks, after])	Inserts a new keyword+value card into the Header at a given location, similar to list.insert.
items(self)	Like dict.items().
keys(self)	Like dict.keys()–iterating directly over the Header instance has the same behavior.
pop(self, *args)	Works like list.pop() if no arguments or an index argument are supplied; otherwise works like dict.pop().
popitem(self)	Similar to dict.popitem().
remove(self, keyword[, ignore_missing, . . .])	Removes the first instance of the given keyword from the header similar to list.remove if the Header object is treated as a list of keywords.
rename_keyword(self, oldkeyword, newkeyword)	Rename a card’s keyword in the header.
set(self, keyword[, value, comment, before, . . .])	Set the value and/or comment and/or position of a specified keyword.

Continued on next page

Table 6 – continued from previous page

setdefault(self, key[, default])	Similar to dict.setdefault().
tofile(self, fh)	Write GUPPI file header to filehandle.
tostring(self[, sep, endcard, padding])	Returns a string representation of the header.
totextfile(self, fileobj[, endcard, overwrite])	Write the header as text to a file or a file-like object.
update(self, *[, verify])	Update the header with new values.
values(self)	Like dict.values().
verify(self)	Basic check of integrity.

Attributes Documentation

bps
Bits per elementary sample.

cards
The underlying physical cards that make up this Header; it can be looked at, but it should not be modified directly.

channels_first
True if encoded payload ordering is (nchan, nsample, npol).

comments
View the comments associated with each keyword, if any.

For example, to see the comment on the NAXIS keyword:

```
>>> header.comments['NAXIS']
number of data axes
```

Comments can also be updated through this interface:

```
>>> header.comments['NAXIS'] = 'Number of data axes'
```

complex_data
Whether the data are complex.

frame_nbytes
Size of the frame in bytes.

nbytes
Size of the header in bytes.

nchan
Number of channels.

npol
Number of polarisations.

offset
Offset from start of observation in units of time.

overlap
Number of complete samples that overlap with the next frame.

payload_nbytes
Size of the payload in bytes.

sample_rate
Number of complete samples per second.

Can be set with a negative quantity to set sideband. Overlap samples are not included in the rate.

`sample_shape`
Shape of a sample in the payload (npol, nchan).

`samples_per_frame`
Number of complete samples in the frame, including overlap.

`sideband`
True if upper sideband.

`start_time`
Start time of the observation.

`time`
Start time of the part of the observation covered by this header.

Methods Documentation

`add_blank`(*self*, *value=”*, *before=None*, *after=None*)
Add a blank card.

Parameters

value
[str, optional] Text to be added.

before
[str or int, optional] Same as in `Header.update`

after
[str or int, optional] Same as in `Header.update`

`add_comment`(*self*, *value*, *before=None*, *after=None*)
Add a `COMMENT` card.

Parameters

value
[str] Text to be added.

before
[str or int, optional] Same as in `Header.update`

after
[str or int, optional] Same as in `Header.update`

`add_history`(*self*, *value*, *before=None*, *after=None*)
Add a `HISTORY` card.

Parameters

value
[str] History text to be added.

before
[str or int, optional] Same as in `Header.update`

after
[str or int, optional] Same as in `Header.update`

append(*self*, *card=None*, *useblanks=True*, *bottom=False*, *end=False*)

Appends a new keyword+value card to the end of the Header, similar to `list.append`.

By default if the last cards in the Header have commentary keywords, this will append the new keyword before the commentary (unless the new keyword is also commentary).

Also differs from `list.append` in that it can be called with no arguments: In this case a blank card is appended to the end of the Header. In the case all the keyword arguments are ignored.

Parameters

card
[str, tuple] A keyword or a (keyword, value, [comment]) tuple representing a single header card; the comment is optional in which case a 2-tuple may be used

useblanks
[bool, optional] If there are blank cards at the end of the Header, replace the first blank card so that the total number of cards in the Header does not increase. Otherwise preserve the number of blank cards.

bottom
[bool, optional] If True, instead of appending after the last non-commentary card, append after the last non-blank card.

end
[bool, optional] If True, ignore the useblanks and bottom options, and append at the very end of the Header.

clear(*self*)

Remove all cards from the header.

copy(*self*)

Create a mutable and independent copy of the header.

count(*self*, *keyword*)

Returns the count of the given keyword in the header, similar to `list.count` if the Header object is treated as a list of keywords.

Parameters

keyword
[str] The keyword to count instances of in the header

extend(*self*, *cards*, *strip=True*, *unique=False*, *update=False*, *update_first=False*, *useblanks=True*, *bottom=False*, *end=False*)

Appends multiple keyword+value cards to the end of the header, similar to `list.extend`.

Parameters

cards
[iterable] An iterable of (keyword, value, [comment]) tuples; see `Header.append`.

strip
[bool, optional] Remove any keywords that have meaning only to specific types of HDUs, so that only more general keywords are added from extension Header or Card list (default: `True`).

unique
[bool, optional] If `True`, ensures that no duplicate keywords are appended; keywords al-

ready in this header are simply discarded. The exception is commentary keywords (COMMENT, HISTORY, etc.): they are only treated as duplicates if their values match.

update
[bool, optional] If `True`, update the current header with the values and comments from duplicate keywords in the input header. This supersedes the `unique` argument. Commentary keywords are treated the same as if `unique=True`.

update_first
[bool, optional] If the first keyword in the header is 'SIMPLE', and the first keyword in the input header is 'XTENSION', the 'SIMPLE' keyword is replaced by the 'XTENSION' keyword. Likewise if the first keyword in the header is 'XTENSION' and the first keyword in the input header is 'SIMPLE', the 'XTENSION' keyword is replaced by the 'SIMPLE' keyword. This behavior is otherwise dumb as to whether or not the resulting header is a valid primary or extension header. This is mostly provided to support backwards compatibility with the old `Header.fromTxtFile` method, and only applies if `update=True`.

useblanks, bottom, end
[bool, optional] These arguments are passed to `Header.append()` while appending new cards to the header.

classmethod fromfile(*fh*, *verify=True*)
Reads in GUPPI header block from a file.

Parameters

fh
[filehandle] To read data from.

verify: bool, optional
Whether to do basic checks on whether the header is valid. Verify is automatically called by `fromstring`, so this flag exists only to standardize the API.

classmethod fromkeys(**args*, *verify=True*, *mutable=True*, ***kwargs*)
Initialise a header from keyword values.

Like fromvalues, but without any interpretation of keywords.

Note that this just passes kwargs to the class initializer as a dict (for compatibility with fits.Header). It is present for compatibility with other header classes only.

classmethod fromstring(*data*, *sep=''*)
Creates an HDU header from a byte string containing the entire header data.

Parameters

data
[str or bytes] String or bytes containing the entire header. In the case of bytes they will be decoded using latin-1 (only plain ASCII characters are allowed in FITS headers but latin-1 allows us to retain any invalid bytes that might appear in malformatted FITS files).

sep
[str, optional] The string separating cards from each other, such as a newline. By default there is no card separator (as is the case in a raw FITS file). In general this is only used in cases where a header was printed as text (e.g. with newlines after each card) and you want to create a new `Header` from it by copy/pasting.

Returns

header
A new Header instance.

Examples

```
>>> from astropy.io.fits import Header
>>> hdr = Header({'SIMPLE': True})
>>> Header.fromstring(hdr.tostring()) == hdr
True
```

If you want to create a Header from printed text it's not necessary to have the exact binary structure as it would appear in a FITS file, with the full 80 byte card length. Rather, each "card" can end in a newline and does not have to be padded out to a full card length as long as it "looks like" a FITS header:

```
>>> hdr = Header.fromstring("""\
... SIMPLE  =                    T / conforms to FITS standard
... BITPIX  =                    8 / array data type
... NAXIS   =                    0 / number of array dimensions
... EXTEND  =                    T
... """, sep='\n')
>>> hdr['SIMPLE']
True
>>> hdr['BITPIX']
8
>>> len(hdr)
4
```

classmethod fromtextfile(*fileobj*, *endcard=False*)
Read a header from a simple text file or file-like object.

Equivalent to:

```
>>> Header.fromfile(fileobj, sep='\n', endcard=False,
...                 padding=False)
```

See also:

`fromfile`

classmethod fromvalues(***kwargs*)
Initialise a header from parsed values.

Here, the parsed values must be given as keyword arguments, i.e., for any header, `cls.fromvalues(**header) == header`.

However, unlike for the `fromkeys` class method, data can also be set using arguments named after header methods, such as `time`.

Furthermore, some header defaults are set in `GUPPIHeader._defaults`.

get(*self*, *key*, *default=None*)
Similar to `dict.get()`–returns the value associated with keyword in the header, or a default value if the keyword is not found.

Parameters

key
[str] A keyword that may or may not be in the header.

default
[optional] A default value to return if the keyword is not found in the header.

Returns

value
The value associated with the given keyword, or the default value if the keyword is not in the header.

`index`(*self*, *keyword*, *start=None*, *stop=None*)
Returns the index if the first instance of the given keyword in the header, similar to `list.index` if the Header object is treated as a list of keywords.

Parameters

keyword
[str] The keyword to look up in the list of all keywords in the header

start
[int, optional] The lower bound for the index

stop
[int, optional] The upper bound for the index

`insert`(*self*, *key*, *card*, *useblanks=True*, *after=False*)
Inserts a new keyword+value card into the Header at a given location, similar to `list.insert`.

Parameters

key
[int, str, or tuple] The index into the list of header keywords before which the new keyword should be inserted, or the name of a keyword before which the new keyword should be inserted. Can also accept a (keyword, index) tuple for inserting around duplicate keywords.

card
[str, tuple] A keyword or a (keyword, value, [comment]) tuple; see `Header.append`

useblanks
[bool, optional] If there are blank cards at the end of the Header, replace the first blank card so that the total number of cards in the Header does not increase. Otherwise preserve the number of blank cards.

after
[bool, optional] If set to `True`, insert *after* the specified index or keyword, rather than before it. Defaults to `False`.

`items`(*self*)
Like `dict.items()`.

`keys`(*self*)
Like `dict.keys()`–iterating directly over the `Header` instance has the same behavior.

`pop`(*self*, **args*)
Works like `list.pop()` if no arguments or an index argument are supplied; otherwise works like `dict.pop()`.

popitem(*self*)
Similar to `dict.popitem()`.

remove(*self*, *keyword*, *ignore_missing=False*, *remove_all=False*)
Removes the first instance of the given keyword from the header similar to `list.remove` if the Header object is treated as a list of keywords.

Parameters

keyword
[str] The keyword of which to remove the first instance in the header.

ignore_missing
[bool, optional] When True, ignores missing keywords. Otherwise, if the keyword is not present in the header a KeyError is raised.

remove_all
[bool, optional] When True, all instances of keyword will be removed. Otherwise only the first instance of the given keyword is removed.

rename_keyword(*self*, *oldkeyword*, *newkeyword*, *force=False*)
Rename a card's keyword in the header.

Parameters

oldkeyword
[str or int] Old keyword or card index

newkeyword
[str] New keyword

force
[bool, optional] When `True`, if the new keyword already exists in the header, force the creation of a duplicate keyword. Otherwise a `ValueError` is raised.

set(*self*, *keyword*, *value=None*, *comment=None*, *before=None*, *after=None*)
Set the value and/or comment and/or position of a specified keyword.

If the keyword does not already exist in the header, a new keyword is created in the specified position, or appended to the end of the header if no position is specified.

This method is similar to `Header.update()` prior to Astropy v0.1.

Note: It should be noted that `header.set(keyword, value)` and `header.set(keyword, value, comment)` are equivalent to `header[keyword] = value` and `header[keyword] = (value, comment)` respectively.

New keywords can also be inserted relative to existing keywords using, for example:

```
>>> header.insert('NAXIS1', ('NAXIS', 2, 'Number of axes'))
```

to insert before an existing keyword, or:

```
>>> header.insert('NAXIS', ('NAXIS1', 4096), after=True)
```

to insert after an existing keyword.

The only advantage of using `Header.set()` is that it easily replaces the old usage of `Header.update()` both conceptually and in terms of function signature.

Parameters

keyword
[str] A header keyword

value
[str, optional] The value to set for the given keyword; if None the existing value is kept, but ‘’ may be used to set a blank value

comment
[str, optional] The comment to set for the given keyword; if None the existing comment is kept, but `''` may be used to set a blank comment

before
[str, int, optional] Name of the keyword, or index of the `Card` before which this card should be located in the header. The argument `before` takes precedence over `after` if both specified.

after
[str, int, optional] Name of the keyword, or index of the `Card` after which this card should be located in the header.

`setdefault`(*self*, *key*, *default=None*)
Similar to `dict.setdefault()`.

`tofile`(*self*, *fh*)
Write GUPPI file header to filehandle.

Uses `tostring`.

`tostring`(*self*, *sep=”*, *endcard=True*, *padding=True*)
Returns a string representation of the header.

By default this uses no separator between cards, adds the END card, and pads the string with spaces to the next multiple of 2880 bytes. That is, it returns the header exactly as it would appear in a FITS file.

Parameters

sep
[str, optional] The character or string with which to separate cards. By default there is no separator, but one could use `'\\n'`, for example, to separate each card with a new line

endcard
[bool, optional] If True (default) adds the END card to the end of the header string

padding
[bool, optional] If True (default) pads the string with spaces out to the next multiple of 2880 characters

Returns

s
[str] A string representing a FITS header.

`totextfile`(*self*, *fileobj*, *endcard=False*, *overwrite=False*)
Write the header as text to a file or a file-like object.

Equivalent to:

```
>>> Header.tofile(fileobj, sep='\n', endcard=False,
...               padding=False, overwrite=overwrite)
```

Changed in version 1.3: `overwrite` replaces the deprecated `clobber` argument.

See also:

`tofile`

update(*self*, ***, *verify=True*, ***kwargs*)

Update the header with new values.

Here, any keywords matching properties are processed as well, in the order set by the class (in `_properties`), and after all other keywords have been processed.

Parameters

verify
[bool, optional] If `True` (default), verify integrity after updating.

****kwargs**
Arguments used to set keywords and properties.

values(*self*)

Like `dict.values()`.

verify(*self*)

Basic check of integrity.

GUPPIPayload

class baseband.guppi.**GUPPIPayload**(*words*, *header=None*, *sample_shape=()*, *bps=8*, *complex_data=False*, *channels_first=True*)

Bases: `baseband.vlbi_base.payload.VLBIPayloadBase`

Container for decoding and encoding GUPPI payloads.

Parameters

words
[`ndarray`] Array containg LSB unsigned words (with the right size) that encode the payload.

header
[`GUPPIHeader`] Header that provides information about how the payload is encoded. If not given, the following arguments have to be passed in.

bps
[int, optional] Number of bits per sample part (i.e., per channel and per real or imaginary component). Default: 8.

sample_shape
[tuple, optional] Shape of the samples; e.g., (nchan,). Default: ().

complex_data
[bool, optional] Whether data are complex. Default: `False`.

channels_first
[bool, optional] Whether the encoded payload is stored as (nchan, nsample, npol), rather than (nsample, nchan, npol). Default: `True`.

Attributes Summary

`data`	Full decoded payload.
`dtype`	Numeric type of the decoded data array.
`nbytes`	Size of the payload in bytes.
`ndim`	Number of dimensions of the decoded data array.
`shape`	Shape of the decoded data array.
`size`	Total number of component samples in the decoded data array.

Methods Summary

`fromdata`(data[, header, bps, channels_first])	Encode data as a payload.
`fromfile`(fh[, header, memmap, payload_nbytes])	Read or map encoded data in file.
`tofile`(self, fh)	Write payload to filehandle.

Attributes Documentation

`data`
Full decoded payload.

`dtype`
Numeric type of the decoded data array.

`nbytes`
Size of the payload in bytes.

`ndim`
Number of dimensions of the decoded data array.

`shape`
Shape of the decoded data array.

`size`
Total number of component samples in the decoded data array.

Methods Documentation

`classmethod fromdata`(*data*, *header=None*, *bps=8*, *channels_first=True*)
Encode data as a payload.

Parameters

data
[`ndarray`] Data to be encoded. The last dimension is taken as the number of channels.

header
[`GUPPIHeader`, optional] If given, used to infer the `bps` and `channels_first`.

bps
[int, optional] Bits per elementary sample, used if `header` is `None`. Default: 8.

channels_first
[bool, optional] Whether encoded data should be ordered as (nchan, nsample, npol), used if `header` is `None`. Default: `True`.

classmethod fromfile(*fh*, *header=None*, *memmap=False*, *payload_nbytes=None*, ***kwargs*)
Read or map encoded data in file.

Parameters

fh
[filehandle] Handle to the file which will be read or mapped.

header
[`GUPPIHeader`, optional] If given, used to infer `payload_nbytes`, `bps`, `sample_shape`, `complex_data` and `channels_first`. If not given, those have to be passed in.

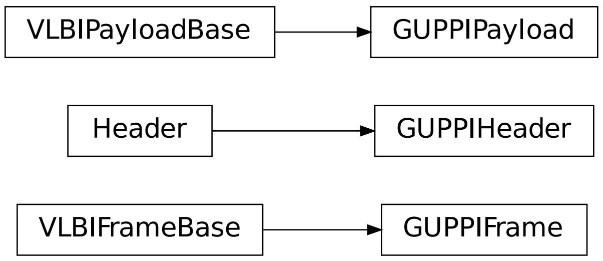
memmap
[bool, optional] If `False` (default), read from file. Otherwise, map the file in memory (see `memmap`).

payload_nbytes
[int, optional] Number of bytes to read (default: as given in `header`, `cls._nbytes`, or, for mapping, to the end of the file).

****kwargs**
Additional arguments are passed on to the class initializer. These are only needed if `header` is not given.

tofile(*self*, *fh*)
Write payload to filehandle.

Class Inheritance Diagram



9.3.2 baseband.guppi.header Module

Definitions for GUPPI headers.

Implements a GUPPIHeader class that reads & writes FITS-like headers from file.

Classes

GUPPIHeader(*args[, verify, mutable])	GUPPI baseband file format header.

GUPPIHeader

class baseband.guppi.header.**GUPPIHeader**(**args*, *verify=True*, *mutable=True*, ***kwargs*)

Bases: astropy.io.fits.Header

GUPPI baseband file format header.

Parameters

***args**
[str or iterable] If a string, parsed as a GUPPI header from a file, otherwise as for the astropy.io.fits.Header baseclass.

verify
[bool, optional] Whether to do minimal verification that the header is consistent with the GUPPI standard. Default: True.

mutable
[bool, optional] Whether to allow the header to be changed after initialisation. Default: True.

****kwargs**
Any further header keywords to be set.

Notes

Like Header, the initialiser does not accept keyword arguments to populate an array - instead, one must pass an iterable. In order to ensure keywords are kept in the right order, one should pass on values as a tuple, not as a dict. E.g., to copy a header, one should not do `GUPPIHeader({key: header[key] for key in header})`, but rather:

```
GUPPIHeader(((key, header[key]) for key in header))
```

or, to also keep the comments:

```
GUPPIHeader(((key, (header[key], header.comments[key]))
             for key in header))
```

Attributes Summary

bps	Bits per elementary sample.
cards	The underlying physical cards that make up this Header; it can be looked at, but it should not be modified directly.
channels_first	True if encoded payload ordering is (nchan, nsample, npol).

Continued on next page

Table 10 – continued from previous page

comments	View the comments associated with each keyword, if any.
complex_data	Whether the data are complex.
frame_nbytes	Size of the frame in bytes.
nbytes	Size of the header in bytes.
nchan	Number of channels.
npol	Number of polarisations.
offset	Offset from start of observation in units of time.
overlap	Number of complete samples that overlap with the next frame.
payload_nbytes	Size of the payload in bytes.
sample_rate	Number of complete samples per second.
sample_shape	Shape of a sample in the payload (npol, nchan).
samples_per_frame	Number of complete samples in the frame, including overlap.
sideband	True if upper sideband.
start_time	Start time of the observation.
time	Start time of the part of the observation covered by this header.

Methods Summary

add_blank(self[, value, before, after])	Add a blank card.
add_comment(self, value[, before, after])	Add a COMMENT card.
add_history(self, value[, before, after])	Add a HISTORY card.
append(self[, card, useblanks, bottom, end])	Appends a new keyword+value card to the end of the Header, similar to list.append.
clear(self)	Remove all cards from the header.
copy(self)	Create a mutable and independent copy of the header.
count(self, keyword)	Returns the count of the given keyword in the header, similar to list.count if the Header object is treated as a list of keywords.
extend(self, cards[, strip, unique, update, . . .])	Appends multiple keyword+value cards to the end of the header, similar to list.extend.
fromfile(fh[, verify])	Reads in GUPPI header block from a file.
fromkeys(*args[, verify, mutable])	Initialise a header from keyword values.
fromstring(data[, sep])	Creates an HDU header from a byte string containing the entire header data.
fromtextfile(fileobj[, endcard])	Read a header from a simple text file or file-like object.
fromvalues(**kwargs)	Initialise a header from parsed values.
get(self, key[, default])	Similar to dict.get()–returns the value associated with keyword in the header, or a default value if the keyword is not found.
index(self, keyword[, start, stop])	Returns the index if the first instance of the given keyword in the header, similar to list.index if the Header object is treated as a list of keywords.
insert(self, key, card[, useblanks, after])	Inserts a new keyword+value card into the Header at a given location, similar to list.insert.
items(self)	Like dict.items().

Continued on next page

Table 11 – continued from previous page

keys(self)	Like dict.keys()–iterating directly over the Header instance has the same behavior.
pop(self, *args)	Works like list.pop() if no arguments or an index argument are supplied; otherwise works like dict.pop().
popitem(self)	Similar to dict.popitem().
remove(self, keyword[, ignore_missing, . . .])	Removes the first instance of the given keyword from the header similar to list.remove if the Header object is treated as a list of keywords.
rename_keyword(self, oldkeyword, newkeyword)	Rename a card's keyword in the header.
set(self, keyword[, value, comment, before, . . .])	Set the value and/or comment and/or position of a specified keyword.
setdefault(self, key[, default])	Similar to dict.setdefault().
tofile(self, fh)	Write GUPPI file header to filehandle.
tostring(self[, sep, endcard, padding])	Returns a string representation of the header.
totextfile(self, fileobj[, endcard, overwrite])	Write the header as text to a file or a file-like object.
update(self, *[, verify])	Update the header with new values.
values(self)	Like dict.values().
verify(self)	Basic check of integrity.

Attributes Documentation

bps
Bits per elementary sample.

cards
The underlying physical cards that make up this Header; it can be looked at, but it should not be modified directly.

channels_first
True if encoded payload ordering is (nchan, nsample, npol).

comments
View the comments associated with each keyword, if any.

For example, to see the comment on the NAXIS keyword:

```
>>> header.comments['NAXIS']
number of data axes
```

Comments can also be updated through this interface:

```
>>> header.comments['NAXIS'] = 'Number of data axes'
```

complex_data
Whether the data are complex.

frame_nbytes
Size of the frame in bytes.

nbytes
Size of the header in bytes.

nchan
Number of channels.

`npol`
Number of polarisations.

`offset`
Offset from start of observation in units of time.

`overlap`
Number of complete samples that overlap with the next frame.

`payload_nbytes`
Size of the payload in bytes.

`sample_rate`
Number of complete samples per second.

Can be set with a negative quantity to set `sideband`. Overlap samples are not included in the rate.

`sample_shape`
Shape of a sample in the payload (npol, nchan).

`samples_per_frame`
Number of complete samples in the frame, including overlap.

`sideband`
True if upper sideband.

`start_time`
Start time of the observation.

`time`
Start time of the part of the observation covered by this header.

Methods Documentation

`add_blank`(*self*, *value=”*, *before=None*, *after=None*)
Add a blank card.

Parameters

value
[str, optional] Text to be added.

before
[str or int, optional] Same as in `Header.update`

after
[str or int, optional] Same as in `Header.update`

`add_comment`(*self*, *value*, *before=None*, *after=None*)
Add a `COMMENT` card.

Parameters

value
[str] Text to be added.

before
[str or int, optional] Same as in `Header.update`

after
[str or int, optional] Same as in `Header.update`

add_history(*self*, *value*, *before=None*, *after=None*)
Add a `HISTORY` card.

Parameters

value
[str] History text to be added.

before
[str or int, optional] Same as in `Header.update`

after
[str or int, optional] Same as in `Header.update`

append(*self*, *card=None*, *useblanks=True*, *bottom=False*, *end=False*)
Appends a new keyword+value card to the end of the Header, similar to `list.append`.

By default if the last cards in the Header have commentary keywords, this will append the new keyword before the commentary (unless the new keyword is also commentary).

Also differs from `list.append` in that it can be called with no arguments: In this case a blank card is appended to the end of the Header. In the case all the keyword arguments are ignored.

Parameters

card
[str, tuple] A keyword or a (keyword, value, [comment]) tuple representing a single header card; the comment is optional in which case a 2-tuple may be used

useblanks
[bool, optional] If there are blank cards at the end of the Header, replace the first blank card so that the total number of cards in the Header does not increase. Otherwise preserve the number of blank cards.

bottom
[bool, optional] If True, instead of appending after the last non-commentary card, append after the last non-blank card.

end
[bool, optional] If True, ignore the useblanks and bottom options, and append at the very end of the Header.

clear(*self*)
Remove all cards from the header.

copy(*self*)
Create a mutable and independent copy of the header.

count(*self*, *keyword*)
Returns the count of the given keyword in the header, similar to `list.count` if the Header object is treated as a list of keywords.

Parameters

keyword
[str] The keyword to count instances of in the header

extend(*self*, *cards*, *strip=True*, *unique=False*, *update=False*, *update_first=False*, *useblanks=True*, *bottom=False*, *end=False*)
Appends multiple keyword+value cards to the end of the header, similar to `list.extend`.

Parameters

cards
[iterable] An iterable of (keyword, value, [comment]) tuples; see `Header.append`.

strip
[bool, optional] Remove any keywords that have meaning only to specific types of HDUs, so that only more general keywords are added from extension Header or Card list (default: `True`).

unique
[bool, optional] If `True`, ensures that no duplicate keywords are appended; keywords already in this header are simply discarded. The exception is commentary keywords (COMMENT, HISTORY, etc.): they are only treated as duplicates if their values match.

update
[bool, optional] If `True`, update the current header with the values and comments from duplicate keywords in the input header. This supersedes the `unique` argument. Commentary keywords are treated the same as if `unique=True`.

update_first
[bool, optional] If the first keyword in the header is 'SIMPLE', and the first keyword in the input header is 'XTENSION', the 'SIMPLE' keyword is replaced by the 'XTENSION' keyword. Likewise if the first keyword in the header is 'XTENSION' and the first keyword in the input header is 'SIMPLE', the 'XTENSION' keyword is replaced by the 'SIMPLE' keyword. This behavior is otherwise dumb as to whether or not the resulting header is a valid primary or extension header. This is mostly provided to support backwards compatibility with the old `Header.fromTxtFile` method, and only applies if `update=True`.

useblanks, bottom, end
[bool, optional] These arguments are passed to `Header.append()` while appending new cards to the header.

classmethod fromfile(*fh*, *verify=True*)
Reads in GUPPI header block from a file.

Parameters

fh
[filehandle] To read data from.

verify: bool, optional
Whether to do basic checks on whether the header is valid. Verify is automatically called by `fromstring`, so this flag exists only to standardize the API.

classmethod fromkeys(**args*, *verify=True*, *mutable=True*, ***kwargs*)
Initialise a header from keyword values.

Like fromvalues, but without any interpretation of keywords.

Note that this just passes kwargs to the class initializer as a dict (for compatibility with fits.Header). It is present for compatibility with other header classes only.

classmethod fromstring(*data*, *sep=''*)
Creates an HDU header from a byte string containing the entire header data.

Parameters

data
[str or bytes] String or bytes containing the entire header. In the case of bytes they will be decoded using latin-1 (only plain ASCII characters are allowed in FITS headers but latin-1 allows us to retain any invalid bytes that might appear in malformatted FITS files).

sep
[str, optional] The string separating cards from each other, such as a newline. By default there is no card separator (as is the case in a raw FITS file). In general this is only used in cases where a header was printed as text (e.g. with newlines after each card) and you want to create a new `Header` from it by copy/pasting.

Returns

header
A new `Header` instance.

Examples

```
>>> from astropy.io.fits import Header
>>> hdr = Header({'SIMPLE': True})
>>> Header.fromstring(hdr.tostring()) == hdr
True
```

If you want to create a `Header` from printed text it's not necessary to have the exact binary structure as it would appear in a FITS file, with the full 80 byte card length. Rather, each "card" can end in a newline and does not have to be padded out to a full card length as long as it "looks like" a FITS header:

```
>>> hdr = Header.fromstring("""\
... SIMPLE  =                    T / conforms to FITS standard
... BITPIX  =                    8 / array data type
... NAXIS   =                    0 / number of array dimensions
... EXTEND  =                    T
... """, sep='\n')
>>> hdr['SIMPLE']
True
>>> hdr['BITPIX']
8
>>> len(hdr)
4
```

classmethod fromtextfile(*fileobj*, *endcard=False*)
Read a header from a simple text file or file-like object.

Equivalent to:

```
>>> Header.fromfile(fileobj, sep='\n', endcard=False,
...                 padding=False)
```

See also:

`fromfile`

classmethod fromvalues(***kwargs*)
Initialise a header from parsed values.

Here, the parsed values must be given as keyword arguments, i.e., for any `header`, `cls.fromvalues(**header) == header`.

However, unlike for the `fromkeys` class method, data can also be set using arguments named after header methods, such as `time`.

Furthermore, some header defaults are set in `GUPPIHeader._defaults`.

get(*self*, *key*, *default=None*)
Similar to `dict.get()`–returns the value associated with keyword in the header, or a default value if the keyword is not found.

Parameters

key
[str] A keyword that may or may not be in the header.

default
[optional] A default value to return if the keyword is not found in the header.

Returns

value
The value associated with the given keyword, or the default value if the keyword is not in the header.

index(*self*, *keyword*, *start=None*, *stop=None*)
Returns the index if the first instance of the given keyword in the header, similar to `list.index` if the Header object is treated as a list of keywords.

Parameters

keyword
[str] The keyword to look up in the list of all keywords in the header

start
[int, optional] The lower bound for the index

stop
[int, optional] The upper bound for the index

insert(*self*, *key*, *card*, *useblanks=True*, *after=False*)
Inserts a new keyword+value card into the Header at a given location, similar to `list.insert`.

Parameters

key
[int, str, or tuple] The index into the list of header keywords before which the new keyword should be inserted, or the name of a keyword before which the new keyword should be inserted. Can also accept a (keyword, index) tuple for inserting around duplicate keywords.

card
[str, tuple] A keyword or a (keyword, value, [comment]) tuple; see `Header.append`

useblanks
[bool, optional] If there are blank cards at the end of the Header, replace the first blank card so that the total number of cards in the Header does not increase. Otherwise preserve the number of blank cards.

after
[bool, optional] If set to `True`, insert *after* the specified index or keyword, rather than before it. Defaults to `False`.

`items`(*self*)
Like `dict.items()`.

`keys`(*self*)
Like `dict.keys()`–iterating directly over the `Header` instance has the same behavior.

`pop`(*self*, **args*)
Works like `list.pop()` if no arguments or an index argument are supplied; otherwise works like `dict.pop()`.

`popitem`(*self*)
Similar to `dict.popitem()`.

`remove`(*self*, *keyword*, *ignore_missing=False*, *remove_all=False*)
Removes the first instance of the given keyword from the header similar to `list.remove` if the Header object is treated as a list of keywords.

Parameters

keyword
[str] The keyword of which to remove the first instance in the header.

ignore_missing
[bool, optional] When True, ignores missing keywords. Otherwise, if the keyword is not present in the header a KeyError is raised.

remove_all
[bool, optional] When True, all instances of keyword will be removed. Otherwise only the first instance of the given keyword is removed.

`rename_keyword`(*self*, *oldkeyword*, *newkeyword*, *force=False*)
Rename a card's keyword in the header.

Parameters

oldkeyword
[str or int] Old keyword or card index

newkeyword
[str] New keyword

force
[bool, optional] When `True`, if the new keyword already exists in the header, force the creation of a duplicate keyword. Otherwise a `ValueError` is raised.

`set`(*self*, *keyword*, *value=None*, *comment=None*, *before=None*, *after=None*)
Set the value and/or comment and/or position of a specified keyword.

If the keyword does not already exist in the header, a new keyword is created in the specified position, or appended to the end of the header if no position is specified.

This method is similar to `Header.update()` prior to Astropy v0.1.

Note: It should be noted that `header.set(keyword, value)` and `header.set(keyword, value, comment)` are equivalent to `header[keyword] = value` and `header[keyword] = (value, comment)` respectively.

New keywords can also be inserted relative to existing keywords using, for example:

```
>>> header.insert('NAXIS1', ('NAXIS', 2, 'Number of axes'))
```

to insert before an existing keyword, or:

```
>>> header.insert('NAXIS', ('NAXIS1', 4096), after=True)
```

to insert after an existing keyword.

The only advantage of using `Header.set()` is that it easily replaces the old usage of `Header.update()` both conceptually and in terms of function signature.

Parameters

keyword
[str] A header keyword

value
[str, optional] The value to set for the given keyword; if None the existing value is kept, but '' may be used to set a blank value

comment
[str, optional] The comment to set for the given keyword; if None the existing comment is kept, but `''` may be used to set a blank comment

before
[str, int, optional] Name of the keyword, or index of the `Card` before which this card should be located in the header. The argument `before` takes precedence over `after` if both specified.

after
[str, int, optional] Name of the keyword, or index of the `Card` after which this card should be located in the header.

`setdefault`(*self*, *key*, *default=None*)
Similar to `dict.setdefault()`.

`tofile`(*self*, *fh*)
Write GUPPI file header to filehandle.

Uses `tostring`.

`tostring`(*self*, *sep=''*, *endcard=True*, *padding=True*)
Returns a string representation of the header.

By default this uses no separator between cards, adds the END card, and pads the string with spaces to the next multiple of 2880 bytes. That is, it returns the header exactly as it would appear in a FITS file.

Parameters

sep
[str, optional] The character or string with which to separate cards. By default there is no separator, but one could use `'\\n'`, for example, to separate each card with a new line

endcard
[bool, optional] If True (default) adds the END card to the end of the header string

padding
[bool, optional] If True (default) pads the string with spaces out to the next multiple of 2880 characters

Returns

s
[str] A string representing a FITS header.

totextfile(*self*, *fileobj*, *endcard=False*, *overwrite=False*)
Write the header as text to a file or a file-like object.

Equivalent to:

```
>>> Header.tofile(fileobj, sep='\n', endcard=False,
...               padding=False, overwrite=overwrite)
```

Changed in version 1.3: `overwrite` replaces the deprecated `clobber` argument.

See also:

`tofile`

update(*self*, ***, *verify=True*, ***kwargs*)
Update the header with new values.

Here, any keywords matching properties are processed as well, in the order set by the class (in `_properties`), and after all other keywords have been processed.

Parameters

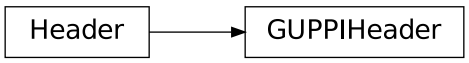
verify
[bool, optional] If `True` (default), verify integrity after updating.

****kwargs**
Arguments used to set keywords and properties.

values(*self*)
Like `dict.values()`.

verify(*self*)
Basic check of integrity.

Class Inheritance Diagram



9.3.3 baseband.guppi.payload Module

Payload for GUPPI format.

Classes

`GUPPIPayload`(words[, header, sample_shape, . . .])	Container for decoding and encoding GUPPI payloads.

GUPPIPayload

class baseband.guppi.payload.**GUPPIPayload**(*words*, *header=None*, *sample_shape=()*, *bps=8*, *complex_data=False*, *channels_first=True*)

Bases: `baseband.vlbi_base.payload.VLBIPayloadBase`

Container for decoding and encoding GUPPI payloads.

Parameters

words
[`ndarray`] Array containg LSB unsigned words (with the right size) that encode the payload.

header
[`GUPPIHeader`] Header that provides information about how the payload is encoded. If not given, the following arguments have to be passed in.

bps
[int, optional] Number of bits per sample part (i.e., per channel and per real or imaginary component). Default: 8.

sample_shape
[tuple, optional] Shape of the samples; e.g., (nchan,). Default: ().

complex_data
[bool, optional] Whether data are complex. Default: `False`.

channels_first
[bool, optional] Whether the encoded payload is stored as (nchan, nsample, npol), rather than (nsample, nchan, npol). Default: `True`.

Attributes Summary

`data`	Full decoded payload.
`dtype`	Numeric type of the decoded data array.
`nbytes`	Size of the payload in bytes.
`ndim`	Number of dimensions of the decoded data array.
`shape`	Shape of the decoded data array.
`size`	Total number of component samples in the decoded data array.

Methods Summary

fromdata(data[, header, bps, channels_first])	Encode data as a payload.
fromfile(fh[, header, memmap, payload_nbytes])	Read or map encoded data in file.
tofile(self, fh)	Write payload to filehandle.

Attributes Documentation

data
Full decoded payload.

dtype
Numeric type of the decoded data array.

nbytes
Size of the payload in bytes.

ndim
Number of dimensions of the decoded data array.

shape
Shape of the decoded data array.

size
Total number of component samples in the decoded data array.

Methods Documentation

classmethod fromdata(*data*, *header=None*, *bps=8*, *channels_first=True*)
Encode data as a payload.

Parameters

data
[ndarray] Data to be encoded. The last dimension is taken as the number of channels.

header
[GUPPIHeader, optional] If given, used to infer the bps and `channels_first`.

bps
[int, optional] Bits per elementary sample, used if `header` is `None`. Default: 8.

channels_first
[bool, optional] Whether encoded data should be ordered as (nchan, nsample, npol), used if `header` is `None`. Default: `True`.

classmethod fromfile(*fh*, *header=None*, *memmap=False*, *payload_nbytes=None*, ***kwargs*)
Read or map encoded data in file.

Parameters

fh
[filehandle] Handle to the file which will be read or mapped.

header
[GUPPIHeader, optional] If given, used to infer `payload_nbytes`, `bps`, `sample_shape`, `complex_data` and `channels_first`. If not given, those have to be passed in.

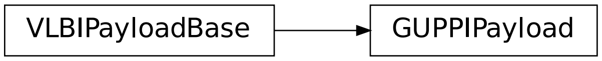
memmap
[bool, optional] If `False` (default), read from file. Otherwise, map the file in memory (see `memmap`).

payload_nbytes
[int, optional] Number of bytes to read (default: as given in `header`, `cls._nbytes`, or, for mapping, to the end of the file).

****kwargs**
Additional arguments are passed on to the class initializer. These are only needed if `header` is not given.

tofile(*self*, *fh*)
Write payload to filehandle.

Class Inheritance Diagram



9.3.4 baseband.guppi.frame Module

Classes

`GUPPIFrame`(header, payload[, valid, verify])	Representation of a GUPPI file, consisting of a header and payload.

GUPPIFrame

class `baseband.guppi.frame.`**GUPPIFrame**(*header*, *payload*, *valid=True*, *verify=True*)
Bases: `baseband.vlbi_base.frame.VLBIFrameBase`

Representation of a GUPPI file, consisting of a header and payload.

Parameters

header
[`GUPPIHeader`] Wrapper around the header lines, providing access to the values.

payload
[`GUPPIPayload`] Wrapper around the payload, provding mechanisms to decode it.

valid
[bool, optional] Whether the data are valid. Default: `True`.

verify
[bool, optional] Whether to do basic verification of integrity. Default: `True`.

Notes

GUPPI files do not support storing whether data are valid or not on disk. Hence, this has to be determined independently. If `valid=False`, any decoded data are set to `cls.fill_value` (by default, 0).

The Frame can also be instantiated using class methods:

fromfile : read header and and map or read payload from a filehandle

fromdata : encode data as payload

Of course, one can also do the opposite:

tofile : method to write header and payload to filehandle

data : property that yields full decoded payload

One can decode part of the payload by indexing or slicing the frame.

A number of properties are defined: `shape`, `dtype` and `size` are the shape, type and number of complete samples of the data array, and `nbytes` the frame size in bytes. Furthermore, the frame acts as a dictionary, with keys those of the header. Any attribute that is not defined on the frame itself, such as `.time` will be looked up on the header as well.

Attributes Summary

`data`	Full decoded frame.
`dtype`	Numeric type of the frame data.
`fill_value`	Value to replace invalid data in the frame.
`nbytes`	Size of the encoded frame in bytes.
`ndim`	Number of dimensions of the frame data.
`sample_shape`	Shape of a sample in the frame (nchan,).
`shape`	Shape of the frame data.
`size`	Total number of component samples in the frame data.
`valid`	Whether frame contains valid data.

Methods Summary

`fromdata`(data[, header, valid, verify])	Construct frame from data and header.
`fromfile`(fh[, memmap, valid, verify])	Read a frame from a filehandle, possible mapping the payload.
`keys`(self)	
`tofile`(self, fh)	Write encoded frame to filehandle.
`verify`(self)	Simple verification.

Attributes Documentation

`data`
Full decoded frame.

`dtype`
Numeric type of the frame data.

`fill_value`
Value to replace invalid data in the frame.

nbytes
Size of the encoded frame in bytes.

ndim
Number of dimensions of the frame data.

sample_shape
Shape of a sample in the frame (nchan,).

shape
Shape of the frame data.

size
Total number of component samples in the frame data.

valid
Whether frame contains valid data.

Methods Documentation

classmethod fromdata(*data*, *header=None*, *valid=True*, *verify=True*, ***kwargs*)
Construct frame from data and header.

Note that since GUPPI files are generally very large, one would normally map the file, and then set pieces of it by assigning to slices of the frame. See `memmap_frame`.

Parameters

data
[`ndarray`] Array holding complex or real data to be encoded.

header
[`GUPPIHeader` or None, optional] If not given, will attempt to generate one using the keywords.

valid
[bool, optional] Whether the data are valid (default: `True`). Note that this information cannot be written to disk.

verify
[bool, optional] Whether or not to do basic assertions that check the integrity. Default: `True`.

****kwargs**
If `header` is not given, these are used to initialize one.

classmethod fromfile(*fh*, *memmap=True*, *valid=True*, *verify=True*)
Read a frame from a filehandle, possible mapping the payload.

Parameters

fh
[filehandle] To read header from.

memmap
[bool, optional] If `True` (default), use `memmap` to map the payload. If `False`, just read it from disk.

valid
[bool, optional] Whether the data are valid (default: `True`). Note that this cannot be inferred from the header or payload itself. If `False`, any data read will be set to `cls.fill_value`.

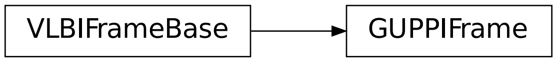
verify
[bool, optional] Whether to do basic verification of integrity. Default: `True`.

keys(*self*)

tofile(*self*, *fh*)
Write encoded frame to filehandle.

verify(*self*)
Simple verification. To be added to by subclasses.

Class Inheritance Diagram



9.3.5 baseband.guppi.base Module

Functions

open(name[, mode])	Open GUPPI file(s) for reading or writing.

open

`baseband.guppi.base.`**open**(*name*, *mode='rs'*, ***kwargs*)
Open GUPPI file(s) for reading or writing.

Opened as a binary file, one gets a wrapped filehandle that adds methods to read/write a frame. Opened as a stream, the handle is wrapped further, with methods such as reading and writing to the file as if it were a stream of samples.

Parameters

name
[str or filehandle, or sequence of str] File name, filehandle, or sequence of file names (see Notes).

mode
[{'rb', 'wb', 'rs', or 'ws'}, optional] Whether to open for reading or writing, and as a regular binary file or as a stream. Default: 'rs', for reading a stream.

****kwargs**
Additional arguments when opening the file as a stream.

— For reading a stream
[(see `GUPPIStreamReader`)]

squeeze
[bool, optional] If `True` (default), remove any dimensions of length unity from decoded data.

subset
[indexing object or tuple of objects, optional] Specific components of the complete sample to decode (after possibly squeezing). If a single indexing object is passed, it selects polarizations. With a tuple, the first selects polarizations and the second selects channels. If the tuple is empty (default), all components are read.

— For writing a stream
[(see `GUPPIStreamWriter`)]

header0
[`GUPPIHeader`] Header for the first frame, holding time information, etc. Can instead give keyword arguments to construct a header (see `**kwargs`).

squeeze
[bool, optional] If `True` (default), writer accepts squeezed arrays as input, and adds any dimensions of length unity.

frames_per_file
[int, optional] When writing to a sequence of files, sets the number of frames within each file. Default: 128.

****kwargs**
If the header is not given, an attempt will be made to construct one with any further keyword arguments.

— Header keywords
[(see `fromvalues()`)]

time
[`Time`] Start time of the file. Must have an integer number of seconds.

sample_rate
[`Quantity`] Number of complete samples per second, i.e. the rate at which each channel of each polarization is sampled.

samples_per_frame
[int] Number of complete samples per frame. Can alternatively give `payload_nbytes`.

payload_nbytes
[int] Number of bytes per payload. Can alternatively give `samples_per_frame`.

offset
[`Quantity` or `TimeDelta`, optional] Time offset from the start of the whole observation (default: 0).

npol
[int, optional] Number of polarizations (default: 1).

nchan
[int, optional] Number of channels (default: 1). For GUPPI, complex data is only allowed when nchan > 1.

bps
[int, optional] Bits per elementary sample, i.e. per real or imaginary component for complex data (default: 8).

Returns

Filehandle
`GUPPIFileReader` or `GUPPIFileWriter` (binary), or `GUPPIStreamReader` or `GUPPIStreamWriter` (stream).

Notes

For streams, one can also pass to `name` a list of files, or a template string that can be formatted using 'stt_imjd', 'src_name', and other header keywords (by `GUPPIFileNameSequencer`).

For writing, one can mimic, for example, what is done at Arecibo by using the template 'puppi_{stt_imjd}_{src_name}_{scannum}.{file_nr:04d}.raw'. GUPPI typically has 128 frames per file; to change this, use the `frames_per_file` keyword. `file_size` is set by `frames_per_file` and cannot be passed.

For reading, to read series such as the above, you will need to use something like 'puppi_58132_J1810+1744_2176.{file_nr:04d}.raw'. Here we have to pass in the MJD, source name and scan number explicitly, since the template is used to get the first file name, before any header is read, and therefore the only keyword available is 'file_nr', which is assumed to be zero for the first file. To avoid this restriction, pass in keyword arguments with values appropriate for the first file.

One may also pass in a `sequentialfile` object (opened in 'rb' mode for reading or 'w+b' for writing), though for typical use cases it is practically identical to passing in a list or template.

Classes

`GUPPIFileNameSequencer`(template[, header])	List-like generator of GUPPI filenames using a template.
`GUPPIFileReader`(fh_raw)	Simple reader for GUPPI files.
`GUPPIFileWriter`(fh_raw)	Simple writer/mapper for GUPPI files.
`GUPPIStreamBase`(fh_raw, header0[, squeeze, ...])	Base for GUPPI streams.
`GUPPIStreamReader`(fh_raw[, squeeze, subset, ...])	GUPPI format reader.
`GUPPIStreamWriter`(fh_raw, header0[, squeeze])	GUPPI format writer.

GUPPIFileNameSequencer

class `baseband.guppi.base.`**`GUPPIFileNameSequencer`**(*template*, *header={}*)
Bases: `baseband.helpers.sequentialfile.FileNameSequencer`

List-like generator of GUPPI filenames using a template.

The template is formatted, filling in any items in curly brackets with values from the header, as well as possibly a file number equal to the indexing value, indicated with '{file_nr}'.

The length of the instance will be the number of files that exist that match the template for increasing values of the file number (when writing, it is the number of files that have so far been generated).

Parameters

template

[str] Template to format to get specific filenames. Curly bracket item keywords are not case-sensitive.

header
[dict-like] Structure holding key'd values that are used to fill in the format. Keys must be in all caps (eg. DATE), as with GUPPI header keys.

Examples

```
>>> from baseband import guppi
>>> gfs = guppi.base.GUPPIFileNameSequencer(
...     '{date}_{file_nr:03d}.raw', {'DATE': "2018-01-01"})
>>> gfs[10]
'2018-01-01_010.raw'
>>> from baseband.data import SAMPLE_PUPPI
>>> with open(SAMPLE_PUPPI, 'rb') as fh:
...     header = guppi.GUPPIHeader.fromfile(fh)
>>> template = 'puppi_{stt_imjd}_{src_name}_{scannum}.{file_nr:04d}.raw'
>>> gfs = guppi.base.GUPPIFileNameSequencer(template, header)
>>> gfs[0]
'puppi_58132_J1810+1744_2176.0000.raw'
>>> gfs[10]
'puppi_58132_J1810+1744_2176.0010.raw'
```

GUPPIFileReader

class baseband.guppi.base.**GUPPIFileReader**(*fh_raw*)
Bases: baseband.vlbi_base.base.VLBIFileReaderBase

Simple reader for GUPPI files.

Wraps a binary filehandle, providing methods to help interpret the data, such as read_frame and get_frame_rate. By default, frame payloads are mapped rather than fully read into physical memory.

Parameters

fh_raw
[filehandle] Filehandle of the raw binary data file.

Attributes Summary

info()	

Methods Summary

close(self)	
get_frame_rate(self)	Determine the number of frames per second.
read_frame(self[, memmap, verify])	Read the frame header and read or map the corresponding payload.
read_header(self)	Read a single header from the file.

Continued on next page

Table 21 – continued from previous page

temporary_offset(self)	Context manager for temporarily seeking to another file position.

Attributes Documentation

info

Methods Documentation

close(*self*)

get_frame_rate(*self*)

Determine the number of frames per second.

The routine uses the sample rate and number of samples per frame (excluding overlap) from the first header in the file.

Returns

frame_rate
[Quantity] Frames per second.

read_frame(*self*, *memmap=True*, *verify=True*)

Read the frame header and read or map the corresponding payload.

Parameters

memmap
[bool, optional] If True (default), map the payload using memmap, so that parts are only loaded into memory as needed to access data.

verify
[bool, optional] Whether to do basic checks of frame integrity. Default: True.

Returns

frame
[GUPPIFrame] With .header and .payload properties. The .data property returns all data encoded in the frame. Since this may be too large to fit in memory, it may be better to access the parts of interest by slicing the frame.

read_header(*self*)

Read a single header from the file.

Returns

header
[GUPPIHeader]

temporary_offset(*self*)

Context manager for temporarily seeking to another file position.

To be used as part of a with statement:

```
with fh_raw.temporary_offset() [as fh_raw]:
    with-block
```

On exiting the `with-block`, the file pointer is moved back to its original position.

GUPPIFileWriter

class baseband.guppi.base.**GUPPIFileWriter**(*fh_raw*)

Bases: `baseband.vlbi_base.base.VLBIFileBase`

Simple writer/mapper for GUPPI files.

Adds `write_frame` and `memmap_frame` methods to the VLBI binary file wrapper. The latter allows one to encode data in pieces, writing to disk as needed.

Methods Summary

`close`(self)	
`memmap_frame`(self[, header])	Get frame by writing the header to disk and mapping its payload.
`temporary_offset`(self)	Context manager for temporarily seeking to another file position.
`write_frame`(self, data[, header])	Write a single frame (header plus payload).

Methods Documentation

close(*self*)

memmap_frame(*self*, *header=None*, ***kwargs*)

Get frame by writing the header to disk and mapping its payload.

The header is written to disk immediately, but the payload is mapped, so that it can be filled in pieces, by setting slices of the frame.

Parameters

header
[`GUPPIHeader`] Written to disk immediately. Can instead give keyword arguments to construct a header.

****kwargs**
If `header` is not given, these are used to initialize one.

Returns

frame: `GUPPIFrame`
By assigning slices to data, the payload can be encoded piecewise.

temporary_offset(*self*)

Context manager for temporarily seeking to another file position.

To be used as part of a `with` statement:

```
with fh_raw.temporary_offset() [as fh_raw]:
    with-block
```

On exiting the `with-block`, the file pointer is moved back to its original position.

write_frame(*self*, *data*, *header=None*, ***kwargs*)
Write a single frame (header plus payload).

Parameters

data
[`ndarray` or `GUPPIFrame`] If an array, a `header` should be given, which will be used to get the information needed to encode the array, and to construct the GUPPI frame.

header
[`GUPPIHeader`] Can instead give keyword arguments to construct a header. Ignored if `data` is a `GUPPIFrame` instance.

****kwargs**
If `header` is not given, these are used to initialize one.

GUPPIStreamBase

class baseband.guppi.base.**GUPPIStreamBase**(*fh_raw*, *header0*, *squeeze=True*, *subset=()*, *verify=True*)
Bases: `baseband.vlbi_base.base.VLBIStreamBase`

Base for GUPPI streams.

Attributes Summary

`bps`	Bits per elementary sample.
`complex_data`	Whether the data are complex.
`header0`	First header of the file.
`sample_rate`	Number of complete samples per second.
`sample_shape`	Shape of a complete sample (possibly subset or squeezed).
`samples_per_frame`	Number of complete samples per frame, excluding overlap.
`squeeze`	Whether data arrays have dimensions with length unity removed.
`start_time`	Start time of the file.
`subset`	Specific components of the complete sample to decode.
`time`	Time of the sample pointer's current offset in file.
`verify`	Whether to do consistency checks on frames being read.

Methods Summary

`close`(self)	
`tell`(self[, unit])	Current offset in the file.

Attributes Documentation

bps
Bits per elementary sample.

complex_data
Whether the data are complex.

header0
First header of the file.

sample_rate
Number of complete samples per second.

sample_shape
Shape of a complete sample (possibly subset or squeezed).

samples_per_frame
Number of complete samples per frame, excluding overlap.

squeeze
Whether data arrays have dimensions with length unity removed.

If `True`, data read out has such dimensions removed, and data passed in for writing has them inserted.

start_time
Start time of the file.

See also `time` for the time of the sample pointer's current offset.

subset
Specific components of the complete sample to decode.

The order of dimensions is the same as for `sample_shape`. Set by the class initializer.

time
Time of the sample pointer's current offset in file.

See also `start_time` for the start time of the file.

verify
Whether to do consistency checks on frames being read.

Methods Documentation

close(*self*)

tell(*self*, *unit=None*)
Current offset in the file.

Parameters

unit
[`Unit` or str, optional] Time unit the offset should be returned in. By default, no unit is used, i.e., an integer enumerating samples is returned. For the special string 'time', the absolute time is calculated.

Returns

offset
[int, `Quantity`, or `Time`] Offset in current file (or time at current position).

GUPPIStreamReader

class `baseband.guppi.base.`**`GUPPIStreamReader`**(*fh_raw*, *squeeze=True*, *subset=()*, *verify=True*)

Bases: `baseband.guppi.base.GUPPIStreamBase`, `baseband.vlbi_base.base.VLBIStreamReaderBase`

GUPPI format reader.

Allows access to GUPPI files as a continuous series of samples.

Parameters

fh_raw
[filehandle] Filehandle of the raw GUPPI stream.

squeeze
[bool, optional] If `True` (default), remove any dimensions of length unity from decoded data.

subset
[indexing object or tuple of objects, optional] Specific components of the complete sample to decode (after possibly squeezing). If a single indexing object is passed, it selects polarizations. With a tuple, the first selects polarizations and the second selects channels. If the tuple is empty (default), all components are read.

verify
[bool, optional] Whether to do basic checks of frame integrity when reading. The first frame of the stream is always checked, so `verify` is effective only when reading sequences of files. Default: `True`.

Attributes Summary

`bps`	Bits per elementary sample.
`complex_data`	Whether the data are complex.
`dtype`	
`fill_value`	Value to use for invalid or missing data.
`header0`	First header of the file.
`info`()	Standardized information on stream readers.
`ndim`	Number of dimensions of the (squeezed/subset) stream data.
`sample_rate`	Number of complete samples per second.
`sample_shape`	Shape of a complete sample (possibly subset or squeezed).
`samples_per_frame`	Number of complete samples per frame, excluding overlap.
`shape`	Shape of the (squeezed/subset) stream data.
`size`	Total number of component samples in the (squeezed/subset) stream data.
`squeeze`	Whether data arrays have dimensions with length unity removed.
`start_time`	Start time of the file.

Continued on next page

Table 25 – continued from previous page

stop_time	Time at the end of the file, just after the last sample.
subset	Specific components of the complete sample to decode.
time	Time of the sample pointer's current offset in file.
verify	Whether to do consistency checks on frames being read.

Methods Summary

close(self)	
read(self[, count, out])	Read a number of complete (or subset) samples.
readable(self)	Whether the file can be read and decoded.
seek(self, offset[, whence])	Change the stream position.
tell(self[, unit])	Current offset in the file.

Attributes Documentation

bps
Bits per elementary sample.

complex_data
Whether the data are complex.

dtype

fill_value
Value to use for invalid or missing data. Default: 0.

header0
First header of the file.

info
Standardized information on stream readers.

The `info` descriptor provides a few standard attributes, all of which can also be accessed directly on the stream filehandle. More detailed information on the underlying file is stored in its info, accessible via `info.file_info`.

Attributes

start_time
[Time] Time of the first complete sample.

stop_time
[Time] Time of the complete sample just beyond the end of the file.

sample_rate
[Quantity] Complete samples per unit of time.

shape
[tuple] Equivalent shape of the whole file, i.e., combining the number of complete samples and the shape of those samples.

bps
[int] Number of bits used to encode each elementary sample.

complex_data
[bool] Whether the data are complex.

readable
[bool] Whether the first sample could be read and decoded.

ndim
Number of dimensions of the (squeezed/subset) stream data.

sample_rate
Number of complete samples per second.

sample_shape
Shape of a complete sample (possibly subset or squeezed).

samples_per_frame
Number of complete samples per frame, excluding overlap.

shape
Shape of the (squeezed/subset) stream data.

size
Total number of component samples in the (squeezed/subset) stream data.

squeeze
Whether data arrays have dimensions with length unity removed.

If `True`, data read out has such dimensions removed, and data passed in for writing has them inserted.

start_time
Start time of the file.

See also `time` for the time of the sample pointer's current offset, and (if available) `stop_time` for the time at the end of the file.

stop_time
Time at the end of the file, just after the last sample.

See also `start_time` for the start time of the file, and `time` for the time of the sample pointer's current offset.

subset
Specific components of the complete sample to decode.

The order of dimensions is the same as for `sample_shape`. Set by the class initializer.

time
Time of the sample pointer's current offset in file.

See also `start_time` for the start time, and (if available) `stop_time` for the end time, of the file.

verify
Whether to do consistency checks on frames being read.

Methods Documentation

close(*self*)

read(*self*, *count=None*, *out=None*)
Read a number of complete (or subset) samples.

The range retrieved can span multiple frames.

Parameters

count
[int or None, optional] Number of complete/subset samples to read. If `None` (default) or negative, the whole file is read. Ignored if `out` is given.

out
[None or array, optional] Array to store the data in. If given, `count` will be inferred from the first dimension; the other dimension should equal `sample_shape`.

Returns

out
[`ndarray` of float or complex] The first dimension is sample-time, and the remainder given by `sample_shape`.

readable(*self*)
Whether the file can be read and decoded.

seek(*self*, *offset*, *whence=0*)
Change the stream position.

This works like a normal filehandle seek, but the offset is in samples (or a relative or absolute time).

Parameters

offset
[int, `Quantity`, or `Time`] Offset to move to. Can be an (integer) number of samples, an offset in time units, or an absolute time.

whence
[{0, 1, 2, 'start', 'current', or 'end'}, optional] Like regular seek, the offset is taken to be from the start if `whence=0` (default), from the current position if 1, and from the end if 2. One can alternativey use 'start', 'current', or 'end' for 0, 1, or 2, respectively. Ignored if `offset` is a time.

tell(*self*, *unit=None*)
Current offset in the file.

Parameters

unit
[`Unit` or str, optional] Time unit the offset should be returned in. By default, no unit is used, i.e., an integer enumerating samples is returned. For the special string 'time', the absolute time is calculated.

Returns

offset
[int, `Quantity`, or `Time`] Offset in current file (or time at current position).

GUPPIStreamWriter

class baseband.guppi.base.**GUPPIStreamWriter**(*fh_raw*, *header0*, *squeeze=True*)
Bases: `baseband.guppi.base.GUPPIStreamBase`, `baseband.vlbi_base.base.VLBIStreamWriterBase`

GUPPI format writer.

Encodes and writes sequences of samples to file.

Parameters

raw
[filehandle] For writing the header and raw data to storage.

header0
[`GUPPIHeader`] Header for the first frame, holding time information, etc.

squeeze
[bool, optional] If `True` (default), `write` accepts squeezed arrays as input, and adds any dimensions of length unity.

Attributes Summary

`bps`	Bits per elementary sample.
`complex_data`	Whether the data are complex.
`header0`	First header of the file.
`sample_rate`	Number of complete samples per second.
`sample_shape`	Shape of a complete sample (possibly subset or squeezed).
`samples_per_frame`	Number of complete samples per frame, excluding overlap.
`squeeze`	Whether data arrays have dimensions with length unity removed.
`start_time`	Start time of the file.
`subset`	Specific components of the complete sample to decode.
`time`	Time of the sample pointer's current offset in file.
`verify`	Whether to do consistency checks on frames being read.

Methods Summary

`close`(self)	
`tell`(self[, unit])	Current offset in the file.
`write`(self, data[, valid])	Write data, buffering by frames as needed.

Attributes Documentation

`bps`
Bits per elementary sample.

`complex_data`
Whether the data are complex.

`header0`
First header of the file.

`sample_rate`
Number of complete samples per second.

sample_shape
Shape of a complete sample (possibly subset or squeezed).

samples_per_frame
Number of complete samples per frame, excluding overlap.

squeeze
Whether data arrays have dimensions with length unity removed.

If True, data read out has such dimensions removed, and data passed in for writing has them inserted.

start_time
Start time of the file.

See also time for the time of the sample pointer's current offset.

subset
Specific components of the complete sample to decode.

The order of dimensions is the same as for sample_shape. Set by the class initializer.

time
Time of the sample pointer's current offset in file.

See also start_time for the start time of the file.

verify
Whether to do consistency checks on frames being read.

Methods Documentation

close(*self*)

tell(*self*, *unit=None*)
Current offset in the file.

Parameters

unit
[Unit or str, optional] Time unit the offset should be returned in. By default, no unit is used, i.e., an integer enumerating samples is returned. For the special string 'time', the absolute time is calculated.

Returns

offset
[int, Quantity, or Time] Offset in current file (or time at current position).

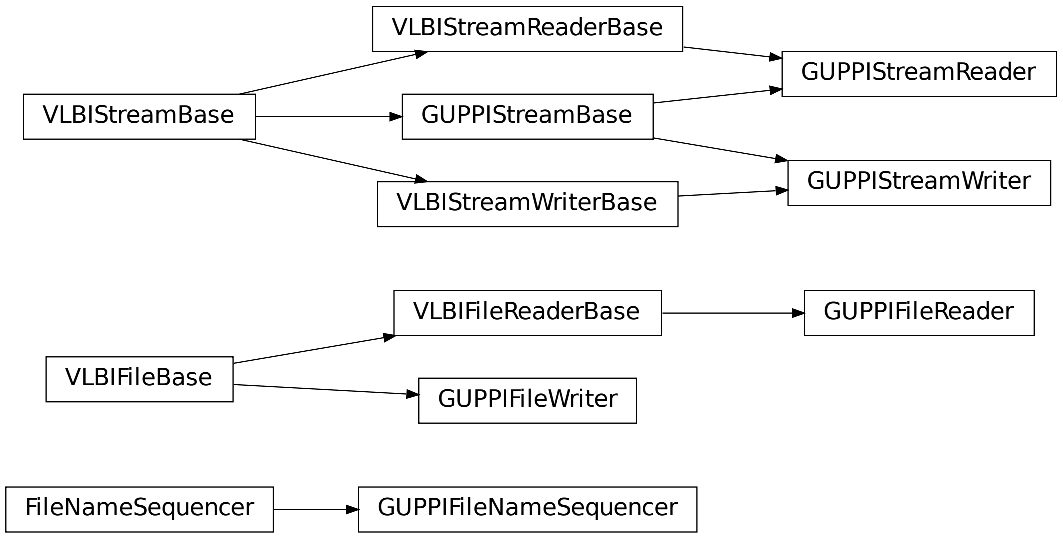
write(*self*, *data*, *valid=True*)
Write data, buffering by frames as needed.

Parameters

data
[ndarray] Piece of data to be written, with sample dimensions as given by sample_shape. This should be properly scaled to make best use of the dynamic range delivered by the encoding.

valid
[bool, optional] Whether the current data are valid. Default: `True`.

Class Inheritance Diagram



CHAPTER

TEN

GSB

The GMRT software backend (GSB) file format is the standard output of the initial correlator of the Giant Metrewave Radio Telescope (GMRT). The GSB design is described by Roy et al. (2010, Exper. Astron. 28:25-60) with further specifications and operating procedures given on the relevant GMRT/GSB pages.

10.1 File Structure

A GSB dataset consists of an ASCII file with a sequence of *headers*, and one or more accompanying binary data files. Each line in the header and its corresponding data comprise a *data frame*, though these do not have explicit divisions in the data files.

Baseband currently supports two forms of GSB data: **rawdump**, for storing real-valued raw voltage timestreams, and **phased**, for storing complex pre-channelized data from the GMRT in phased array baseband mode.

Data in rawdump format is stored in a binary file representing the voltage stream from one polarization of a single dish. Each such file is accompanied by a header file which contains GPS timestamps, in the form:

```
YYYY MM DD HH MM SS 0.SSSSSSSSS
```

In the default rawdump observing setup, samples are recorded at a rate of 33.3333… megasamples per second (Msps). Each sample is 4 bits in size, and two samples are grouped into bytes such that the oldest sample occupies the least significant bit. Each frame consists of **4 megabytes** of data, or 2^{23}, samples; as such, the timespan of one frame is exactly **0.25165824 s**.

Data in phased format is normally spread over four binary files and one accompanying header file. The binary files come in two pairs, one for each polarization, with the pair contain the first and second half of the data of each frame.

When recording GSB in phased array voltage beam (ie. baseband) mode, the “raw”, or pre-channelized, *sample rate* is either 33.3333… Msps at 8 bits per sample or 66.6666… Msps at 4 bits per sample (in the latter case, sample bit-ordering is the same as for rawdump). Channelization via fast Fourier transform sets the channelized *complete sample* rate to the raw rate divided by $2N_\mathrm{F}$, where N_F is the number of Fourier channels (either 256 or 512). The timespan of one frame is **0.25165824 s**, and one frame is **8 megabytes** in size, for either raw sample rate.

The phased header’s structure is:

```
<PC TIME> <GPS TIME> <SEQ NUMBER> <MEM BLOCK>
```

where `<PC TIME>` and `<GPS TIME>` are the less accurate computer-based and exact GPS-based timestamps, respectively, with the same format as the rawdump timestamp; `<SEQ NUMBER>` is the frame number; and `<MEM BLOCK>` a redundant modulo-8 shared memory block number.

10.2 Usage Notes

This section covers reading and writing GSB files with Baseband; general usage is covered in the *Using Baseband* section. While Baseband features the general `baseband.open` and `baseband.file_info` functions, these cannot read GSB binary files without the accompanying timestamp file (at which point it is obvious the files are GSB). `baseband.file_info`, however, can be used on the timestamp file to determine if it is in rawdump or phased format.

The examples below use the samplefiles in the `baseband/data/gsb/` directory, and the `numpy`, `astropy.units` and `baseband.gsb` modules:

```
>>> import numpy as np
>>> import astropy.units as u
>>> from baseband import gsb
>>> from baseband.data import (
...     SAMPLE_GSB_RAWDUMP, SAMPLE_GSB_RAWDUMP_HEADER,
...     SAMPLE_GSB_PHASED, SAMPLE_GSB_PHASED_HEADER)
```

A single timestamp file can be opened with `open` in text mode:

```
>>> ft = gsb.open(SAMPLE_GSB_RAWDUMP_HEADER, 'rt')
>>> ft.read_timestamp()
<GSBRawdumpHeader gps: 2015 04 27 18 45 00 0.000000240>
>>> ft.close()
```

Reading payloads requires the samples per frame or sample rate. For phased the sample rate is:

```
sample_rate = raw_sample_rate / (2 * nchan)
```

where the raw sample rate is the pre-channelized one, and `nchan` the number of Fourier channels. The samples per frame for both rawdump and phased is:

```
samples_per_frame = timespan_of_frame * sample_rate
```

Note: Since the number of samples per frame is an integer number while both the frame timespan and sample rate are not, it is better to separately caculate `samples_per_frame` rather than multiplying `timespan_of_frame` with `sample_rate` in order to avoid rounding issues.

Alternatively, if the size of the frame buffer and the frame rate are known, the former can be used to determine `samples_per_frame`, and the latter used to determine `sample_rate` by inverting the above equation.

If `samples_per_frame` is not given, Baseband assumes it is the equivalent of 4 megabytes of data for rawdump, or 8 megabytes if phased. If `sample_rate` is not given, it is calculated from `samples_per_frame` assuming `timespan_of_frame = 0.25165824` (see *File Structure* above).

A single payload file can be opened with `open` in binary mode. Here, for our sample file, we have to take into account that in order to keep these files small, their sample size has been reduced to only **4 or 8 kilobytes** worth of samples per frame (for the default timespan). So, we define their sample rate here, and use that to calculate `payload_nbytes`, the size of one frame in bytes. Since rawdump samples are 4 bits, `payload_nbytes` is just `samples_per_frame / 2`:

```
>>> rawdump_samples_per_frame = 2**13
>>> payload_nbytes = rawdump_samples_per_frame // 2
>>> fb = gsb.open(SAMPLE_GSB_RAWDUMP, 'rb', payload_nbytes=payload_nbytes,
...               nchan=1, bps=4, complex_data=False)
>>> payload = fb.read_payload()
>>> payload[:4]
```

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```
array([[ 0.],
       [-2.],
       [-2.],
       [ 0.]], dtype=float32)
>>> fb.close()
```

(payload_nbytes for phased data is the size of one frame *divided by the number of binary files*.)

Opening in stream mode allows timestamp and binary files to be read in concert to create data frames, and also wraps the low-level routines such that reading and writing is in units of samples, and provides access to header information.

When opening a rawdump file in stream mode, we pass the timestamp file as the first argument, and the binary file to the raw keyword. As per above, we also pass samples_per_frame:

```
>>> fh_rd = gsb.open(SAMPLE_GSB_RAWDUMP_HEADER, mode='rs',
...                  raw=SAMPLE_GSB_RAWDUMP,
...                  samples_per_frame=rawdump_samples_per_frame)
>>> fh_rd.header0
<GSBRawdumpHeader gps: 2015 04 27 18 45 00 0.000000240>
>>> dr = fh_rd.read()
>>> dr.shape
(81920,)
>>> dr[:3]
array([ 0., -2., -2.], dtype=float32)
>>> fh_rd.close()
```

To open a phased fileset in stream mode, we package the binary files into a nested tuple with the format:

```
((L pol stream 1, L pol stream 2), (R pol stream 1, R pol stream 2))
```

The nested tuple is passed to raw (note that we again have to pass a non-default sample rate):

```
>>> phased_samples_per_frame = 2**3
>>> fh_ph = gsb.open(SAMPLE_GSB_PHASED_HEADER, mode='rs',
...                  raw=SAMPLE_GSB_PHASED,
...                  samples_per_frame=phased_samples_per_frame)
>>> header0 = fh_ph.header0     # To be used for writing, below.
>>> dp = fh_ph.read()
>>> dp.shape
(80, 2, 512)
>>> dp[0, 0, :3]
array([30.+12.j, -1. +8.j,  7.+19.j], dtype=complex64)
>>> fh_ph.close()
```

To set up a file for writing, we need to pass names for both timestamp and raw files, as well as sample_rate, samples_per_frame, and either the first header or a time object. We first calculate sample_rate:

```
>>> timespan = 0.25165824 * u.s
>>> rawdump_sample_rate = (rawdump_samples_per_frame / timespan).to(u.MHz)
>>> phased_sample_rate = (phased_samples_per_frame / timespan).to(u.MHz)
```

To write a rawdump file:

```
>>> from astropy.time import Time
>>> fw_rd = gsb.open('test_rawdump.timestamp',
...                  mode='ws', raw='test_rawdump.dat',
...                  sample_rate=rawdump_sample_rate,
```

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```
...                    samples_per_frame=rawdump_samples_per_frame,
...                    time=Time('2015-04-27T13:15:00'))
>>> fw_rd.write(dr)
>>> fw_rd.close()
>>> fh_rd = gsb.open('test_rawdump.timestamp', mode='rs',
...                    raw='test_rawdump.dat',
...                    sample_rate=rawdump_sample_rate,
...                    samples_per_frame=rawdump_samples_per_frame)
>>> np.all(dr == fh_rd.read())
True
>>> fh_rd.close()
```

To write a phased file, we need to pass a nested tuple of filenames or filehandles:

```
>>> test_phased_bin = (('test_phased_pL1.dat', 'test_phased_pL2.dat'),
...                    ('test_phased_pR1.dat', 'test_phased_pR2.dat'))
>>> fw_ph = gsb.open('test_phased.timestamp',
...                    mode='ws', raw=test_phased_bin,
...                    sample_rate=phased_sample_rate,
...                    samples_per_frame=phased_samples_per_frame,
...                    header0=header0)
>>> fw_ph.write(dp)
>>> fw_ph.close()
>>> fh_ph = gsb.open('test_phased.timestamp', mode='rs',
...                    raw=test_phased_bin,
...                    sample_rate=phased_sample_rate,
...                    samples_per_frame=phased_samples_per_frame)
>>> np.all(dp == fh_ph.read())
True
>>> fh_ph.close()
```

Baseband does not use the PC time in the phased header, and, when writing, simply uses the same time for both GPS and PC times. Since the PC time can drift from the GPS time by several tens of milliseconds, `test_phased.timestamp` will not be identical to `SAMPLE_GSB_PHASED`, even though we have written the exact same data to file.

10.3 Reference/API

10.3.1 baseband.gsb Package

GMRT Software Backend (GSB) data reader.

See http://gmrt.ncra.tifr.res.in/gmrt_hpage/sub_system/gmrt_gsb/index.htm

Functions

`open`(name[, mode])	Open GSB file(s) for reading or writing.

open

`baseband.gsb.`**`open`**`(`*name*, *mode='rs'*, ***kwargs*`)`

Open GSB file(s) for reading or writing.

A GSB data set contains a text header file and one or more raw data files. When the file is opened as text, one gets a standard filehandle, but with methods to read/write timestamps. When it is opened as a binary, one similarly gets methods to read/write frames. Opened as a stream, the file is interpreted as a timestamp file, but raw files need to be given too. This allows access to the stream(s) as series of samples.

Parameters

name
[str] Filename of timestamp or raw data file.

mode
[{'rb', 'wb', 'rt', 'wt', 'rs', or 'ws'}, optional] Whether to open for reading or writing, and as a regular text or binary file (for timestamps and data, respectively) or as a stream. Default: 'rs', for reading a stream.

****kwargs**
Additional arguments when opening the file as a stream.

— For both reading and writing of streams :

raw
[str or (tuple of) tuple of str] Name of files holding payload data. A single file is needed for rawdump, and a tuple for phased. For a nested tuple, the outer tuple determines the number of polarizations, and the inner tuple(s) the number of streams per polarization. E.g., `((polL1, polL2), (polR1, polR2))` for two streams per polarization. A single tuple is interpreted as streams of a single polarization.

sample_rate
[`Quantity`, optional] Number of complete samples per second, i.e. the rate at which each channel of each polarization is sampled. If `None`, will be inferred assuming the frame rate is exactly 251.658240 ms.

samples_per_frame
[int, optional] Number of complete samples per frame. Can give `payload_nbytes` instead.

payload_nbytes
[int, optional] Number of bytes per payload, divided by the number of raw files. If both `samples_per_frame` and `payload_nbytes` are `None`, `payload_nbytes` is set to `2**22` (4 MB) for rawdump, and `2**23` (8 MB) divided by the number of streams per polarization for phased.

nchan
[int, optional] Number of channels. Default: 1 for rawdump, 512 for phased.

bps
[int, optional] Bits per elementary sample, i.e. per real or imaginary component for complex data. Default: 4 for rawdump, 8 for phased.

complex_data
[bool, optional] Whether data are complex. Default: `False` for rawdump, `True` for phased.

squeeze
[bool, optional] If `True` (default) and reading, remove any dimensions of length unity from decoded data. If `True` and writing, accept squeezed arrays as input, and adds any dimensions of length unity.

— For reading only
[(see `GSBStreamReader`)]

subset
[indexing object or tuple of objects, optional] Specific components of the complete sample to decode (after possibly squeezing). If a single indexing object is passed, it selects (available) polarizations. If a tuple is passed, the first selects polarizations and the second selects channels. If the tuple is empty (default), all components are read.

verify
[bool, optional] Whether to do basic checks of frame integrity when reading. The first frame of the stream is always checked. Default: `True`.

— For writing only
[(see `GSBStreamWriter`)]

header0
[`GSBHeader`] Header for the first frame, holding time information, etc. Can instead give keyword arguments to construct a header.

****kwargs**
If the header is not given, an attempt will be made to construct one with any further keyword arguments. If one requires to explicitly set the mode of the GSB stream, use `header_mode`. If not given, it will be 'rawdump' if only a single raw file is present, or 'phased' otherwise. See `GSBStreamWriter`.

Returns

Filehandle
`GSBFileReader` or `GSBFileWriter` (binary), or `GSBStreamReader` or `GSBStreamWriter` (stream)

Classes

`GSBFrame`(header, payload[, valid, verify])	Frame encapsulating GSB rawdump or phased data.
`GSBHeader`(words[, mode, nbytes, utc_offset, . . .])	GSB Header, based on a line from a timestamp file.
`GSBPayload`(words[, sample_shape, bps, . . .])	Container for decoding and encoding GSB payloads.

GSBFrame

class baseband.gsb.**GSBFrame**(*header*, *payload*, *valid=True*, *verify=True*)
Bases: `baseband.vlbi_base.frame.VLBIFrameBase`

Frame encapsulating GSB rawdump or phased data.

For rawdump data, lines in the timestamp file are associated with single blocks of raw data. For phased data, the lines are associated with one or two polarisations, each consisting of two blocks of raw data. Hence, the raw data come from two or four files.

Parameters

header
[`GSBHeader`] Based on line from rawdump or phased timestamp file.

payload
[`GSBPayload`] Based on a single block of rawdump data, or the combined blocks for phased data.

valid
[bool, optional] Whether the data are valid. Default: `True`.

verify
[bool, optional] Whether to verify consistency of the frame parts. Default: `True`.

Notes

GSB files do not support storing whether data are valid or not on disk. Hence, this has to be determined independently. If `valid=False`, any decoded data are set to `cls.fill_value` (by default, 0).

The Frame can also be read instantiated using class methods:

fromfile : read header and payload from their respective filehandles

fromdata : encode data as payload

Of course, one can also do the opposite:

tofile
[method to write header and payload to filehandles (splitting] payload in the appropriate files).

data : property that yields full decoded payload

A number of properties are defined: `shape`, `dtype` and `size` are the shape, type and number of complete samples of the data array, and `nbytes` the frame size in bytes. Furthermore, the frame acts as a dictionary, with keys those of the header. Any attribute that is not defined on the frame itself, such as `.time` will be looked up on the header as well.

Attributes Summary

`data`	Full decoded frame.
`dtype`	Numeric type of the frame data.
`fill_value`	Value to replace invalid data in the frame.
`nbytes`	Size of the encoded frame in the raw data file in bytes.
`ndim`	Number of dimensions of the frame data.
`sample_shape`	Shape of a sample in the frame (nchan,).
`shape`	Shape of the frame data.
`size`	Total number of component samples in the frame data.
`valid`	Whether frame contains valid data.

Methods Summary

`fromdata`(data, header, *args[, valid, verify])	Construct frame from data and header.
`fromfile`(fh_ts, fh_raw[, payload_nbytes, . . .])	Read a frame from timestamp and raw data filehandles.
`keys`(self)	
`tofile`(self, fh_ts, fh_raw)	Write encoded frame to timestamp and raw data filehandles.
`verify`(self)	Simple verification.

Attributes Documentation

`data`
Full decoded frame.

`dtype`
Numeric type of the frame data.

`fill_value`
Value to replace invalid data in the frame.

`nbytes`
Size of the encoded frame in the raw data file in bytes.

`ndim`
Number of dimensions of the frame data.

`sample_shape`
Shape of a sample in the frame (nchan,).

`shape`
Shape of the frame data.

`size`
Total number of component samples in the frame data.

`valid`
Whether frame contains valid data.

Methods Documentation

`classmethod fromdata`(*data*, *header*, **args*, *valid=True*, *verify=True*, ***kwargs*)
Construct frame from data and header.

Parameters

data
[`ndarray`] Array holding data to be encoded.

header
[`VLBIHeaderBase`] Header for the frame.

***args, **kwargs :**
Any arguments beyond the filehandle are used to help initialize the payload, except for `valid` and `verify`, which are passed on to the header and class initializers.

valid
[bool, optional] Whether this payload contains valid data.

verify
[bool, optional] Whether to verify the header and frame correctness.

`classmethod fromfile`(*fh_ts*, *fh_raw*, *payload_nbytes=16777216*, *nchan=1*, *bps=4*, *complex_data=False*, *valid=True*, *verify=True*)
Read a frame from timestamp and raw data filehandles.

Any arguments beyond the filehandle are used to help initialize the payload, except for `valid` and `verify`, which are passed on to the header and class initializers.

Parameters

fh_ts
[filehandle] To the timestamp file. The next line will be read.

fh_raw
[file_handle or tuple] Should be a single handle for a rawdump data frame, or a tuple containing tuples with pairs of handles for a phased one. E.g., `((L1, L2), (R1, R2))` for left and right polarisations.

payload_nbytes
[int, optional] Size of the individual payloads in bytes. Default: `2**24` (16 MB).

nchan
[int, optional] Number of channels. Default: 1.

bps
[int, optional] Bits per elementary sample. Default: 4.

complex_data
[bool, optional] Whether data are complex. Default: `False`.

valid
[bool, optional] Whether the data are valid (default: `True`). Note that this cannot be inferred from the header or payload itself. If `False`, any data read will be set to `cls.fill_value`.

verify
[bool, optional] Whether to verify consistency of the frame parts. Default: `True`.

keys(*self*)

tofile(*self*, *fh_ts*, *fh_raw*)
Write encoded frame to timestamp and raw data filehandles.

Parameters

fh_ts
[filehandle] To the timestamp file. A line will be added to it.

fh_raw
[file_handle or tuple] Should be a single handle for a rawdump data frame, or a tuple containing tuples with pairs of handles for a phased one. E.g., `((L1, L2), (R1, R2))` for left and right polarisations.

verify(*self*)
Simple verification. To be added to by subclasses.

GSBHeader

class baseband.gsb.**GSBHeader**(*words*, *mode=None*, *nbytes=None*, *utc_offset=<Quantity 5.5 h>*, *verify=True*)
Bases: `baseband.vlbi_base.header.VLBIHeaderBase`

GSB Header, based on a line from a timestamp file.

Parameters

words
[list of str, or None] If `None`, set to a list of empty strings for later initialisation.

mode
[str or None, optional] Mode in which data was taken: 'phased' or 'rawdump'. If `None`, it is determined from the words.

nbytes
[int or None, optional] Number of characters in the header, including trailing blank spaces and carriage returns. If `None`, is determined from the words assuming one trailing blank space and one CR.

verify
[bool, optional] Whether to do basic verification of integrity. Default: `True`.

Returns

header
[`GSBHeader` subclass] As appropriate for the mode.

Attributes Summary

`mode`	Mode in which data was taken: 'phased' or 'rawdump'.
`mutable`	Whether the header can be modified.
`nbytes`	Size of the header in characters.

Methods Summary

`copy`(self, **kwargs)	Create a mutable and independent copy of the header.
`fromfile`(fh, *args, **kwargs)	Read GSB Header from a line from a timestamp file.
`fromkeys`([mode, nbytes])	Initialise a header from parsed values.
`fromvalues`([mode, nbytes])	Initialise a header from parsed values.
`keys`(self)	
`seek_offset`(self, n[, nbytes])	Offset in bytes needed to move a file pointer to another header.
`tofile`(self, fh)	Write GSB header as a line to the filehandle.
`update`(self, *[, verify])	Update the header by setting keywords or properties.
`verify`(self)	Verify that the length of the words is consistent.

Attributes Documentation

`mode`
Mode in which data was taken: 'phased' or 'rawdump'.

`mutable`
Whether the header can be modified.

`nbytes`
Size of the header in characters.

Assumes the string terminates in one blank space and one carriage return.

Methods Documentation

copy(*self*, ***kwargs*)

Create a mutable and independent copy of the header.

Keyword arguments can be passed on as needed by possible subclasses.

classmethod fromfile(*fh*, **args*, ***kwargs*)

Read GSB Header from a line from a timestamp file.

Arguments are the same as for class initialisation. The header constructed will be immutable.

classmethod fromkeys(*mode=None*, *nbytes=None*, **args*, ***kwargs*)

Initialise a header from parsed values.

Like fromvalues, but without any interpretation of keywords.

Raises

KeyError
[if not all keys required are present in `kwargs`]

classmethod fromvalues(*mode=None*, *nbytes=None*, **args*, ***kwargs*)

Initialise a header from parsed values.

Here, the parsed values must be given as keyword arguments, i.e., for any `header = cls(<words>)`, `cls.fromvalues(**header) == header`.

However, unlike for the `fromkeys` class method, data can also be set using arguments named after header methods, such as `time`.

Parameters

***args**
Possible arguments required to initialize an empty header.

****kwargs**
Values used to initialize header keys or methods.

keys(*self*)

seek_offset(*self*, *n*, *nbytes=None*)

Offset in bytes needed to move a file pointer to another header.

Some GSB headers have variable size and hence one cannot trivially jump to another entry in a timestamp file. This routine allows one to calculate the offset required to move the file pointer `n` headers.

Parameters

n
[int] The number of headers to move to, relative to the present header.

nbytes
[int, optional] The size in bytes of the present header (if not given, will use the header's `nbytes` property).

tofile(*self*, *fh*)

Write GSB header as a line to the filehandle.

update(*self*, **, *verify=True*, ***kwargs*)

Update the header by setting keywords or properties.

Here, any keywords matching header keys are applied first, and any remaining ones are used to set header properties, in the order set by the class (in `_properties`).

Parameters

verify
[bool, optional] If `True` (default), verify integrity after updating.

****kwargs**
Arguments used to set keywords and properties.

verify(*self*)

Verify that the length of the words is consistent.

Subclasses should override this to do more thorough checks.

GSBPayload

class baseband.gsb.**GSBPayload**(*words*, *sample_shape=()*, *bps=2*, *complex_data=False*)

Bases: `baseband.vlbi_base.payload.VLBIPayloadBase`

Container for decoding and encoding GSB payloads.

Parameters

words
[`ndarray`] Array containg LSB unsigned words (with the right size) that encode the payload.

sample_shape
[tuple, optional] Shape of the samples; e.g., (nchan,). Default: ().

bps
[int, optional] Bits per elementary sample. Default: 2.

complex_data
[bool, optional] Whether data are complex. Default: `False`.

Attributes Summary

`data`	Full decoded payload.
`dtype`	Numeric type of the decoded data array.
`nbytes`	Size of the payload in bytes.
`ndim`	Number of dimensions of the decoded data array.
`shape`	Shape of the decoded data array.
`size`	Total number of component samples in the decoded data array.

Methods Summary

`fromdata`(data[, header, bps])	Encode data as a payload.

Continued on next page

Table 8 – continued from previous page

`fromfile`(fh[, payload_nbytes, nchan, bps, . . .])	Read payloads from several threads.
`tofile`(self, fh)	Write payload to filehandle.

Attributes Documentation

`data`
Full decoded payload.

`dtype`
Numeric type of the decoded data array.

`nbytes`
Size of the payload in bytes.

`ndim`
Number of dimensions of the decoded data array.

`shape`
Shape of the decoded data array.

`size`
Total number of component samples in the decoded data array.

Methods Documentation

`classmethod fromdata`(*data*, *header=None*, *bps=2*)
Encode data as a payload.

Parameters

data
[`ndarray`] Data to be encoded. The last dimension is taken as the number of channels.

header
[header instance, optional] If given, used to infer the bps.

bps
[int, optional] Bits per elementary sample, i.e., per channel and per real or imaginary component, used if header is not given. Default: 2.

`classmethod fromfile`(*fh*, *payload_nbytes=None*, *nchan=1*, *bps=4*, *complex_data=False*)
Read payloads from several threads.

Parameters

fh
[filehandle or tuple of tuple of filehandle] Handles to the sets of files from which data are read. The outer tuple holds distinct threads, while the inner ones holds parts of those threads. Typically, these are the two polarisations and the two parts of each in which phased baseband data are stored.

payload_nbytes
[int] Number of bytes to read from each part.

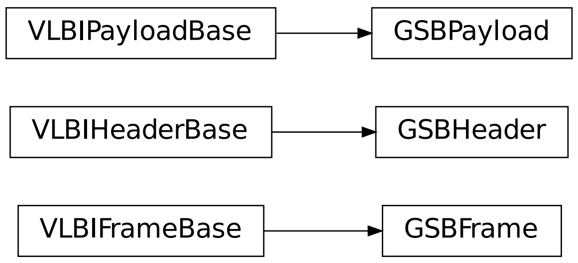
nchan
[int, optional] Number of channels. Default: 1.

bps
[int, optional] Bits per elementary sample. Default: 4.

complex_data
[bool, optional] Whether data are complex. Default: `False`.

tofile(*self*, *fh*)
Write payload to filehandle.

Class Inheritance Diagram



10.3.2 baseband.gsb.header Module

Definitions for GSB Headers, using the timestamp files.

Somewhat out of data description for phased data: http://gmrt.ncra.tifr.res.in/gmrt_hpage/sub_system/gmrt_gsb/GSB_beam_timestamp_note_v1.pdf and for rawdump data http://gmrt.ncra.tifr.res.in/gmrt_hpage/sub_system/gmrt_gsb/GSB_rawdump_data_format_v2.pdf

Classes

`TimeGSB`(val1, val2, scale, precision, . . . [, . . .])	GSB header date-time format `YYYY MM DD HH MM SS 0.SSSSSSSSS`.
`GSBHeader`(words[, mode, nbytes, utc_offset, . . .])	GSB Header, based on a line from a timestamp file.
`GSBRawdumpHeader`(words[, mode, nbytes, . . .])	GSB rawdump header.
`GSBPhasedHeader`(words[, mode, nbytes, . . .])	GSB phased header.

TimeGSB

class baseband.gsb.header.**TimeGSB**(*val1*, *val2*, *scale*, *precision*, *in_subfmt*, *out_subfmt*, *from_jd=False*)
Bases: `astropy.time.TimeString`

GSB header date-time format `YYYY MM DD HH MM SS 0.SSSSSSSSS`.

For example, `2000 01 01 00 00 00 0.000000000` is midnight on January 1, 2000.

Attributes Summary

cache	Return the cache associated with this instance.
jd2_filled	
mask	
masked	
name	
scale	Time scale
value	

Methods Summary

format_string(self, str_fmt, **kwargs)	Write time to a string using a given format.
mask_if_needed(self, value)	
parse_string(self, timestr, subfmts)	Read time from a single string, using a set of possible formats.
set_jds(self, val1, val2)	Parse the time strings contained in val1 and set jd1, jd2
str_kwargs(self)	Generator that yields a dict of values corresponding to the calendar date and time for the internal JD values.
to_value(self[, parent])	Return time representation from internal jd1 and jd2.

Attributes Documentation

cache
Return the cache associated with this instance.

jd2_filled

mask

masked

name = 'gsb'

scale
Time scale

value

Methods Documentation

format_string(*self*, *str_fmt*, ***kwargs*)
Write time to a string using a given format.

By default, just interprets str_fmt as a format string, but subclasses can add to this.

mask_if_needed(*self*, *value*)

parse_string(*self*, *timestr*, *subfmts*)
Read time from a single string, using a set of possible formats.

set_jds(*self*, *val1*, *val2*)
Parse the time strings contained in val1 and set jd1, jd2

str_kwargs(*self*)
Generator that yields a dict of values corresponding to the calendar date and time for the internal JD values.

to_value(*self*, *parent=None*)
Return time representation from internal jd1 and jd2. This is the base method that ignores `parent` and requires that subclasses implement the `value` property. Subclasses that require `parent` or have other optional args for `to_value` should compute and return the value directly.

GSBHeader

class `baseband.gsb.header.`**GSBHeader**(*words*, *mode=None*, *nbytes=None*, *utc_offset=<Quantity 5.5 h>*, *verify=True*)
Bases: `baseband.vlbi_base.header.VLBIHeaderBase`

GSB Header, based on a line from a timestamp file.

Parameters

words
[list of str, or None] If `None`, set to a list of empty strings for later initialisation.

mode
[str or None, optional] Mode in which data was taken: 'phased' or 'rawdump'. If `None`, it is determined from the words.

nbytes
[int or None, optional] Number of characters in the header, including trailing blank spaces and carriage returns. If `None`, is determined from the words assuming one trailing blank space and one CR.

verify
[bool, optional] Whether to do basic verification of integrity. Default: `True`.

Returns

header
[`GSBHeader` subclass] As appropriate for the mode.

Attributes Summary

`mode`	Mode in which data was taken: 'phased' or 'rawdump'.
`mutable`	Whether the header can be modified.
`nbytes`	Size of the header in characters.

Methods Summary

copy(self, **kwargs)	Create a mutable and independent copy of the header.
fromfile(fh, *args, **kwargs)	Read GSB Header from a line from a timestamp file.
fromkeys([mode, nbytes])	Initialise a header from parsed values.
fromvalues([mode, nbytes])	Initialise a header from parsed values.
keys(self)	
seek_offset(self, n[, nbytes])	Offset in bytes needed to move a file pointer to another header.
tofile(self, fh)	Write GSB header as a line to the filehandle.
update(self, *[, verify])	Update the header by setting keywords or properties.
verify(self)	Verify that the length of the words is consistent.

Attributes Documentation

mode
Mode in which data was taken: 'phased' or 'rawdump'.

mutable
Whether the header can be modified.

nbytes
Size of the header in characters.

Assumes the string terminates in one blank space and one carriage return.

Methods Documentation

copy(*self*, ***kwargs*)
Create a mutable and independent copy of the header.

Keyword arguments can be passed on as needed by possible subclasses.

classmethod fromfile(*fh*, **args*, ***kwargs*)
Read GSB Header from a line from a timestamp file.

Arguments are the same as for class initialisation. The header constructed will be immutable.

classmethod fromkeys(*mode=None*, *nbytes=None*, **args*, ***kwargs*)
Initialise a header from parsed values.

Like fromvalues, but without any interpretation of keywords.

Raises

KeyError
[if not all keys required are present in `kwargs`]

classmethod fromvalues(*mode=None*, *nbytes=None*, **args*, ***kwargs*)
Initialise a header from parsed values.

Here, the parsed values must be given as keyword arguments, i.e., for any `header = cls(<words>)`, `cls.fromvalues(**header) == header`.

However, unlike for the `fromkeys` class method, data can also be set using arguments named after header methods, such as `time`.

Parameters

***args**
Possible arguments required to initialize an empty header.

****kwargs**
Values used to initialize header keys or methods.

`keys`(*self*)

`seek_offset`(*self*, *n*, *nbytes=None*)
Offset in bytes needed to move a file pointer to another header.

Some GSB headers have variable size and hence one cannot trivially jump to another entry in a timestamp file. This routine allows one to calculate the offset required to move the file pointer `n` headers.

Parameters

n
[int] The number of headers to move to, relative to the present header.

nbytes
[int, optional] The size in bytes of the present header (if not given, will use the header's `nbytes` property).

`tofile`(*self*, *fh*)
Write GSB header as a line to the filehandle.

`update`(*self*, ***, *verify=True*, ***kwargs*)
Update the header by setting keywords or properties.

Here, any keywords matching header keys are applied first, and any remaining ones are used to set header properties, in the order set by the class (in `_properties`).

Parameters

verify
[bool, optional] If `True` (default), verify integrity after updating.

****kwargs**
Arguments used to set keywords and properties.

`verify`(*self*)
Verify that the length of the words is consistent.

Subclasses should override this to do more thorough checks.

GSBRawdumpHeader

`class baseband.gsb.header.GSBRawdumpHeader`(*words*, *mode=None*, *nbytes=None*, *utc_offset=<Quantity 5.5 h>*, *verify=True*)

Bases: `baseband.gsb.header.GSBHeader`

GSB rawdump header.

Attributes Summary

gps_time	
mode	Mode in which data was taken: 'phased' or 'rawdump'.
mutable	Whether the header can be modified.
nbytes	Size of the header in characters.
time	

Methods Summary

copy(self, **kwargs)	Create a mutable and independent copy of the header.
fromfile(fh, *args, **kwargs)	Read GSB Header from a line from a timestamp file.
fromkeys([mode, nbytes])	Initialise a header from parsed values.
fromvalues([mode, nbytes])	Initialise a header from parsed values.
keys(self)	
seek_offset(self, n[, nbytes])	Offset in bytes needed to move a file pointer to another header.
tofile(self, fh)	Write GSB header as a line to the filehandle.
update(self, *[, verify])	Update the header by setting keywords or properties.
verify(self)	Verify that the length of the words is consistent.

Attributes Documentation

gps_time

mode
Mode in which data was taken: 'phased' or 'rawdump'.

mutable
Whether the header can be modified.

nbytes
Size of the header in characters.

Assumes the string terminates in one blank space and one carriage return.

time

Methods Documentation

copy(*self*, ***kwargs*)
Create a mutable and independent copy of the header.

Keyword arguments can be passed on as needed by possible subclasses.

classmethod fromfile(*fh*, **args*, ***kwargs*)
Read GSB Header from a line from a timestamp file.

Arguments are the same as for class initialisation. The header constructed will be immutable.

classmethod fromkeys(*mode=None*, *nbytes=None*, **args*, ***kwargs*)
Initialise a header from parsed values.

Like fromvalues, but without any interpretation of keywords.

Raises

KeyError
[if not all keys required are present in `kwargs`]

classmethod fromvalues(*mode=None*, *nbytes=None*, **args*, ***kwargs*)
Initialise a header from parsed values.

Here, the parsed values must be given as keyword arguments, i.e., for any `header = cls(<words>)`, `cls.fromvalues(**header) == header`.

However, unlike for the `fromkeys` class method, data can also be set using arguments named after header methods, such as `time`.

Parameters

***args**
Possible arguments required to initialize an empty header.

****kwargs**
Values used to initialize header keys or methods.

keys(*self*)

seek_offset(*self*, *n*, *nbytes=None*)
Offset in bytes needed to move a file pointer to another header.

Some GSB headers have variable size and hence one cannot trivially jump to another entry in a timestamp file. This routine allows one to calculate the offset required to move the file pointer `n` headers.

Parameters

n
[int] The number of headers to move to, relative to the present header.

nbytes
[int, optional] The size in bytes of the present header (if not given, will use the header's `nbytes` property).

tofile(*self*, *fh*)
Write GSB header as a line to the filehandle.

update(*self*, ***, *verify=True*, ***kwargs*)
Update the header by setting keywords or properties.

Here, any keywords matching header keys are applied first, and any remaining ones are used to set header properties, in the order set by the class (in `_properties`).

Parameters

verify
[bool, optional] If `True` (default), verify integrity after updating.

****kwargs**
Arguments used to set keywords and properties.

verify(*self*)
Verify that the length of the words is consistent.

Subclasses should override this to do more thorough checks.

GSBPhasedHeader

class baseband.gsb.header.**GSBPhasedHeader**(*words*, *mode=None*, *nbytes=None*, *utc_offset=<Quantity 5.5 h>*, *verify=True*)

Bases: baseband.gsb.header.GSBRawdumpHeader

GSB phased header.

Attributes Summary

gps_time	
mode	Mode in which data was taken: ‘phased’ or ‘rawdump’.
mutable	Whether the header can be modified.
nbytes	Size of the header in characters.
pc_time	
time	

Methods Summary

copy(self, **kwargs)	Create a mutable and independent copy of the header.
fromfile(fh, *args, **kwargs)	Read GSB Header from a line from a timestamp file.
fromkeys([mode, nbytes])	Initialise a header from parsed values.
fromvalues([mode, nbytes])	Initialise a header from parsed values.
keys(self)	
seek_offset(self, n[, nbytes])	Offset in bytes needed to move a file pointer to another header.
tofile(self, fh)	Write GSB header as a line to the filehandle.
update(self, *[, verify])	Update the header by setting keywords or properties.
verify(self)	Verify that the length of the words is consistent.

Attributes Documentation

gps_time

mode

Mode in which data was taken: ‘phased’ or ‘rawdump’.

mutable

Whether the header can be modified.

nbytes

Size of the header in characters.

Assumes the string terminates in one blank space and one carriage return.

pc_time

time

Methods Documentation

`copy`(*self*, ***kwargs*)

Create a mutable and independent copy of the header.

Keyword arguments can be passed on as needed by possible subclasses.

`classmethod fromfile`(*fh*, **args*, ***kwargs*)

Read GSB Header from a line from a timestamp file.

Arguments are the same as for class initialisation. The header constructed will be immutable.

`classmethod fromkeys`(*mode=None*, *nbytes=None*, **args*, ***kwargs*)

Initialise a header from parsed values.

Like fromvalues, but without any interpretation of keywords.

Raises

KeyError
[if not all keys required are present in `kwargs`]

`classmethod fromvalues`(*mode=None*, *nbytes=None*, **args*, ***kwargs*)

Initialise a header from parsed values.

Here, the parsed values must be given as keyword arguments, i.e., for any `header = cls(<words>)`, `cls.fromvalues(**header) == header`.

However, unlike for the `fromkeys` class method, data can also be set using arguments named after header methods, such as `time`.

Parameters

***args**
Possible arguments required to initialize an empty header.

****kwargs**
Values used to initialize header keys or methods.

`keys`(*self*)

`seek_offset`(*self*, *n*, *nbytes=None*)

Offset in bytes needed to move a file pointer to another header.

GSB headers for phased data differ in size depending on the sequence number, making it impossible to trivially jump to another entry in a timestamp file. This routine allows one to calculate the offset required to move the file pointer `n` headers.

Parameters

n
[int] The number of headers to move to, relative to the present header.

nbytes
[int, optional] The size in bytes of the present header (if not given, will use the header's `nbytes` property).

tofile(*self*, *fh*)
Write GSB header as a line to the filehandle.

update(*self*, ***, *verify=True*, ***kwargs*)
Update the header by setting keywords or properties.

Here, any keywords matching header keys are applied first, and any remaining ones are used to set header properties, in the order set by the class (in `_properties`).

Parameters

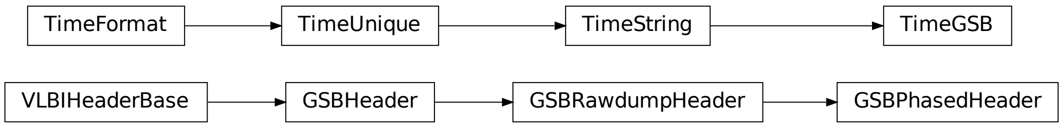
verify
[bool, optional] If `True` (default), verify integrity after updating.

****kwargs**
Arguments used to set keywords and properties.

verify(*self*)
Verify that the length of the words is consistent.

Subclasses should override this to do more thorough checks.

Class Inheritance Diagram



10.3.3 baseband.gsb.payload Module

Definitions for GSB payloads.

Implements a GSBPayload class used to store payload blocks, and decode to or encode from a data array.

See http://gmrt.ncra.tifr.res.in/gmrt_hpage/sub_system/gmrt_gsb/index.htm

Classes

`GSBPayload`(words[, sample_shape, bps, . . .])	Container for decoding and encoding GSB payloads.

GSBPayload

class baseband.gsb.payload.**GSBPayload**(*words*, *sample_shape=()*, *bps=2*, *complex_data=False*)
Bases: `baseband.vlbi_base.payload.VLBIPayloadBase`

Container for decoding and encoding GSB payloads.

Parameters

words
[ndarray] Array containg LSB unsigned words (with the right size) that encode the payload.

sample_shape
[tuple, optional] Shape of the samples; e.g., (nchan,). Default: ().

bps
[int, optional] Bits per elementary sample. Default: 2.

complex_data
[bool, optional] Whether data are complex. Default: `False`.

Attributes Summary

`data`	Full decoded payload.
`dtype`	Numeric type of the decoded data array.
`nbytes`	Size of the payload in bytes.
`ndim`	Number of dimensions of the decoded data array.
`shape`	Shape of the decoded data array.
`size`	Total number of component samples in the decoded data array.

Methods Summary

`fromdata`(data[, header, bps])	Encode data as a payload.
`fromfile`(fh[, payload_nbytes, nchan, bps, . . .])	Read payloads from several threads.
`tofile`(self, fh)	Write payload to filehandle.

Attributes Documentation

`data`
Full decoded payload.

`dtype`
Numeric type of the decoded data array.

`nbytes`
Size of the payload in bytes.

`ndim`
Number of dimensions of the decoded data array.

`shape`
Shape of the decoded data array.

`size`
Total number of component samples in the decoded data array.

Methods Documentation

`classmethod fromdata`(*data*, *header=None*, *bps=2*)
Encode data as a payload.

Parameters

data
[ndarray] Data to be encoded. The last dimension is taken as the number of channels.

header
[header instance, optional] If given, used to infer the bps.

bps
[int, optional] Bits per elementary sample, i.e., per channel and per real or imaginary component, used if header is not given. Default: 2.

classmethod fromfile(*fh*, *payload_nbytes=None*, *nchan=1*, *bps=4*, *complex_data=False*)
Read payloads from several threads.

Parameters

fh
[filehandle or tuple of tuple of filehandle] Handles to the sets of files from which data are read. The outer tuple holds distinct threads, while the inner ones holds parts of those threads. Typically, these are the two polarisations and the two parts of each in which phased baseband data are stored.

payload_nbytes
[int] Number of bytes to read from each part.

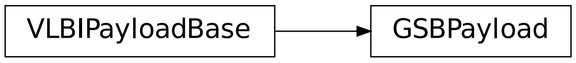
nchan
[int, optional] Number of channels. Default: 1.

bps
[int, optional] Bits per elementary sample. Default: 4.

complex_data
[bool, optional] Whether data are complex. Default: `False`.

tofile(*self*, *fh*)
Write payload to filehandle.

Class Inheritance Diagram



10.3.4 baseband.gsb.frame Module

Classes

`GSBFrame`(header, payload[, valid, verify])	Frame encapsulating GSB rawdump or phased data.

GSBFrame

class `baseband.gsb.frame.`**`GSBFrame`**(*header*, *payload*, *valid=True*, *verify=True*)

Bases: `baseband.vlbi_base.frame.VLBIFrameBase`

Frame encapsulating GSB rawdump or phased data.

For rawdump data, lines in the timestamp file are associated with single blocks of raw data. For phased data, the lines are associated with one or two polarisations, each consisting of two blocks of raw data. Hence, the raw data come from two or four files.

Parameters

header
[`GSBHeader`] Based on line from rawdump or phased timestamp file.

payload
[`GSBPayload`] Based on a single block of rawdump data, or the combined blocks for phased data.

valid
[bool, optional] Whether the data are valid. Default: `True`.

verify
[bool, optional] Whether to verify consistency of the frame parts. Default: `True`.

Notes

GSB files do not support storing whether data are valid or not on disk. Hence, this has to be determined independently. If `valid=False`, any decoded data are set to `cls.fill_value` (by default, 0).

The Frame can also be read instantiated using class methods:

fromfile : read header and payload from their respective filehandles

fromdata : encode data as payload

Of course, one can also do the opposite:

tofile
[method to write header and payload to filehandles (splitting] payload in the appropriate files).

data : property that yields full decoded payload

A number of properties are defined: `shape`, `dtype` and `size` are the shape, type and number of complete samples of the data array, and `nbytes` the frame size in bytes. Furthermore, the frame acts as a dictionary, with keys those of the header. Any attribute that is not defined on the frame itself, such as `.time` will be looked up on the header as well.

Attributes Summary

`data`	Full decoded frame.
`dtype`	Numeric type of the frame data.

Continued on next page

Table 22 – continued from previous page

fill_value	Value to replace invalid data in the frame.
nbytes	Size of the encoded frame in the raw data file in bytes.
ndim	Number of dimensions of the frame data.
sample_shape	Shape of a sample in the frame (nchan,).
shape	Shape of the frame data.
size	Total number of component samples in the frame data.
valid	Whether frame contains valid data.

Methods Summary

fromdata(data, header, *args[, valid, verify])	Construct frame from data and header.
fromfile(fh_ts, fh_raw[, payload_nbytes, . . .])	Read a frame from timestamp and raw data filehandles.
keys(self)	
tofile(self, fh_ts, fh_raw)	Write encoded frame to timestamp and raw data filehandles.
verify(self)	Simple verification.

Attributes Documentation

data
Full decoded frame.

dtype
Numeric type of the frame data.

fill_value
Value to replace invalid data in the frame.

nbytes
Size of the encoded frame in the raw data file in bytes.

ndim
Number of dimensions of the frame data.

sample_shape
Shape of a sample in the frame (nchan,).

shape
Shape of the frame data.

size
Total number of component samples in the frame data.

valid
Whether frame contains valid data.

Methods Documentation

classmethod fromdata(*data*, *header*, **args*, *valid=True*, *verify=True*, ***kwargs*)
Construct frame from data and header.

Parameters

data
[ndarray] Array holding data to be encoded.

header
[VLBIHeaderBase] Header for the frame.

***args, **kwargs :**
Any arguments beyond the filehandle are used to help initialize the payload, except for `valid` and `verify`, which are passed on to the header and class initializers.

valid
[bool, optional] Whether this payload contains valid data.

verify
[bool, optional] Whether to verify the header and frame correctness.

classmethod fromfile(*fh_ts*, *fh_raw*, *payload_nbytes=16777216*, *nchan=1*, *bps=4*, *complex_data=False*, *valid=True*, *verify=True*)
Read a frame from timestamp and raw data filehandles.

Any arguments beyond the filehandle are used to help initialize the payload, except for `valid` and `verify`, which are passed on to the header and class initializers.

Parameters

fh_ts
[filehandle] To the timestamp file. The next line will be read.

fh_raw
[file_handle or tuple] Should be a single handle for a rawdump data frame, or a tuple containing tuples with pairs of handles for a phased one. E.g., `((L1, L2), (R1, R2))` for left and right polarisations.

payload_nbytes
[int, optional] Size of the individual payloads in bytes. Default: `2**24` (16 MB).

nchan
[int, optional] Number of channels. Default: 1.

bps
[int, optional] Bits per elementary sample. Default: 4.

complex_data
[bool, optional] Whether data are complex. Default: `False`.

valid
[bool, optional] Whether the data are valid (default: `True`). Note that this cannot be inferred from the header or payload itself. If `False`, any data read will be set to `cls.fill_value`.

verify
[bool, optional] Whether to verify consistency of the frame parts. Default: `True`.

keys(*self*)

tofile(*self*, *fh_ts*, *fh_raw*)
Write encoded frame to timestamp and raw data filehandles.

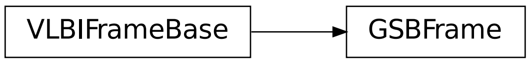
Parameters

fh_ts
[filehandle] To the timestamp file. A line will be added to it.

fh_raw
[file_handle or tuple] Should be a single handle for a rawdump data frame, or a tuple containing tuples with pairs of handles for a phased one. E.g., `((L1, L2), (R1, R2))` for left and right polarisations.

`verify`(*self*)
Simple verification. To be added to by subclasses.

Class Inheritance Diagram



10.3.5 baseband.gsb.base Module

Functions

open(name[, mode])	Open GSB file(s) for reading or writing.

open

`baseband.gsb.base.`**`open`**(*name*, *mode='rs'*, ***kwargs*)
Open GSB file(s) for reading or writing.

A GSB data set contains a text header file and one or more raw data files. When the file is opened as text, one gets a standard filehandle, but with methods to read/write timestamps. When it is opened as a binary, one similarly gets methods to read/write frames. Opened as a stream, the file is interpreted as a timestamp file, but raw files need to be given too. This allows access to the stream(s) as series of samples.

Parameters

name
[str] Filename of timestamp or raw data file.

mode
[{'rb', 'wb', 'rt', 'wt', 'rs', or 'ws'}, optional] Whether to open for reading or writing, and as a regular text or binary file (for timestamps and data, respectively) or as a stream. Default: 'rs', for reading a stream.

****kwargs**
Additional arguments when opening the file as a stream.

— For both reading and writing of streams :

raw
[str or (tuple of) tuple of str] Name of files holding payload data. A single file is needed for rawdump, and a tuple for phased. For a nested tuple, the outer tuple determines the number of polarizations, and the inner tuple(s) the number of streams per polarization. E.g., `((polL1, polL2), (polR1, polR2))` for two streams per polarization. A single tuple is interpreted as streams of a single polarization.

sample_rate
[`Quantity`, optional] Number of complete samples per second, i.e. the rate at which each channel of each polarization is sampled. If `None`, will be inferred assuming the frame rate is exactly 251.658240 ms.

samples_per_frame
[int, optional] Number of complete samples per frame. Can give `payload_nbytes` instead.

payload_nbytes
[int, optional] Number of bytes per payload, divided by the number of raw files. If both `samples_per_frame` and `payload_nbytes` are `None`, `payload_nbytes` is set to `2**22` (4 MB) for rawdump, and `2**23` (8 MB) divided by the number of streams per polarization for phased.

nchan
[int, optional] Number of channels. Default: 1 for rawdump, 512 for phased.

bps
[int, optional] Bits per elementary sample, i.e. per real or imaginary component for complex data. Default: 4 for rawdump, 8 for phased.

complex_data
[bool, optional] Whether data are complex. Default: `False` for rawdump, `True` for phased.

squeeze
[bool, optional] If `True` (default) and reading, remove any dimensions of length unity from decoded data. If `True` and writing, accept squeezed arrays as input, and adds any dimensions of length unity.

— For reading only
[(see `GSBStreamReader`)]

subset
[indexing object or tuple of objects, optional] Specific components of the complete sample to decode (after possibly squeezing). If a single indexing object is passed, it selects (available) polarizations. If a tuple is passed, the first selects polarizations and the second selects channels. If the tuple is empty (default), all components are read.

verify
[bool, optional] Whether to do basic checks of frame integrity when reading. The first frame of the stream is always checked. Default: `True`.

— For writing only
[(see `GSBStreamWriter`)]

header0
[`GSBHeader`] Header for the first frame, holding time information, etc. Can instead give keyword arguments to construct a header.

****kwargs**
If the header is not given, an attempt will be made to construct one with any further keyword

arguments. If one requires to explicitly set the mode of the GSB stream, use `header_mode`. If not given, it will be 'rawdump' if only a single raw file is present, or 'phased' otherwise. See `GSBStreamWriter`.

Returns

Filehandle
`GSBFileReader` or `GSBFileWriter` (binary), or `GSBStreamReader` or `GSBStreamWriter` (stream)

Classes

`GSBTimeStampIO`(fh_raw)	Simple reader/writer for GSB time stamp files.
`GSBFileReader`(fh_raw, payload_nbytes[, ...])	Simple reader for GSB data files.
`GSBFileWriter`(fh_raw)	Simple writer for GSB data files.
`GSBStreamBase`(fh_ts, fh_raw, header0[, ...])	Base for GSB streams.
`GSBStreamReader`(fh_ts, fh_raw[, ...])	GSB format reader.
`GSBStreamWriter`(fh_ts, fh_raw[, header0, ...])	GSB format writer.

GSBTimeStampIO

class baseband.gsb.base.**GSBTimeStampIO**(*fh_raw*)
Bases: `baseband.vlbi_base.base.VLBIFileBase`

Simple reader/writer for GSB time stamp files.

Wraps a binary filehandle, providing methods `read_timestamp`, `write_timestamp`, and `get_frame_rate`.

Parameters

fh_raw
[filehandle] Filehandle to the timestamp file, opened in binary mode.

Attributes Summary

`info`()	

Methods Summary

`close`(self)	
`get_frame_rate`(self)	Determine the number of frames per second.
`read_timestamp`(self)	Read a single timestamp.
`temporary_offset`(self)	Context manager for temporarily seeking to another file position.
`write_timestamp`(self[, header])	Write a single timestamp.

Attributes Documentation

info

Methods Documentation

close(*self*)

get_frame_rate(*self*)
Determine the number of frames per second.

The frame rate is inferred from the first two timestamps.

Returns

frame_rate
[Quantity] Frames per second.

read_timestamp(*self*)
Read a single timestamp.

Returns

frame
[GSBHeader] With a .time property that returns the time encoded.

temporary_offset(*self*)
Context manager for temporarily seeking to another file position.

To be used as part of a with statement:

```
with fh_raw.temporary_offset() [as fh_raw]:
    with-block
```

On exiting the with-block, the file pointer is moved back to its original position.

write_timestamp(*self*, *header=None*, ***kwargs*)
Write a single timestamp.

Parameters

header
[GSBHeader, optional] Header holding time to be written to disk. Can instead give keyword arguments to construct a header.

****kwargs :**
If header is not given, these are used to initialize one.

GSBFileReader

class baseband.gsb.base.**GSBFileReader**(*fh_raw*, *payload_nbytes*, *nchan=1*, *bps=4*, *complex_data=False*)
Bases: baseband.vlbi_base.base.VLBIFileBase

Simple reader for GSB data files.

Wraps a binary filehandle, providing a read_payload method to help interpret the data.

Parameters

payload_nbytes
[int] Number of bytes to read.

nchan
[int, optional] Number of channels. Default: 1.

bps
[int, optional] Bits per elementary sample, i.e. per real or imaginary component for complex data. Default: 4.

complex_data
[bool, optional] Whether data are complex. Default: `False`.

Methods Summary

`close`(self)	
`read_payload`(self)	Read a single block.
`temporary_offset`(self)	Context manager for temporarily seeking to another file position.

Methods Documentation

close(*self*)

read_payload(*self*)
Read a single block.

Returns

frame
[`GSBPayload`] With a `.data` property that returns the data encoded.

temporary_offset(*self*)
Context manager for temporarily seeking to another file position.

To be used as part of a `with` statement:

```
with fh_raw.temporary_offset() [as fh_raw]:
    with-block
```

On exiting the `with-block`, the file pointer is moved back to its original position.

GSBFileWriter

class baseband.gsb.base.**GSBFileWriter**(*fh_raw*)
Bases: `baseband.vlbi_base.base.VLBIFileBase`

Simple writer for GSB data files.

Adds `write_payload` method to the basic VLBI binary file wrapper.

Methods Summary

close(self)	
temporary_offset(self)	Context manager for temporarily seeking to another file position.
write_payload(self, data[, bps])	Write single data block.

Methods Documentation

close(*self*)

temporary_offset(*self*)

Context manager for temporarily seeking to another file position.

To be used as part of a `with` statement:

```
with fh_raw.temporary_offset() [as fh_raw]:
    with-block
```

On exiting the `with-block`, the file pointer is moved back to its original position.

write_payload(*self*, *data*, *bps=4*)

Write single data block.

Parameters

data
[ndarray or GSBPayload] If an array, bps needs to be passed in.

bps
[int, optional] Bits per elementary sample, to use when encoding the payload. Ignored if `data` is a GSB payload. Default: 4.

GSBStreamBase

class baseband.gsb.base.**GSBStreamBase**(*fh_ts*, *fh_raw*, *header0*, *sample_rate=None*, *samples_per_frame=None*, *payload_nbytes=None*, *nchan=None*, *bps=None*, *complex_data=None*, *squeeze=True*, *subset=()*, *verify=True*)

Bases: `baseband.vlbi_base.base.VLBIStreamBase`

Base for GSB streams.

Attributes Summary

bps	Bits per elementary sample.
complex_data	Whether the data are complex.
header0	First header of the file.
sample_rate	Number of complete samples per second.
sample_shape	Shape of a complete sample (possibly subset or squeezed).
samples_per_frame	Number of complete samples per frame.

Continued on next page

Table 30 – continued from previous page

squeeze	Whether data arrays have dimensions with length unity removed.
start_time	Start time of the file.
subset	Specific components of the complete sample to decode.
time	Time of the sample pointer's current offset in file.
verify	Whether to do consistency checks on frames being read.

Methods Summary

close(self)	
tell(self[, unit])	Current offset in the file.

Attributes Documentation

bps
Bits per elementary sample.

complex_data
Whether the data are complex.

header0
First header of the file.

sample_rate
Number of complete samples per second.

sample_shape
Shape of a complete sample (possibly subset or squeezed).

samples_per_frame
Number of complete samples per frame.

squeeze
Whether data arrays have dimensions with length unity removed.

If `True`, data read out has such dimensions removed, and data passed in for writing has them inserted.

start_time
Start time of the file.

See also `time` for the time of the sample pointer's current offset.

subset
Specific components of the complete sample to decode.

The order of dimensions is the same as for `sample_shape`. Set by the class initializer.

time
Time of the sample pointer's current offset in file.

See also `start_time` for the start time of the file.

verify
Whether to do consistency checks on frames being read.

Methods Documentation

close(*self*)

tell(*self*, *unit=None*)

Current offset in the file.

Parameters

unit
[`Unit` or str, optional] Time unit the offset should be returned in. By default, no unit is used, i.e., an integer enumerating samples is returned. For the special string 'time', the absolute time is calculated.

Returns

offset
[int, `Quantity`, or `Time`] Offset in current file (or time at current position).

GSBStreamReader

class baseband.gsb.base.**GSBStreamReader**(*fh_ts*, *fh_raw*, *sample_rate=None*, *samples_per_frame=None*, *payload_nbytes=None*, *nchan=None*, *bps=None*, *complex_data=None*, *squeeze=True*, *subset=()*, *verify=True*)

Bases: `baseband.gsb.base.GSBStreamBase`, `baseband.vlbi_base.base.VLBIStreamReaderBase`

GSB format reader.

Allows access to GSB files as a continuous series of samples. Requires both a timestamp and one or more corresponding raw data files.

Parameters

fh_ts
[`GSBTimeStampIO`] Header filehandle.

fh_raw
[filehandle, or nested tuple of filehandles] Raw binary data filehandle(s). A single file is needed for rawdump, and a tuple for phased. For a nested tuple, the outer tuple determines the number of polarizations, and the inner tuple(s) the number of streams per polarization. E.g., `((polL1, polL2), (polR1, polR2))` for two streams per polarization. A single tuple is interpreted as streams of a single polarization.

sample_rate
[`Quantity`, optional] Number of complete samples per second, i.e. the rate at which each channel of each polarization is sampled. If `None`, will be inferred assuming the frame rate is exactly 0.25165824 s.

samples_per_frame
[int, optional] Number of complete samples per frame. Can give `payload_nbytes` instead.

payload_nbytes
[int, optional] Number of bytes per payload, divided by the number of raw files. If both `samples_per_frame` and `payload_nbytes` are `None`, `payload_nbytes` is set to `2**22` (4

MB) for rawdump, and 2**23 (8 MB) divided by the number of streams per polarization for phased.

nchan
[int, optional] Number of channels. Default: 1 for rawdump, 512 for phased.

bps
[int, optional] Bits per elementary sample, i.e. per real or imaginary component for complex data. Default: 4 for rawdump, 8 for phased.

complex_data
[bool, optional] Whether data are complex. Default: `False` for rawdump, `True` for phased.

squeeze
[bool, optional] If `True` (default), remove any dimensions of length unity from decoded data.

subset
[indexing object or tuple of objects, optional] Specific components of the complete sample to decode (after possibly squeezing). If a single indexing object is passed, it selects (available) polarizations. If a tuple is passed, the first selects polarizations and the second selects channels. If the tuple is empty (default), all components are read.

verify
[bool, optional] Whether to do basic checks of frame integrity when reading. The first frame of the stream is always checked. Default: `True`.

Attributes Summary

`bps`	Bits per elementary sample.
`complex_data`	Whether the data are complex.
`dtype`	
`fill_value`	Value to use for invalid or missing data.
`header0`	First header of the file.
`info`()	
`ndim`	Number of dimensions of the (squeezed/subset) stream data.
`sample_rate`	Number of complete samples per second.
`sample_shape`	Shape of a complete sample (possibly subset or squeezed).
`samples_per_frame`	Number of complete samples per frame.
`shape`	Shape of the (squeezed/subset) stream data.
`size`	Total number of component samples in the (squeezed/subset) stream data.
`squeeze`	Whether data arrays have dimensions with length unity removed.
`start_time`	Start time of the file.
`stop_time`	Time at the end of the file, just after the last sample.
`subset`	Specific components of the complete sample to decode.
`time`	Time of the sample pointer's current offset in file.
`verify`	Whether to do consistency checks on frames being read.

Methods Summary

close(self)	
read(self[, count, out])	Read a number of complete (or subset) samples.
readable(self)	Whether the file can be read and decoded.
seek(self, offset[, whence])	Change the stream position.
tell(self[, unit])	Current offset in the file.

Attributes Documentation

bps
Bits per elementary sample.

complex_data
Whether the data are complex.

dtype

fill_value
Value to use for invalid or missing data. Default: 0.

header0
First header of the file.

info

ndim
Number of dimensions of the (squeezed/subset) stream data.

sample_rate
Number of complete samples per second.

sample_shape
Shape of a complete sample (possibly subset or squeezed).

samples_per_frame
Number of complete samples per frame.

shape
Shape of the (squeezed/subset) stream data.

size
Total number of component samples in the (squeezed/subset) stream data.

squeeze
Whether data arrays have dimensions with length unity removed.

If `True`, data read out has such dimensions removed, and data passed in for writing has them inserted.

start_time
Start time of the file.

See also `time` for the time of the sample pointer's current offset, and (if available) `stop_time` for the time at the end of the file.

stop_time
Time at the end of the file, just after the last sample.

See also `start_time` for the start time of the file, and `time` for the time of the sample pointer's current offset.

`subset`
Specific components of the complete sample to decode.

The order of dimensions is the same as for `sample_shape`. Set by the class initializer.

`time`
Time of the sample pointer's current offset in file.

See also `start_time` for the start time, and (if available) `stop_time` for the end time, of the file.

`verify`
Whether to do consistency checks on frames being read.

Methods Documentation

`close`(*self*)

`read`(*self*, *count=None*, *out=None*)
Read a number of complete (or subset) samples.

The range retrieved can span multiple frames.

Parameters

count
[int or None, optional] Number of complete/subset samples to read. If `None` (default) or negative, the whole file is read. Ignored if `out` is given.

out
[None or array, optional] Array to store the data in. If given, `count` will be inferred from the first dimension; the other dimension should equal `sample_shape`.

Returns

out
[`ndarray` of float or complex] The first dimension is sample-time, and the remainder given by `sample_shape`.

`readable`(*self*)
Whether the file can be read and decoded.

`seek`(*self*, *offset*, *whence=0*)
Change the stream position.

This works like a normal filehandle seek, but the offset is in samples (or a relative or absolute time).

Parameters

offset
[int, `Quantity`, or `Time`] Offset to move to. Can be an (integer) number of samples, an offset in time units, or an absolute time.

whence
[{0, 1, 2, 'start', 'current', or 'end'}, optional] Like regular seek, the offset is taken to be from the start if `whence=0` (default), from the current position if 1, and from the end if 2.

One can alternativey use 'start', 'current', or 'end' for 0, 1, or 2, respectively. Ignored if `offset` is a time.

tell(*self*, *unit=None*)
Current offset in the file.

Parameters

unit
[`Unit` or str, optional] Time unit the offset should be returned in. By default, no unit is used, i.e., an integer enumerating samples is returned. For the special string 'time', the absolute time is calculated.

Returns

offset
[int, `Quantity`, or `Time`] Offset in current file (or time at current position).

GSBStreamWriter

class baseband.gsb.base.**GSBStreamWriter**(*fh_ts*, *fh_raw*, *header0=None*, *sample_rate=None*, *samples_per_frame=None*, *payload_nbytes=None*, *nchan=None*, *bps=None*, *complex_data=None*, *squeeze=True*, ***kwargs*)
Bases: `baseband.gsb.base.GSBStreamBase`, `baseband.vlbi_base.base.VLBIStreamWriterBase`

GSB format writer.

Encodes and writes sequences of samples to file.

Parameters

fh_ts
[`GSBTimeStampIO`] For writing headers to storage.

fh_raw
[filehandle, or nested tuple of filehandles] For writing raw binary data to storage. A single file is needed for rawdump, and a tuple for phased. For a nested tuple, the outer tuple determines the number of polarizations, and the inner tuple(s) the number of streams per polarization. E.g., `((polL1, polL2), (polR1, polR2))` for two streams per polarization. A single tuple is interpreted as streams of a single polarization.

header0
[`GSBHeader`] Header for the first frame, holding time information, etc. Can instead give keyword arguments to construct a header (see `**kwargs`).

sample_rate
[`Quantity`, optional] Number of complete samples per second, i.e. the rate at which each channel of each polarization is sampled. If not given, will be inferred assuming the frame rate is exactly 0.25165824 s.

samples_per_frame
[int, optional] Number of complete samples per frame. Can give `payload_nbytes` instead.

payload_nbytes
[int, optional] Number of bytes per payload, divided by the number of raw files. If both `samples_per_frame` and `payload_nbytes` are `None`, `payload_nbytes` is set to `2**22` (4

MB) for rawdump, and 2**23 (8 MB) divided by the number of streams per polarization for phased.

nchan
[int, optional] Number of channels. Default: 1 for rawdump, 512 for phased.

bps
[int, optional] Bits per elementary sample, i.e. per real or imaginary component for complex data. Default: 4 for rawdump, 8 for phased.

complex_data
[bool, optional] Whether data are complex. Default: `False` for rawdump, `True` for phased.

squeeze
[bool, optional] If `True` (default), `write` accepts squeezed arrays as input, and adds any dimensions of length unity.

****kwargs**
If no header is given, an attempt is made to construct one from these. For a standard header, this would include the following.

— Header keywords
[(see `fromvalues()`)]

time
[`Time`] Start time of the file.

header_mode
['rawdump' or 'phased', optional] Used to explicitly set the mode of the GSB stream. Default: 'rawdump' if only a single raw file is present, or 'phased' otherwise.

seq_nr
[int, optional] Frame number, only used for phased (default: 0).

Attributes Summary

`bps`	Bits per elementary sample.
`complex_data`	Whether the data are complex.
`header0`	First header of the file.
`sample_rate`	Number of complete samples per second.
`sample_shape`	Shape of a complete sample (possibly subset or squeezed).
`samples_per_frame`	Number of complete samples per frame.
`squeeze`	Whether data arrays have dimensions with length unity removed.
`start_time`	Start time of the file.
`subset`	Specific components of the complete sample to decode.
`time`	Time of the sample pointer's current offset in file.
`verify`	Whether to do consistency checks on frames being read.

Methods Summary

close(self)	
flush(self)	
tell(self[, unit])	Current offset in the file.
write(self, data[, valid])	Write data, buffering by frames as needed.

Attributes Documentation

bps
Bits per elementary sample.

complex_data
Whether the data are complex.

header0
First header of the file.

sample_rate
Number of complete samples per second.

sample_shape
Shape of a complete sample (possibly subset or squeezed).

samples_per_frame
Number of complete samples per frame.

squeeze
Whether data arrays have dimensions with length unity removed.

If `True`, data read out has such dimensions removed, and data passed in for writing has them inserted.

start_time
Start time of the file.

See also `time` for the time of the sample pointer's current offset.

subset
Specific components of the complete sample to decode.

The order of dimensions is the same as for `sample_shape`. Set by the class initializer.

time
Time of the sample pointer's current offset in file.

See also `start_time` for the start time of the file.

verify
Whether to do consistency checks on frames being read.

Methods Documentation

close(*self*)

flush(*self*)

tell(*self*, *unit=None*)
Current offset in the file.

Parameters

unit
[Unit or str, optional] Time unit the offset should be returned in. By default, no unit is used, i.e., an integer enumerating samples is returned. For the special string 'time', the absolute time is calculated.

Returns

offset
[int, Quantity, or Time] Offset in current file (or time at current position).

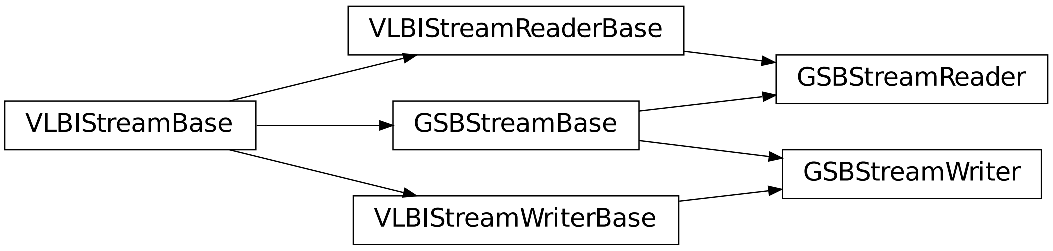
write(*self*, *data*, *valid=True*)
Write data, buffering by frames as needed.

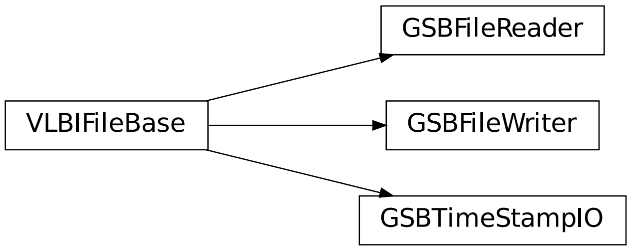
Parameters

data
[ndarray] Piece of data to be written, with sample dimensions as given by sample_shape. This should be properly scaled to make best use of the dynamic range delivered by the encoding.

valid
[bool, optional] Whether the current data are valid. Default: True.

Class Inheritance Diagram





Part III

Core Framework and Utilities

These sections contain APIs and usage notes for the sequential file opener, the API for the set of core utility functions and classes located in `vlbi_base`, and sample data that come with baseband (mostly used for testing).

CHAPTER

ELEVEN

BASEBAND HELPERS

Helpers assist with reading and writing all file formats. Currently, they only include the `sequentialfile` module for reading a sequence of files as a single one.

11.1 Sequential File

The `sequentialfile` module is for reading from and writing to a sequence of files as if they were a single, contiguous one. Like with file formats, there is a master `sequentialfile.open` function to open sequences either for reading or writing. It returns sequential file objects that have `read`, `write`, `seek`, `tell`, and `close` methods that work identically to their single file object counterparts. They additionally have `memmap` methods to read or write to files through `numpy.memmap`.

It is usually unnecessary to directly access `sequentialfile`, since it is used by `baseband.open` and all format openers (except GSB) whenever a sequence of files is passed - see the *Using Baseband documentation* for details. For finer control of file opening, however, one may manually create a `sequentialfile` object, then pass it to an opener.

To illustrate, we rewrite the multi-file example from *Using Baseband*. We first load the required data:

```
>>> from baseband import vdif
>>> from baseband.data import SAMPLE_VDIF
>>> import numpy as np
>>> fh = vdif.open(SAMPLE_VDIF, 'rs')
>>> d = fh.read()
```

We now create a sequence of filenames and calculate the byte size per file, then pass these to `open`:

```
>>> from baseband.helpers import sequentialfile as sf
>>> filenames = ["seqvdif_{0}".format(i) for i in range(2)]
>>> file_size = fh.fh_raw.seek(0, 2) // 2
>>> fwr = sf.open(filenames, mode='w+b', file_size=file_size)
```

The first argument passed to `open` must be a **time-ordered sequence** of filenames in a list, tuple, or other container that returns `IndexError` when the index is out of bounds. The read mode is 'w+b' (a requirement of all format openers just in case they use `numpy.memmap`), and `file_size` determines the largest size a file may reach before the next one in the sequence is opened for writing. We set `file_size` such that each file holds exactly one frameset.

To write the data, we pass `fwr` to `vdif.open`:

```
>>> fw = vdif.open(fwr, 'ws', header0=fh.header0,
...                sample_rate=fh.sample_rate,
...                nthread=fh.sample_shape.nthread)
>>> fw.write(d)
>>> fw.close()    # This implicitly closes fwr.
```

To read the sequence and confirm their contents are identical to the sample file's, we may again use open:

```
>>> frr = sf.open(filenames, mode='rb')
>>> fr = vdif.open(frr, 'rs', sample_rate=fh.sample_rate)
>>> fr.header0.time == fh.header0.time
True
>>> np.all(fr.read() == d)
True
>>> fr.close()
>>> fh.close()  # Close sample file.
```

11.2 Reference/API

11.2.1 baseband.helpers Package

11.2.2 baseband.helpers.sequentialfile Module

Functions

open(files[, mode, file_size, opener])	Read or write several files as if they were one contiguous one.

open

baseband.helpers.sequentialfile.**open**(*files*, *mode='rb'*, *file_size=None*, *opener=None*)

Read or write several files as if they were one contiguous one.

Parameters

files
[list, tuple, or other iterable of str, filehandle] Contains the names of the underlying files that should be combined, ordered in time. If not a list or tuple, it should allow indexing with positive indices, and raise IndexError if these are out of range.

mode
[str, optional] The mode with which the files should be opened (default: 'rb').

file_size
[int, optional] For writing, the maximum size of a file, beyond which a new file should be opened. Default: None, which means it is unlimited and only a single file will be written.

opener
[callable, optional] Function to open a single file (default: io.open).

Notes

The returned reader/writer will have a memmap method with which part of the files can be mapped to memory (like with memmap), as long as those parts do not span files (and the underlying files are regular ones). For writing, this requires opening in read-write mode (i.e., 'w+b').

Methods other than read, write, seek, tell, and close are tried on the underlying file. This implies, e.g., readline is possible, though the line cannot span multiple files.

The reader assumes the sequence of files is **contiguous in time**, ie. with no gaps in the data.

Classes

`FileNameSequencer`(template[, header])	List-like generator of filenames using a template.
`SequentialFileBase`(files[, mode, opener])	Deal with several files as if they were one contiguous one.
`SequentialFileReader`(files[, mode, opener])	Read several files as if they were one contiguous one.
`SequentialFileWriter`(files[, mode, . . .])	Write several files as if they were one contiguous one.

FileNameSequencer

class `baseband.helpers.sequentialfile.`**`FileNameSequencer`**(*template*, *header={}*)

Bases: `object`

List-like generator of filenames using a template.

The template is formatted, filling in any items in curly brackets with values from the header. It is additionally possible to insert a file number equal to the indexing value, indicated with '{file_nr}'.

The length of the instance will be the number of files that exist that match the template for increasing values of the file number (when writing, it is the number of files that have so far been generated).

Parameters

template
[str] Template to format to get specific filenames. Curly bracket item keywords are case-sensitive (eg. '{FRAME_NR}' or '{Frame_NR}' will not use `header['frame_nr']`.

header
[dict-like] Structure holding key'd values that are used to fill in the format.

Examples

```
>>> from baseband import vdif
>>> from baseband.helpers import sequentialfile as sf
>>> vfs = sf.FileNameSequencer('a{file_nr:03d}.vdif')
>>> vfs[10]
'a010.vdif'
>>> from baseband.data import SAMPLE_VDIF
>>> with vdif.open(SAMPLE_VDIF, 'rb') as fh:
...     header = vdif.VDIFHeader.fromfile(fh)
>>> vfs = sf.FileNameSequencer('obs.edv{edv:d}.{file_nr:05d}.vdif', header)
>>> vfs[10]
'obs.edv3.00010.vdif'
```

SequentialFileBase

class `baseband.helpers.sequentialfile.`**`SequentialFileBase`**(*files*, *mode='rb'*, *opener=None*)

Bases: `object`

Deal with several files as if they were one contiguous one.

For details, see SequentialFileReader and SequentialFileWriter.

Methods Summary

close(self)	Close the currently open local file, and therewith the set.
memmap(self[, dtype, mode, offset, shape, order])	Map part of the file in memory.
tell(self)	Return the current stream position.

Methods Documentation

close(*self*)
Close the currently open local file, and therewith the set.

memmap(*self*, *dtype=<class 'numpy.uint8'>*, *mode=None*, *offset=None*, *shape=None*, *order='C'*)
Map part of the file in memory.

Note that the map cannnot span multiple underlying files. Parameters are as for memmap.

tell(*self*)
Return the current stream position.

SequentialFileReader

class baseband.helpers.sequentialfile.**SequentialFileReader**(*files*, *mode='rb'*, *opener=None*)
Bases: baseband.helpers.sequentialfile.SequentialFileBase

Read several files as if they were one contiguous one.

Parameters

files
[list, tuple, or other iterable of str, filehandle] The contains the names of the underlying files that should be combined. If not a list or tuple, it should allow indexing with positive indices, and raise IndexError if these are out of range.

mode
[str, optional] The mode with which the files should be opened (default: 'rb')

opener
[callable, optional] Function to open a single file (default: io.open).

Attributes Summary

file_size	Size of the underlying file currently open for reading.
size	Size of all underlying files combined.

Methods Summary

close(self)	Close the currently open local file, and therewith the set.
memmap(self[, dtype, mode, offset, shape, order])	Map part of the file in memory.
read(self[, count])	Read and return up to n bytes.
seek(self, offset[, whence])	Change stream position.
tell(self)	Return the current stream position.

Attributes Documentation

file_size
Size of the underlying file currently open for reading.

size
Size of all underlying files combined.

Methods Documentation

close(*self*)
Close the currently open local file, and therewith the set.

memmap(*self*, *dtype=<class 'numpy.uint8'>*, *mode=None*, *offset=None*, *shape=None*, *order='C'*)
Map part of the file in memory.

Note that the map cannnot span multiple underlying files. Parameters are as for `memmap`.

read(*self*, *count=None*)
Read and return up to n bytes.

If the argument is omitted, None, or negative, reads and returns all data until EOF.

If the argument is positive, and the underlying raw stream is not 'interactive', multiple raw reads may be issued to satisfy the byte count (unless EOF is reached first). But for interactive raw streams (as well as sockets and pipes), at most one raw read will be issued, and a short result does not imply that EOF is imminent.

Returns an empty bytes object on EOF.

Returns None if the underlying raw stream was open in non-blocking mode and no data is available at the moment.

seek(*self*, *offset*, *whence=0*)
Change stream position.

Change the stream position to the given byte offset. The offset is interpreted relative to the position indicated by whence. Values for whence are:

- 0 – start of stream (the default); offset should be zero or positive
- 1 – current stream position; offset may be negative
- 2 – end of stream; offset is usually negative

Return the new absolute position.

tell(*self*)
Return the current stream position.

SequentialFileWriter

class baseband.helpers.sequentialfile.**SequentialFileWriter**(*files*, *mode='w+b'*, *file_size=None*, *opener=None*)

Bases: `baseband.helpers.sequentialfile.SequentialFileBase`

Write several files as if they were one contiguous one.

Note that the file is not seekable and readable.

Parameters

files
[list, tuple, or other iterable of str, filehandle] The contains the names of the underlying files that should be combined. If not a list or tuple, it should allow indexing with positive indices (e.g., returning a name as derived from a template). It should raise raise `IndexError` if the index is out of range.

mode
[str, optional] The mode with which the files should be opened (default: 'w+b'). If this does not include '+' for reading, memory maps are not possibe.

file_size
[int, optional] The maximum size a file is allowed to have. Default: `None`, which means it is unlimited and only a single file will be written (making using this class somewhat pointless).

opener
[callable, optional] Function to open a single file (default: `io.open`).

Methods Summary

`close`(self)	Close the currently open local file, and therewith the set.
`memmap`(self[, dtype, mode, offset, shape, order])	Map part of the file in memory.
`tell`(self)	Return the current stream position.
`write`(self, data)	Write the given buffer to the IO stream.

Methods Documentation

close(*self*)
Close the currently open local file, and therewith the set.

memmap(*self*, *dtype=<class 'numpy.uint8'>*, *mode=None*, *offset=None*, *shape=None*, *order='C'*)
Map part of the file in memory. Cannnot span file boundaries.

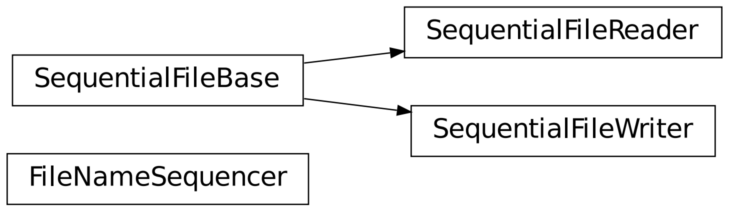
tell(*self*)
Return the current stream position.

write(*self*, *data*)
Write the given buffer to the IO stream.

Returns the number of bytes written, which is always the length of b in bytes.

Raises BlockingIOError if the buffer is full and the underlying raw stream cannot accept more data at the moment.

Class Inheritance Diagram



CHAPTER

TWELVE

VLBI BASE

Routines on which the readers and writers for specific VLBI formats are based.

12.1 Reference/API

12.1.1 baseband.vlbi_base Package

12.1.2 baseband.vlbi_base.header Module

Base definitions for VLBI Headers, used for VDIF and Mark 5B.

Defines a header class VLBIHeaderBase that can be used to hold the words corresponding to a frame header, providing access to the values encoded in via a dict-like interface. Definitions for headers are constructed using the HeaderParser class.

Functions

`make_parser`(word_index, bit_index, bit_length)	Construct a function that converts specific bits from a header.
`make_setter`(word_index, bit_index, bit_length)	Construct a function that uses a value to set specific bits in a header.

make_parser

`baseband.vlbi_base.header.`**`make_parser`**(*word_index*, *bit_index*, *bit_length*, *default=None*)

Construct a function that converts specific bits from a header.

The function acts on a tuple/array of 32-bit words, extracting given bits from a specific word and convert them to bool (for single bit) or integer.

The parameters are those that define header keywords, and all parsers do `(words[word_index] >> bit_index) & ((1 << bit_length) - 1)`, except that that they have been optimized for the specific cases of single bits, full words, and items starting at bit 0. As a special case, bit_length=64 allows one to extract two words as a single (long) integer.

Parameters

word_index
[int] Index into the tuple of words passed to the function.

bit_index
[int] Index to the starting bit of the part to be extracted.

bit_length
[int] Number of bits to be extracted.

Returns

parser
[function] To be used as `parser(words)`.

make_setter

`baseband.vlbi_base.header.`**`make_setter`**`(`*word_index*, *bit_index*, *bit_length*, *default=None*`)`

Construct a function that uses a value to set specific bits in a header.

The function will act on a tuple/array of words, setting given bits from a given word using a value.

The parameters are just those that define header keywords.

Parameters

word_index
[int] Index into the tuple of words passed to the function.

bit_index
[int] Index to the starting bit of the part to be extracted.

bit_length
[int] Number of bits to be extracted.

default
[int or bool or None] Possible default value to use in function if no default is passed on.

Returns

setter
[function] To be used as `setter(words, value)`.

Classes

`HeaderProperty`(header_parser, getter[, doc])	Mimic a dictionary, calculating entries from header words.
`HeaderPropertyGetter`(getter[, doc])	Special property for attaching HeaderProperty.
`HeaderParser`(*args, **kwargs)	Parser & setter for VLBI header keywords.
`VLBIHeaderBase`(words[, verify])	Base class for all VLBI headers.

HeaderProperty

`class` `baseband.vlbi_base.header.`**`HeaderProperty`**`(`*header_parser*, *getter*, *doc=None*`)`

Bases: `object`

Mimic a dictionary, calculating entries from header words.

Used to calculate setter functions and extract default values.

Parameters

header_parser
[HeaderParser] A dict with header encoding information.

getter
[function] Function that uses the encoding information to calculate a result.

HeaderPropertyGetter

class `baseband.vlbi_base.header.`**`HeaderPropertyGetter`**(*getter*, *doc=None*)
Bases: `object`

Special property for attaching HeaderProperty.

HeaderParser

class `baseband.vlbi_base.header.`**`HeaderParser`**(**args*, ***kwargs*)
Bases: `collections.OrderedDict`

Parser & setter for VLBI header keywords.

An ordered dict of header keywords, with values that describe how they are encoded in a given VLBI header. Initialisation is as a normal OrderedDict, with a key, value pairs. The value should be a tuple containing:

word_index
[int] Index into the header words for this key.

bit_index
[int] Index to the starting bit of the part used for this key.

bit_length
[int] Number of bits.

default
[int or bool or None] Possible default value to use in initialisation (e.g., a sync pattern).

The class provides dict-like properties `parsers`, `setters`, and `defaults`, which return functions that get a given keyword from header words, set the corresponding part of the header words to a value, or return the default value (if defined).

Note that while in principle, parsers and setters could be calculated on the fly, we precalculate the parsers to speed up header keyword access.

Attributes Summary

`defaults`	Dict-like allowing access to default header values.
`parsers`	Dict with functions to get specific header values.
`setters`	Dict-like returning function to set specific header value.

Methods Summary

clear()	
copy(self)	Make an independent copy.
fromkeys(iterable[, value])	Create a new ordered dictionary with keys from iterable and values set to value.
get(self, key[, default])	Return the value for key if key is in the dictionary, else default.
items()	
keys()	
move_to_end(self, /, key[, last])	Move an existing element to the end (or beginning if last is false).
pop()	value.
popitem(self, /[, last])	Remove and return a (key, value) pair from the dictionary.
setdefault(self, /, key[, default])	Insert key with a value of default if key is not in the dictionary.
update(self, other)	Update the parser with the information from another one.
values()	

Attributes Documentation

defaults
Dict-like allowing access to default header values.

parsers
Dict with functions to get specific header values.

setters
Dict-like returning function to set specific header value.

Methods Documentation

clear()

copy(*self*)
Make an independent copy.

fromkeys(*iterable*, *value=None*)
Create a new ordered dictionary with keys from iterable and values set to value.

get(*self*, *key*, *default=None*, */*)
Return the value for key if key is in the dictionary, else default.

items()

keys()

move_to_end(*self*, */*, *key*, *last=True*)
Move an existing element to the end (or beginning if last is false).

Raise KeyError if the element does not exist.

pop()
value. If key is not found, d is returned if given, otherwise KeyError is raised.

popitem(*self*, */*, *last=True*)

Remove and return a (key, value) pair from the dictionary.

Pairs are returned in LIFO order if last is true or FIFO order if false.

setdefault(*self*, */*, *key*, *default=None*)

Insert key with a value of default if key is not in the dictionary.

Return the value for key if key is in the dictionary, else default.

update(*self*, *other*)

Update the parser with the information from another one.

values()

VLBIHeaderBase

class baseband.vlbi_base.header.**VLBIHeaderBase**(*words*, *verify=True*)

Bases: `object`

Base class for all VLBI headers.

Defines a number of common routines.

Generally, the actual class should define:

_struct: `Struct` instance that can pack/unpack header words.

_header_parser: `HeaderParser` instance corresponding to this class.

_properties: tuple of properties accessible/usable in initialisation

It also should define properties (getters *and* setters):

payload_nbytes: number of bytes used by payload

frame_nbytes: total number of bytes for header + payload

get_time, set_time, and a corresponding time property:
time at start of payload

Parameters

words
[tuple or list of int, or None] header words (generally, 32 bit unsigned int). If `None`, set to a list of zeros for later initialisation. If given as a tuple, the header is immutable.

verify
[bool] Whether to do basic verification of integrity. For the base class, checks that the number of words is consistent with the struct size.

Attributes Summary

`mutable`	Whether the header can be modified.
`nbytes`	Size of the header in bytes.

Methods Summary

copy(self, **kwargs)	Create a mutable and independent copy of the header.
fromfile(fh, *args, **kwargs)	Read VLBI Header from file.
fromkeys(*args, **kwargs)	Initialise a header from parsed values.
fromvalues(*args, **kwargs)	Initialise a header from parsed values.
keys(self)	
tofile(self, fh)	Write VLBI frame header to filehandle.
update(self, *[, verify])	Update the header by setting keywords or properties.
verify(self)	Verify that the length of the words is consistent.

Attributes Documentation

mutable
Whether the header can be modified.

nbytes
Size of the header in bytes.

Methods Documentation

copy(*self*, ***kwargs*)
Create a mutable and independent copy of the header.

Keyword arguments can be passed on as needed by possible subclasses.

classmethod fromfile(*fh*, **args*, ***kwargs*)
Read VLBI Header from file.

Arguments are the same as for class initialisation. The header constructed will be immutable.

classmethod fromkeys(**args*, ***kwargs*)
Initialise a header from parsed values.

Like fromvalues, but without any interpretation of keywords.

Raises

KeyError
[if not all keys required are present in `kwargs`]

classmethod fromvalues(**args*, ***kwargs*)
Initialise a header from parsed values.

Here, the parsed values must be given as keyword arguments, i.e., for any `header = cls(<words>)`, `cls.fromvalues(**header) == header`.

However, unlike for the `fromkeys` class method, data can also be set using arguments named after header methods, such as `time`.

Parameters

***args**
Possible arguments required to initialize an empty header.

****kwargs**
Values used to initialize header keys or methods.

keys(*self*)

tofile(*self*, *fh*)
Write VLBI frame header to filehandle.

update(*self*, *, *verify=True*, ***kwargs*)
Update the header by setting keywords or properties.

Here, any keywords matching header keys are applied first, and any remaining ones are used to set header properties, in the order set by the class (in `_properties`).

Parameters

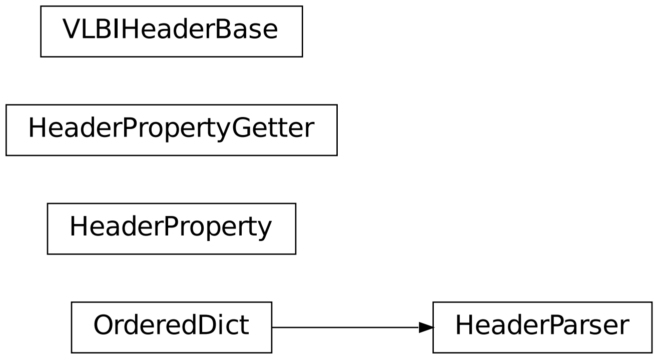
verify
[bool, optional] If `True` (default), verify integrity after updating.

****kwargs**
Arguments used to set keywords and properties.

verify(*self*)
Verify that the length of the words is consistent.

Subclasses should override this to do more thorough checks.

Class Inheritance Diagram



12.1.3 baseband.vlbi_base.payload Module

Base definitions for VLBI payloads, used for VDIF and Mark 5B.

Defines a payload class VLBIPayloadBase that can be used to hold the words corresponding to a frame payload, providing access to the values encoded in it as a numpy array.

Classes

`VLBIPayloadBase`(words[, sample_shape, bps, . . .])	Container for decoding and encoding VLBI payloads.

VLBIPayloadBase

class `baseband.vlbi_base.payload.`**`VLBIPayloadBase`**(*words*, *sample_shape=()*, *bps=2*, *complex_data=False*)

Bases: `object`

Container for decoding and encoding VLBI payloads.

Any subclass should define dictionaries `_decoders` and `_encoders`, which hold functions that decode/encode the payload words to/from ndarray. These dictionaries are assumed to be indexed by `bps`.

Parameters

words
[`ndarray`] Array containg LSB unsigned words (with the right size) that encode the payload.

sample_shape
[tuple] Shape of the samples (e.g., (nchan,)). Default: ().

bps
[int] Bits per elementary sample, i.e., per channel and per real or imaginary component. Default: 2.

complex_data
[bool] Whether the data are complex. Default: `False`.

Attributes Summary

`data`	Full decoded payload.
`dtype`	Numeric type of the decoded data array.
`nbytes`	Size of the payload in bytes.
`ndim`	Number of dimensions of the decoded data array.
`shape`	Shape of the decoded data array.
`size`	Total number of component samples in the decoded data array.

Methods Summary

`fromdata`(data[, header, bps])	Encode data as a payload.
`fromfile`(fh, *args[, payload_nbytes])	Read payload from filehandle and decode it into data.
`tofile`(self, fh)	Write payload to filehandle.

Attributes Documentation

`data`
Full decoded payload.

`dtype`

Numeric type of the decoded data array.

`nbytes`
Size of the payload in bytes.

`ndim`
Number of dimensions of the decoded data array.

`shape`
Shape of the decoded data array.

`size`
Total number of component samples in the decoded data array.

Methods Documentation

`classmethod fromdata`(*data*, *header=None*, *bps=2*)
Encode data as a payload.

Parameters

data
[`ndarray`] Data to be encoded. The last dimension is taken as the number of channels.

header
[header instance, optional] If given, used to infer the bps.

bps
[int, optional] Bits per elementary sample, i.e., per channel and per real or imaginary component, used if header is not given. Default: 2.

`classmethod fromfile`(*fh*, **args*, *payload_nbytes=None*, ***kwargs*)
Read payload from filehandle and decode it into data.

Parameters

fh
[filehandle] From which data is read.

payload_nbytes
[int] Number of bytes to read (default: as given in `cls._nbytes`).

Any other (keyword) arguments are passed on to the class initialiser.

`tofile`(*self*, *fh*)
Write payload to filehandle.

Class Inheritance Diagram

12.1.4 baseband.vlbi_base.frame Module

Base definitions for VLBI frames, used for VDIF and Mark 5B.

Defines a frame class VLBIFrameBase that can be used to hold a header and a payload, providing access to the values encoded in both.

Classes

`VLBIFrameBase`(header, payload[, valid, verify])	Representation of a VLBI data frame, consisting of a header and payload.

VLBIFrameBase

class `baseband.vlbi_base.frame.`**`VLBIFrameBase`**(*header*, *payload*, *valid=True*, *verify=True*)

Bases: `object`

Representation of a VLBI data frame, consisting of a header and payload.

Parameters

header
[`baseband.vlbi_base.header.VLBIHeaderBase`] Wrapper around the encoded header words, providing access to the header information.

payload
[`VLBIPayloadBase`] Wrapper around the payload, provding mechanisms to decode it.

valid
[bool] Whether the data are valid. Default: `True`.

verify
[bool] Whether to do basic verification of integrity. Default: `True`.

Notes

The Frame can also be instantiated using class methods:

fromfile : read header and payload from a filehandle

fromdata : encode data as payload

Of course, one can also do the opposite:

tofile : method to write header and payload to filehandle

data : property that yields full decoded payload

One can decode part of the payload by indexing or slicing the frame. If the frame does not contain valid data, all values returned are set to `self.fill_value`.

A number of properties are defined: `shape` and `dtype` are the shape and type of the data array, and `nbytes` the frame size in bytes. Furthermore, the frame acts as a dictionary, with keys those of the header. Any attribute that is not defined on the frame itself, such as `.time` will be looked up on the header as well.

Attributes Summary

`data`	Full decoded frame.
`dtype`	Numeric type of the frame data.
`fill_value`	Value to replace invalid data in the frame.
`nbytes`	Size of the encoded frame in bytes.
`ndim`	Number of dimensions of the frame data.
`sample_shape`	Shape of a sample in the frame (nchan,).
`shape`	Shape of the frame data.
`size`	Total number of component samples in the frame data.
`valid`	Whether frame contains valid data.

Methods Summary

`fromdata`(data, header, *args[, valid, verify])	Construct frame from data and header.
`fromfile`(fh, *args[, valid, verify])	Read a frame from a filehandle.
`keys`(self)	
`tofile`(self, fh)	Write encoded frame to filehandle.
`verify`(self)	Simple verification.

Attributes Documentation

`data`
Full decoded frame.

`dtype`
Numeric type of the frame data.

`fill_value`
Value to replace invalid data in the frame.

`nbytes`
Size of the encoded frame in bytes.

`ndim`
Number of dimensions of the frame data.

`sample_shape`
Shape of a sample in the frame (nchan,).

`shape`
Shape of the frame data.

size
Total number of component samples in the frame data.

valid
Whether frame contains valid data.

Methods Documentation

classmethod fromdata(*data*, *header*, **args*, *valid=True*, *verify=True*, ***kwargs*)
Construct frame from data and header.

Parameters

data
[ndarray] Array holding data to be encoded.

header
[VLBIHeaderBase] Header for the frame.

***args, **kwargs :**
Any arguments beyond the filehandle are used to help initialize the payload, except for `valid` and `verify`, which are passed on to the header and class initializers.

valid
[bool, optional] Whether this payload contains valid data.

verify
[bool, optional] Whether to verify the header and frame correctness.

classmethod fromfile(*fh*, **args*, *valid=True*, *verify=True*, ***kwargs*)
Read a frame from a filehandle.

Parameters

fh
[filehandle] Handle to read the frame from

***args, **kwargs**
Arguments that help to initialize the payload.

valid
[bool] Whether the data are valid. Default: `True`.

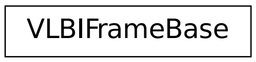
verify
[bool] Whether to do basic verification of integrity. Default: `True`.

keys(*self*)

tofile(*self*, *fh*)
Write encoded frame to filehandle.

verify(*self*)
Simple verification. To be added to by subclasses.

Class Inheritance Diagram



12.1.5 baseband.vlbi_base.base Module

Functions

`make_opener`(fmt, classes[, doc, append_doc])	Create a baseband file opener.

make_opener

`baseband.vlbi_base.base.`**`make_opener`**(*fmt*, *classes*, *doc=”*, *append_doc=True*)

Create a baseband file opener.

Parameters

fmt
[str] Name of the baseband format.

classes
[dict] With the file/stream reader/writer classes keyed by names equal to ‘FileReader’, ‘FileWriter’, ‘StreamReader’, ‘StreamWriter’ prefixed by `fmt`. Typically, one will pass in `classes=globals()`.

doc
[str, optional] If given, used to define the docstring of the opener.

append_doc
[bool, optional] If `True` (default), append doc to the default docstring rather than override it.

Classes

`VLBIFileBase`(fh_raw)	VLBI file wrapper, used to add frame methods to a binary data file.
`VLBIFileReaderBase`(fh_raw)	VLBI wrapped file reader base class.
`VLBIStreamBase`(fh_raw, header0, sample_rate, . . .)	VLBI file wrapper, allowing access as a stream of data.
`VLBIStreamReaderBase`(fh_raw, header0, . . .)	
`VLBIStreamWriterBase`(fh_raw, header0, . . .)	

VLBIFileBase

class baseband.vlbi_base.base.**VLBIFileBase**(*fh_raw*)

Bases: `object`

VLBI file wrapper, used to add frame methods to a binary data file.

The underlying file is stored in `fh_raw` and all attributes that do not exist on the class itself are looked up on it.

Parameters

fh_raw
[filehandle] Filehandle of the raw binary data file.

Methods Summary

`close`(self)	
`temporary_offset`(self)	Context manager for temporarily seeking to another file position.

Methods Documentation

close(*self*)

temporary_offset(*self*)

Context manager for temporarily seeking to another file position.

To be used as part of a `with` statement:

```
with fh_raw.temporary_offset() [as fh_raw]:
    with-block
```

On exiting the `with-block`, the file pointer is moved back to its original position.

VLBIFileReaderBase

class baseband.vlbi_base.base.**VLBIFileReaderBase**(*fh_raw*)

Bases: `baseband.vlbi_base.base.VLBIFileBase`

VLBI wrapped file reader base class.

Typically, a subclass will define `read_header`, `read_frame`, and `find_header` methods. This baseclass includes a `get_frame_rate` method which determines the frame rate by scanning the file for headers, looking for the maximum frame number that occurs before the jump down for the next second. This method requires the subclass to define a `read_header` method and assumes headers have a 'frame_nr' item, and define a `payload_nbytes` property (as do all standard VLBI formats).

Parameters

fh_raw
[filehandle] Filehandle of the raw binary data file.

Attributes Summary

info()	Standardized information on file readers.

Methods Summary

close(self)	
get_frame_rate(self)	Determine the number of frames per second.
temporary_offset(self)	Context manager for temporarily seeking to another file position.

Attributes Documentation

info

Standardized information on file readers.

The info descriptor has a number of standard attributes, which are determined from arguments passed in opening the file, from the first header (info.header0) and from possibly scanning the file to determine the duration of frames.

Examples

The most common use is simply to print information:

```
>>> from baseband.data import SAMPLE_MARK5B
>>> from baseband import mark5b
>>> fh = mark5b.open(SAMPLE_MARK5B, 'rb')
>>> fh.info
File information:
format = mark5b
frame_rate = 6400.0 Hz
bps = 2
complex_data = False
readable = False

missing:  nchan: needed to determine sample shape and rate.
          kday, ref_time: needed to infer full times.

errors:  start_time: unsupported operand type(s) for +: 'NoneType' and 'int'
         frame0: In order to read frames, the file handle should be initialized with nchan␣
↪set.

>>> fh.close()

>>> fh = mark5b.open(SAMPLE_MARK5B, 'rb', kday=56000, nchan=8)
>>> fh.info
File information:
format = mark5b
frame_rate = 6400.0 Hz
sample_rate = 32.0 MHz
samples_per_frame = 5000
sample_shape = (8,)
bps = 2
```

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```
complex_data = False
start_time = 2014-06-13T05:30:01.000000000
readable = True
>>> fh.close()
```

Attributes

format
[str or None] File format, or None if the underlying file cannot be parsed.

frame_rate
[Quantity] Number of data frames per unit of time.

sample_rate
[Quantity] Complete samples per unit of time.

samples_per_frame
[int] Number of complete samples in each frame.

sample_shape
[tuple] Dimensions of each complete sample (e.g., `(nchan,)`).

bps
[int] Number of bits used to encode each elementary sample.

complex_data
[bool] Whether the data are complex.

start_time
[Time] Time of the first complete sample.

readable
[bool] Whether the first sample could be read and decoded.

missing
[dict] Entries are keyed by names of arguments that should be passed to the file reader to obtain full information. The associated entries explain why these arguments are needed.

errors
[dict] Any exceptions raised while trying to determine attributes. Keyed by the attributes.

Methods Documentation

close(*self*)

get_frame_rate(*self*)
Determine the number of frames per second.

The method cycles through headers, starting from the start of the file, finding the largest frame number before it jumps back to 0 for a new second.

Returns

frame_rate
[Quantity] Frames per second.

Raises

`EOFError`
If the file contains less than one second of data.

`temporary_offset`(*self*)
Context manager for temporarily seeking to another file position.

To be used as part of a `with` statement:

```
with fh_raw.temporary_offset() [as fh_raw]:
    with-block
```

On exiting the `with-block`, the file pointer is moved back to its original position.

VLBIStreamBase

class `baseband.vlbi_base.base.`**`VLBIStreamBase`**(*fh_raw*, *header0*, *sample_rate*, *samples_per_frame*, *unsliced_shape*, *bps*, *complex_data*, *squeeze*, *subset=()*, *fill_value=0.0*, *verify=True*)

Bases: `object`

VLBI file wrapper, allowing access as a stream of data.

Attributes Summary

`bps`	Bits per elementary sample.
`complex_data`	Whether the data are complex.
`header0`	First header of the file.
`sample_rate`	Number of complete samples per second.
`sample_shape`	Shape of a complete sample (possibly subset or squeezed).
`samples_per_frame`	Number of complete samples per frame.
`squeeze`	Whether data arrays have dimensions with length unity removed.
`start_time`	Start time of the file.
`subset`	Specific components of the complete sample to decode.
`time`	Time of the sample pointer's current offset in file.
`verify`	Whether to do consistency checks on frames being read.

Methods Summary

`close`(self)	
`tell`(self[, unit])	Current offset in the file.

Attributes Documentation

bps
Bits per elementary sample.

complex_data
Whether the data are complex.

header0
First header of the file.

sample_rate
Number of complete samples per second.

sample_shape
Shape of a complete sample (possibly subset or squeezed).

samples_per_frame
Number of complete samples per frame.

squeeze
Whether data arrays have dimensions with length unity removed.

If `True`, data read out has such dimensions removed, and data passed in for writing has them inserted.

start_time
Start time of the file.

See also `time` for the time of the sample pointer's current offset.

subset
Specific components of the complete sample to decode.

The order of dimensions is the same as for `sample_shape`. Set by the class initializer.

time
Time of the sample pointer's current offset in file.

See also `start_time` for the start time of the file.

verify
Whether to do consistency checks on frames being read.

Methods Documentation

close(*self*)

tell(*self*, *unit=None*)
Current offset in the file.

Parameters

unit
[`Unit` or str, optional] Time unit the offset should be returned in. By default, no unit is used, i.e., an integer enumerating samples is returned. For the special string 'time', the absolute time is calculated.

Returns

offset
[int, `Quantity`, or `Time`] Offset in current file (or time at current position).

VLBIStreamReaderBase

class baseband.vlbi_base.base.**VLBIStreamReaderBase**(*fh_raw*, *header0*, *sample_rate*, *samples_per_frame*, *unsliced_shape*, *bps*, *complex_data*, *squeeze*, *subset*, *fill_value*, *verify*)

Bases: baseband.vlbi_base.base.VLBIStreamBase

Attributes Summary

bps	Bits per elementary sample.
complex_data	Whether the data are complex.
dtype	
fill_value	Value to use for invalid or missing data.
header0	First header of the file.
info()	Standardized information on stream readers.
ndim	Number of dimensions of the (squeezed/subset) stream data.
sample_rate	Number of complete samples per second.
sample_shape	Shape of a complete sample (possibly subset or squeezed).
samples_per_frame	Number of complete samples per frame.
shape	Shape of the (squeezed/subset) stream data.
size	Total number of component samples in the (squeezed/subset) stream data.
squeeze	Whether data arrays have dimensions with length unity removed.
start_time	Start time of the file.
stop_time	Time at the end of the file, just after the last sample.
subset	Specific components of the complete sample to decode.
time	Time of the sample pointer's current offset in file.
verify	Whether to do consistency checks on frames being read.

Methods Summary

close(self)	
read(self[, count, out])	Read a number of complete (or subset) samples.
readable(self)	Whether the file can be read and decoded.
seek(self, offset[, whence])	Change the stream position.
tell(self[, unit])	Current offset in the file.

Attributes Documentation

bps
Bits per elementary sample.

complex_data
Whether the data are complex.

dtype

`fill_value`
Value to use for invalid or missing data. Default: 0.

`header0`
First header of the file.

`info`
Standardized information on stream readers.

The `info` descriptor provides a few standard attributes, all of which can also be accessed directly on the stream filehandle. More detailed information on the underlying file is stored in its info, accessible via `info.file_info`.

Attributes

start_time
[`Time`] Time of the first complete sample.

stop_time
[`Time`] Time of the complete sample just beyond the end of the file.

sample_rate
[`Quantity`] Complete samples per unit of time.

shape
[tuple] Equivalent shape of the whole file, i.e., combining the number of complete samples and the shape of those samples.

bps
[int] Number of bits used to encode each elementary sample.

complex_data
[bool] Whether the data are complex.

readable
[bool] Whether the first sample could be read and decoded.

`ndim`
Number of dimensions of the (squeezed/subset) stream data.

`sample_rate`
Number of complete samples per second.

`sample_shape`
Shape of a complete sample (possibly subset or squeezed).

`samples_per_frame`
Number of complete samples per frame.

`shape`
Shape of the (squeezed/subset) stream data.

`size`
Total number of component samples in the (squeezed/subset) stream data.

`squeeze`
Whether data arrays have dimensions with length unity removed.

If `True`, data read out has such dimensions removed, and data passed in for writing has them inserted.

start_time
Start time of the file.

See also time for the time of the sample pointer's current offset, and (if available) stop_time for the time at the end of the file.

stop_time
Time at the end of the file, just after the last sample.

See also start_time for the start time of the file, and time for the time of the sample pointer's current offset.

subset
Specific components of the complete sample to decode.

The order of dimensions is the same as for sample_shape. Set by the class initializer.

time
Time of the sample pointer's current offset in file.

See also start_time for the start time, and (if available) stop_time for the end time, of the file.

verify
Whether to do consistency checks on frames being read.

Methods Documentation

close(*self*)

read(*self*, *count=None*, *out=None*)
Read a number of complete (or subset) samples.

The range retrieved can span multiple frames.

Parameters

count
[int or None, optional] Number of complete/subset samples to read. If None (default) or negative, the whole file is read. Ignored if out is given.

out
[None or array, optional] Array to store the data in. If given, count will be inferred from the first dimension; the other dimension should equal sample_shape.

Returns

out
[ndarray of float or complex] The first dimension is sample-time, and the remainder given by sample_shape.

readable(*self*)
Whether the file can be read and decoded.

seek(*self*, *offset*, *whence=0*)
Change the stream position.

This works like a normal filehandle seek, but the offset is in samples (or a relative or absolute time).

Parameters

offset
[int, `Quantity`, or `Time`] Offset to move to. Can be an (integer) number of samples, an offset in time units, or an absolute time.

whence
[{0, 1, 2, 'start', 'current', or 'end'}, optional] Like regular seek, the offset is taken to be from the start if `whence=0` (default), from the current position if 1, and from the end if 2. One can alternativey use 'start', 'current', or 'end' for 0, 1, or 2, respectively. Ignored if `offset` is a time.

`tell`(*self*, *unit=None*)
Current offset in the file.

Parameters

unit
[`Unit` or str, optional] Time unit the offset should be returned in. By default, no unit is used, i.e., an integer enumerating samples is returned. For the special string 'time', the absolute time is calculated.

Returns

offset
[int, `Quantity`, or `Time`] Offset in current file (or time at current position).

VLBIStreamWriterBase

class `baseband.vlbi_base.base.`**`VLBIStreamWriterBase`**(*fh_raw*, *header0*, *sample_rate*, *samples_per_frame*, *unsliced_shape*, *bps*, *complex_data*, *squeeze*, *subset*, *fill_value*, *verify*)

Bases: `baseband.vlbi_base.base.VLBIStreamBase`

Attributes Summary

`bps`	Bits per elementary sample.
`complex_data`	Whether the data are complex.
`header0`	First header of the file.
`sample_rate`	Number of complete samples per second.
`sample_shape`	Shape of a complete sample (possibly subset or squeezed).
`samples_per_frame`	Number of complete samples per frame.
`squeeze`	Whether data arrays have dimensions with length unity removed.
`start_time`	Start time of the file.
`subset`	Specific components of the complete sample to decode.
`time`	Time of the sample pointer's current offset in file.
`verify`	Whether to do consistency checks on frames being read.

Methods Summary

close(self)	
tell(self[, unit])	Current offset in the file.
write(self, data[, valid])	Write data, buffering by frames as needed.

Attributes Documentation

bps
Bits per elementary sample.

complex_data
Whether the data are complex.

header0
First header of the file.

sample_rate
Number of complete samples per second.

sample_shape
Shape of a complete sample (possibly subset or squeezed).

samples_per_frame
Number of complete samples per frame.

squeeze
Whether data arrays have dimensions with length unity removed.

If True, data read out has such dimensions removed, and data passed in for writing has them inserted.

start_time
Start time of the file.

See also time for the time of the sample pointer's current offset.

subset
Specific components of the complete sample to decode.

The order of dimensions is the same as for sample_shape. Set by the class initializer.

time
Time of the sample pointer's current offset in file.

See also start_time for the start time of the file.

verify
Whether to do consistency checks on frames being read.

Methods Documentation

close(*self*)

tell(*self*, *unit=None*)
Current offset in the file.

Parameters

unit
[Unit or str, optional] Time unit the offset should be returned in. By default, no unit is used, i.e., an integer enumerating samples is returned. For the special string 'time', the absolute time is calculated.

Returns

offset
[int, Quantity, or Time] Offset in current file (or time at current position).

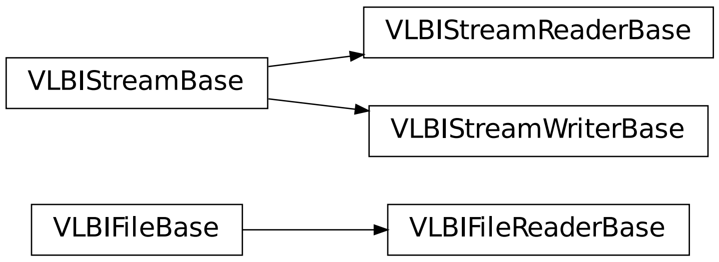
write(*self*, *data*, *valid=True*)
Write data, buffering by frames as needed.

Parameters

data
[ndarray] Piece of data to be written, with sample dimensions as given by sample_shape. This should be properly scaled to make best use of the dynamic range delivered by the encoding.

valid
[bool, optional] Whether the current data are valid. Default: True.

Class Inheritance Diagram



12.1.6 baseband.vlbi_base.file_info Module

Provide a base class for "info" properties.

Loosely based on DataInfo.

Classes

VLBIInfoMeta(name, bases, dct)	
VLBIInfoBase	Container providing a standardized interface to file information.

Continued on next page

Table 24 – continued from previous page

`VLBIFileReaderInfo`	Standardized information on file readers.
`VLBIStreamReaderInfo`	Standardized information on stream readers.

VLBIInfoMeta

class `baseband.vlbi_base.file_info.`**`VLBIInfoMeta`**(*name*, *bases*, *dct*)

Bases: `type`

Methods Summary

`__call__`(self, /, *args, **kwargs)	Call self as a function.
`mro`(self, /)	Return a type's method resolution order.

Methods Documentation

`__call__`(*self*, */*, **args*, ***kwargs*)

Call self as a function.

`mro`(*self*, */*)

Return a type's method resolution order.

VLBIInfoBase

class `baseband.vlbi_base.file_info.`**`VLBIInfoBase`**

Bases: `object`

Container providing a standardized interface to file information.

In order to ensure that information is always returned, all access to the parent should be within `try/except` with a possible error stored in `self.errors`. See `self._getattr` for an example.

Attributes Summary

`attr_names`	Attributes that the container provides.
`format`	

Methods Summary

`__call__`(self)	Create a dict with file information, including missing pieces.

Attributes Documentation

`attr_names = ('format',)`

Attributes that the container provides.

`format = None`

Methods Documentation

`__call__`(*self*)

Create a dict with file information, including missing pieces.

VLBIFileReaderInfo

class `baseband.vlbi_base.file_info.`**`VLBIFileReaderInfo`**

Bases: `baseband.vlbi_base.file_info.VLBIInfoBase`

Standardized information on file readers.

The `info` descriptor has a number of standard attributes, which are determined from arguments passed in opening the file, from the first header (`info.header0`) and from possibly scanning the file to determine the duration of frames.

Examples

The most common use is simply to print information:

```
>>> from baseband.data import SAMPLE_MARK5B
>>> from baseband import mark5b
>>> fh = mark5b.open(SAMPLE_MARK5B, 'rb')
>>> fh.info
File information:
format = mark5b
frame_rate = 6400.0 Hz
bps = 2
complex_data = False
readable = False

missing:  nchan: needed to determine sample shape and rate.
          kday, ref_time: needed to infer full times.

errors:  start_time: unsupported operand type(s) for +: 'NoneType' and 'int'
         frame0: In order to read frames, the file handle should be initialized with nchan set.

>>> fh.close()

>>> fh = mark5b.open(SAMPLE_MARK5B, 'rb', kday=56000, nchan=8)
>>> fh.info
File information:
format = mark5b
frame_rate = 6400.0 Hz
sample_rate = 32.0 MHz
samples_per_frame = 5000
sample_shape = (8,)
bps = 2
complex_data = False
start_time = 2014-06-13T05:30:01.000000000
readable = True
>>> fh.close()
```

Attributes

format
[str or None] File format, or None if the underlying file cannot be parsed.

frame_rate
[Quantity] Number of data frames per unit of time.

sample_rate
[Quantity] Complete samples per unit of time.

samples_per_frame
[int] Number of complete samples in each frame.

sample_shape
[tuple] Dimensions of each complete sample (e.g., `(nchan,)`).

bps
[int] Number of bits used to encode each elementary sample.

complex_data
[bool] Whether the data are complex.

start_time
[Time] Time of the first complete sample.

readable
[bool] Whether the first sample could be read and decoded.

missing
[dict] Entries are keyed by names of arguments that should be passed to the file reader to obtain full information. The associated entries explain why these arguments are needed.

errors
[dict] Any exceptions raised while trying to determine attributes. Keyed by the attributes.

Attributes Summary

`attr_names`
`bps`
`complex_data`
`format`
`frame_rate`
`readable`
`sample_rate`
`sample_shape`
`samples_per_frame`
`start_time`

Methods Summary

`__call__`(self)	Create a dict with file information, including missing pieces.

Attributes Documentation

```
attr_names = ('format', 'frame_rate', 'sample_rate', 'samples_per_frame', 'sample_shape', 'bps', 'comple
```

`bps = None`

`complex_data = None`

`format = None`

`frame_rate = None`

`readable = None`

`sample_rate = None`

`sample_shape = None`

`samples_per_frame = None`

`start_time = None`

Methods Documentation

`__call__`(*self*)
Create a dict with file information, including missing pieces.

VLBIStreamReaderInfo

class `baseband.vlbi_base.file_info.`**`VLBIStreamReaderInfo`**
Bases: `baseband.vlbi_base.file_info.VLBIInfoBase`

Standardized information on stream readers.

The `info` descriptor provides a few standard attributes, all of which can also be accessed directly on the stream filehandle. More detailed information on the underlying file is stored in its info, accessible via `info.file_info`.

Attributes

start_time
[`Time`] Time of the first complete sample.

stop_time
[`Time`] Time of the complete sample just beyond the end of the file.

sample_rate
[`Quantity`] Complete samples per unit of time.

shape
[tuple] Equivalent shape of the whole file, i.e., combining the number of complete samples and the shape of those samples.

bps
[int] Number of bits used to encode each elementary sample.

complex_data
[bool] Whether the data are complex.

readable
[bool] Whether the first sample could be read and decoded.

Attributes Summary

`attr_names`
`bps`
`complex_data`
`format`
`readable`
`sample_rate`
`shape`
`start_time`
`stop_time`

Methods Summary

`__call__`(self)	Create a dict with information about the stream and the raw file.

Attributes Documentation

`attr_names = ('start_time', 'stop_time', 'sample_rate', 'shape', 'format', 'bps', 'complex_data', 'reada`

`bps = None`

`complex_data = None`

`format = None`

`readable = None`

`sample_rate = None`

`shape = None`

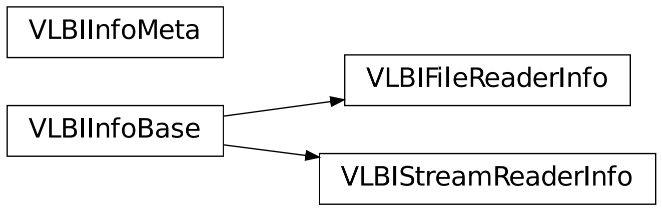
`start_time = None`

`stop_time = None`

Methods Documentation

`__call__`(*self*)
Create a dict with information about the stream and the raw file.

Class Inheritance Diagram



12.1.7 baseband.vlbi_base.encoding Module

Encoders and decoders for generic VLBI data formats.

Functions

`encode_1bit_base`(values)	Generic encoder for data stored using one bit.
`encode_2bit_base`(values)	Generic encoder for data stored using two bits.
`encode_4bit_base`(values)	Generic encoder for data stored using four bits.
`decode_8bit`(words)	Generic decoder for data stored using 8 bits.
`encode_8bit`(values)	Encode 8 bit VDIF data.

encode_1bit_base

`baseband.vlbi_base.encoding.`**`encode_1bit_base`**(*values*)
Generic encoder for data stored using one bit.

This returns an unsigned integer array containing encoded sample values that are either 0 (negative value) or 1 (positive value).

This does not pack the samples into bytes.

encode_2bit_base

`baseband.vlbi_base.encoding.`**`encode_2bit_base`**(*values*)
Generic encoder for data stored using two bits.

This returns an unsigned integer array containing encoded sample values that range from 0 to 3. The conversion from floating point sample value to unsigned int is given below, with `lv = TWO_BIT_1_SIGMA = 2.1745`:

Input range	Output
value < -lv	0
-lv < value < 0.	2
0. < value < lv	1
lv < value	3

This does not pack the samples into bytes.

encode_4bit_base

baseband.vlbi_base.encoding.**encode_4bit_base**(*values*)

Generic encoder for data stored using four bits.

This returns an unsigned integer array containing encoded sample values that range from 0 to 15. Floating point sample values are converted to unsigned int by first scaling them by `FOUR_BIT_1_SIGMA = 2.95`, then adding 8.5 (the 0.5 to ensure proper rounding when typecasting to uint8). Some sample output levels are:

Input range	Output
value*scale < -7.5	0
-7.5 < value*scale < -6.5	1
-0.5 < value*scale < +0.5	8
6.5 < value*scale	15

This does not pack the samples into bytes.

decode_8bit

baseband.vlbi_base.encoding.**decode_8bit**(*words*)

Generic decoder for data stored using 8 bits.

We follow mark5access, which assumes the values 0 to 255 encode -127.5 to 127.5, scaled down to match 2 bit data by a factor of 35.5 (`EIGHT_BIT_1_SIGMA`)

For comparison, GMRT phased data treats the 8-bit data values simply as signed integers.

encode_8bit

baseband.vlbi_base.encoding.**encode_8bit**(*values*)

Encode 8 bit VDIF data.

We follow mark5access, which assumes the values 0 to 255 encode -127.5 to 127.5, scaled down to match 2 bit data by a factor of 35.5 (`EIGHT_BIT_1_SIGMA`)

For comparison, GMRT phased data treats the 8-bit data values simply as signed integers.

Variables

OPTIMAL_2BIT_HIGH	Optimal high value for a 2-bit digitizer for which the low value is 1.
TWO_BIT_1_SIGMA	Optimal level between low and high for the above OPTIMAL_2BIT_HIGH.
FOUR_BIT_1_SIGMA	Scaling for four-bit encoding that makes it look like 2 bit.
EIGHT_BIT_1_SIGMA	Scaling for eight-bit encoding that makes it look like 2 bit.
decoder_levels	Levels for data encoded with different numbers of bits..

OPTIMAL_2BIT_HIGH

`baseband.vlbi_base.encoding.`**`OPTIMAL_2BIT_HIGH = 3.316505`**

Optimal high value for a 2-bit digitizer for which the low value is 1.

It is chosen such that for a normal distribution in which 68.269% of all values are at the low level, this is the mean of the others, i.e.,

$$l = \frac{\int_\sigma^\infty x \exp(-\frac{x^2}{2\sigma^2}) dx}{\int_\sigma^\infty \exp(-\frac{x^2}{2\sigma^2}) dx},$$

where the standard deviation is determined from:

$$1 = \frac{\int_0^\sigma x \exp(-\frac{x^2}{2\sigma^2}) dx}{\int_0^\sigma \exp(-\frac{x^2}{2\sigma^2}) dx}.$$

These give:

$$\sigma = \frac{\sqrt{\frac{\pi}{2}}\mathrm{erf}(\sqrt{1/2})}{1 - \sqrt{1/e}} = 2.174564,$$

and

$$l = \frac{1}{(\sqrt{e} - 1)(1/\mathrm{erf}(\sqrt{1/2}) - 1)} = 3.316505$$

TWO_BIT_1_SIGMA

`baseband.vlbi_base.encoding.`**`TWO_BIT_1_SIGMA = 2.174564`**

Optimal level between low and high for the above OPTIMAL_2BIT_HIGH.

FOUR_BIT_1_SIGMA

`baseband.vlbi_base.encoding.`**`FOUR_BIT_1_SIGMA = 2.95`**

Scaling for four-bit encoding that makes it look like 2 bit.

EIGHT_BIT_1_SIGMA

`baseband.vlbi_base.encoding.`**`EIGHT_BIT_1_SIGMA = 35.5`**

Scaling for eight-bit encoding that makes it look like 2 bit.

decoder_levels

`baseband.vlbi_base.encoding.decoder_levels = {1: array([-1., 1.], dtype=float32), 2: array([-3.316505, -1. ,`

Levels for data encoded with different numbers of bits..

12.1.8 baseband.vlbi_base.utils Module

Functions

`bcd_decode`(value)	
`bcd_encode`(value)	

bcd_decode

`baseband.vlbi_base.utils.bcd_decode`(*value*)

bcd_encode

`baseband.vlbi_base.utils.bcd_encode`(*value*)

Classes

`CRC`(polynomial)	Cyclic Redundancy Check for a bitstream.

CRC

class `baseband.vlbi_base.utils.CRC`(*polynomial*)

Bases: `object`

Cyclic Redundancy Check for a bitstream.

See https://en.wikipedia.org/wiki/Cyclic_redundancy_check

Once initialised, the instance can be used as a function that calculates the CRC, or one can use the check method to verify that the CRC at the end of a stream is correct.

Parameters

polynomial
[int] Binary encoded CRC divisor. For instance, that used by Mark 4 headers is 0x180f, or x^12 + x^11 + x^3 + x^2 + x + 1.

Methods Summary

`__call__`(self, stream)	Calculate CRC for the given stream.

Continued on next page

Table 36 – continued from previous page

check(self, stream)	Check that the CRC at the end of the stream is correct.

Methods Documentation

`__call__`(*self*, *stream*)

Calculate CRC for the given stream.

Parameters

stream
[array of bool or unsigned int] The dimension is treated as the index into the bits. For a single stream, the array should thus be of type `bool`. Integers represent multiple streams. E.g., for a 64-track Mark 4 header, the stream would be an array of `np.uint64` words.

Returns

crc
[array] The crc will have the same dtype as the input stream.

`check`(*self*, *stream*)

Check that the CRC at the end of the stream is correct.

Parameters

stream
[array of bool or unsigned int] The dimension is treated as the index into the bits. For a single stream, the array should thus be of type `bool`. Integers represent multiple streams. E.g., for a 64-track Mark 4 header, the stream would be an array of `np.uint64` words.

Returns

ok
[bool] `True` if the calculated CRC is all zero (which should be the case if the CRC at the end of the stream is correct).

Class Inheritance Diagram

CHAPTER

THIRTEEN

SAMPLE DATA FILES

13.1 baseband.data Package

Sample files with baseband data recorded in different formats.

13.1.1 Variables

SAMPLE_AROCHIME_VDIF	VDIF sample from ARO, written by CHIME backend.
SAMPLE_BPS1_VDIF	VDIF sample from Christian Ploetz.
SAMPLE_DADA	DADA sample from Effelsberg, with header adapted to shortened size.
SAMPLE_DRAO_CORRUPT	Corrupted VDIF sample.
SAMPLE_GSB_PHASED	GSB phased sample.
SAMPLE_GSB_PHASED_HEADER	GSB phased header sample.
SAMPLE_GSB_RAWDUMP	GSB rawdump sample.
SAMPLE_GSB_RAWDUMP_HEADER	GSB rawdump header sample.
SAMPLE_MARK4	Mark 4 sample.
SAMPLE_MARK4_16TRACK	Mark 4 sample.
SAMPLE_MARK4_32TRACK	Mark 4 sample.
SAMPLE_MARK4_32TRACK_FANOUT2	Mark 4 sample.
SAMPLE_MARK5B	Mark 5B sample.
SAMPLE_MWA_VDIF	VDIF sample from MWA.
SAMPLE_PUPPI	GUPPI/PUPPI sample, npol=2, nchan=4.
SAMPLE_VDIF	VDIF sample.
SAMPLE_VLBI_VDIF	VDIF sample.

SAMPLE_AROCHIME_VDIF

baseband.data.**SAMPLE_AROCHIME_VDIF = '/home/docs/checkouts/readthedocs.org/user_builds/baseband/conda/v3.0.0/**

VDIF sample from ARO, written by CHIME backend. EDV=1, nchan=1024, bps=4.

SAMPLE_BPS1_VDIF

baseband.data.**SAMPLE_BPS1_VDIF = '/home/docs/checkouts/readthedocs.org/user_builds/baseband/conda/v3.0.0/lib/**

VDIF sample from Christian Ploetz. EDV=0, nchan=16, bps=1.

SAMPLE_DADA

baseband.data.**SAMPLE_DADA = '/home/docs/checkouts/readthedocs.org/user_builds/baseband/conda/v3.0.0/lib/pytho**

DADA sample from Effelsberg, with header adapted to shortened size.

SAMPLE_DRAO_CORRUPT

baseband.data.**SAMPLE_DRAO_CORRUPT = '/home/docs/checkouts/readthedocs.org/user_builds/baseband/conda/v3.0.0/l**

Corrupted VDIF sample. bps=4.

First ten frames extracted from b0329 DRAO corrupted raw data file 0059000.dat.

SAMPLE_GSB_PHASED

baseband.data.**SAMPLE_GSB_PHASED = (('/home/docs/checkouts/readthedocs.org/user_builds/baseband/conda/v3.0.0/l**

GSB phased sample. samples_per_frame=8

80 complete samples, starting from seq_nr=9994, from 2013-07-27 GMRT observations of PSR J1810+1744, rewritten so each frame has 8 complete samples.

SAMPLE_GSB_PHASED_HEADER

baseband.data.**SAMPLE_GSB_PHASED_HEADER = '/home/docs/checkouts/readthedocs.org/user_builds/baseband/conda/v3.**

GSB phased header sample.

10 header entries, starting from seq_nr=9994, from 2013-07-27 GMRT observations of PSR J1810+1744.

SAMPLE_GSB_RAWDUMP

baseband.data.**SAMPLE_GSB_RAWDUMP = '/home/docs/checkouts/readthedocs.org/user_builds/baseband/conda/v3.0.0/li**

GSB rawdump sample. samples_per_frame=8192

First 81920 samples of node 5 rawdump data from 2015-04-27 GMRT observations of the Crab pulsar.

SAMPLE_GSB_RAWDUMP_HEADER

baseband.data.**SAMPLE_GSB_RAWDUMP_HEADER = '/home/docs/checkouts/readthedocs.org/user_builds/baseband/conda/v3**

GSB rawdump header sample.

First 10 header entries of node 5 rawdump data from 2015-04-27 GMRT observations of the Crab pulsar.

SAMPLE_MARK4

baseband.data.**SAMPLE_MARK4 = '/home/docs/checkouts/readthedocs.org/user_builds/baseband/conda/v3.0.0/lib/pyth**

Mark 4 sample. ntrack=64, fanout=4, bps=2.

Created from a European VLBI Network/Arecibo PSR B1957+20 observation using dd if=gp052d_ar_no0021 of=sample.m4 bs=128000 count=3

SAMPLE_MARK4_16TRACK

`baseband.data.SAMPLE_MARK4_16TRACK = '/home/docs/checkouts/readthedocs.org/user_builds/baseband/conda/v3.0.0/`

Mark 4 sample. ntrack=16, fanout=4, bps=2.

Created from the first two frames an Arecibo observation of the Crab Pulsar on 2013/11/03. (2013_306_raks02ae/ar/gs033a_ar_no0055.m5a)

SAMPLE_MARK4_32TRACK

`baseband.data.SAMPLE_MARK4_32TRACK = '/home/docs/checkouts/readthedocs.org/user_builds/baseband/conda/v3.0.0/`

Mark 4 sample. ntrack=32, fanout=4, bps=2.

Created from a Arecibo observation simultaneous with RadioAstron using dd if=rg10a_ar_no0014 of=sample_32track.m4 bs=10000 count=17

SAMPLE_MARK4_32TRACK_FANOUT2

`baseband.data.SAMPLE_MARK4_32TRACK_FANOUT2 = '/home/docs/checkouts/readthedocs.org/user_builds/baseband/conda`

Mark 4 sample. ntrack=32, fanout=2, bps=2.

Created from an Arecibo observation of PSR B1133+16 using dd if=gk049c_ar_no0011.m5a of=sample_32track_fanout2.m4 bs=10000 count=18

SAMPLE_MARK5B

`baseband.data.SAMPLE_MARK5B = '/home/docs/checkouts/readthedocs.org/user_builds/baseband/conda/v3.0.0/lib/pyt`

Mark 5B sample. nchan=8, bps=2.

Created from a EVN/WSRT PSR B1957+20 observation.

SAMPLE_MWA_VDIF

`baseband.data.SAMPLE_MWA_VDIF = '/home/docs/checkouts/readthedocs.org/user_builds/baseband/conda/v3.0.0/lib/`

VDIF sample from MWA. EDV=0, two threads, bps=8

SAMPLE_PUPPI

`baseband.data.SAMPLE_PUPPI = '/home/docs/checkouts/readthedocs.org/user_builds/baseband/conda/v3.0.0/lib/pyt`

GUPPI/PUPPI sample, npol=2, nchan=4.

Created from the first four frames of a 2018-01-14 Arecibo observation of J1810+1744, with payload shortened to 8192 complete samples (with 512 overlap).

SAMPLE_VDIF

`baseband.data.SAMPLE_VDIF = '/home/docs/checkouts/readthedocs.org/user_builds/baseband/conda/v3.0.0/lib/pytho`

VDIF sample. 8 threads, bps=2.

Created from a EVN/VLBA PSR B1957+20 observation. Timestamps of frames with even thread IDs have been corrected to be consistent with odd-ID frames.

SAMPLE_VLBI_VDIF

`baseband.data.SAMPLE_VLBI_VDIF = '/home/docs/checkouts/readthedocs.org/user_builds/baseband/conda/v3.0.0/lib/`

VDIF sample. 8 threads, bps=2.

Created from a EVN/VLBA PSR B1957+20 observation. Uncorrected version of SAMPLE_VDIF.

Part IV

Developer Documentation

The developer documentation feature tutorials for supporting new formats or format extensions such as VDIF EDV. It also contains instructions for publishing new code releases.

CHAPTER

FOURTEEN

SUPPORTING A NEW VDIF EDV

Users may encounter VDIF files with unusual headers not currently supported by Baseband. These may either have novel EDV, or they may purport to be a supported EDV but not conform to its formal specification. To handle such situations, Baseband supports implementation of new EDVs and overriding of existing EDVs without the need to modify Baseband's source code.

The tutorials below assumes the following modules have been imported:

```
>>> import numpy as np
>>> import astropy.units as u
>>> from baseband import vdif, vlbi_base as vlbi
```

14.1 VDIF Headers

Each VDIF frame begins with a 32-byte, or eight 32-bit **word**, header that is structured as follows:

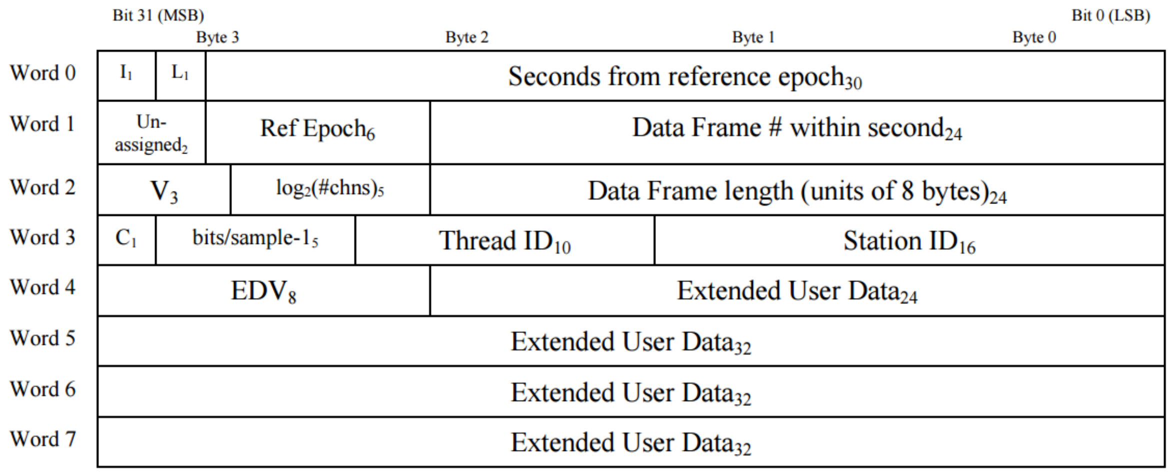


Fig. 1: Schematic of the standard 32-bit VDIF header, from VDIF specification release 1.1.1 document, Fig. 3. 32-bit words are labelled on the left, while byte and bit numbers above indicate relative addresses within each word. Subscripts indicate field length in bits.

where the abbreviated labels are

- I_1 - invalid data
- L_1 - if 1, header is VDIF legacy

- V_3 - VDIF version number
- $\log_2(\#\text{chns})_5$ - $\log_2$ of the number of sub-bands in the frame
- C_1 - if 1, complex data
- EDV_8 - “extended data version” number; see below

Detailed definitions of terms are found on pages 5 to 7 of the VDIF specification document.

Words 4 - 7 hold optional extended user data, using a layout specified by the EDV, in word 4 of the header. EDV formats can be registered on the VDIF website; Baseband aims to support all registered formats (but does not currently support EDV = 4).

14.2 Implementing a New EDV

In this tutorial, we follow the implementation of an EDV=4 header. This would be a first and required step to support that format, but does not suffice, as it also needs a new frame class that allows the purpose of the EDV class, which is to independently store the validity of sub-band channels within a single data frame, rather than using the single invalid-data bit. From the EDV=4 specification, we see that we need to add the following to the standard VDIF header:

- Validity header mask (word 4, bits 16 - 24): integer value between 1 and 64 inclusive indicating the number of validity bits. (This is different than $\log_2(\#\text{chns})_5$, since some channels can be unused.)
- Synchronization pattern (word 5): constant byte sequence `0xACABFEED`, for finding the locations of headers in a data stream.
- Validity mask (words 6 - 7): 64-bit binary mask indicating the validity of sub-bands. Any fraction of 64 sub-bands can be stored in this format, with any unused bands labelled as invalid (`0`) in the mask. If the number of bands exceeds 64, each bit indicates the validity of a group of sub-bands; see specification for details.

See Sec. 3.1 of the specification for best practices on using the invalid data bit I_1 in word 0.

In Baseband, a header is parsed using `VDIFHeader`, which returns a header instance of one of its subclasses, corresponding to the header EDV. This can be seen in the `baseband.vdif.header` module class inheritance diagram. To support a new EDV, we create a new subclass to `baseband.vdif.VDIFHeader`:

```
>>> class VDIFHeader4(vdif.header.VDIFHeader):
...     _edv = 4
...
...     _header_parser = vlbi.header.HeaderParser(
...         (('invalid_data', (0, 31, 1, False)),
...          ('legacy_mode', (0, 30, 1, False)),
...          ('seconds', (0, 0, 30)),
...          ('_1_30_2', (1, 30, 2, 0x0)),
...          ('ref_epoch', (1, 24, 6)),
...          ('frame_nr', (1, 0, 24, 0x0)),
...          ('vdif_version', (2, 29, 3, 0x1)),
...          ('lg2_nchan', (2, 24, 5)),
...          ('frame_length', (2, 0, 24)),
...          ('complex_data', (3, 31, 1)),
...          ('bits_per_sample', (3, 26, 5)),
...          ('thread_id', (3, 16, 10, 0x0)),
...          ('station_id', (3, 0, 16)),
...          ('edv', (4, 24, 8)),
...          ('validity_mask_length', (4, 16, 8, 0)),
...          ('sync_pattern', (5, 0, 32, 0xACABFEED)),
...          ('validity_mask', (6, 0, 64, 0))))
```

VDIFHeader has a metaclass that ensures that whenever it is subclassed, the subclass definition is inserted into the VDIF_HEADER_CLASSES dictionary using its EDV value as the dictionary key. Methods in VDIFHeader use this dictionary to determine the type of object to return for a particular EDV. How all this works is further discussed in the documentation of the VDIF baseband.vdif.header module.

The class must have a private _edv attribute for it to properly be registered in VDIF_HEADER_CLASSES. It must also feature a _header_parser that reads these words to return header properties. For this, we use baseband.vlbi_base.header.HeaderParser. To initialize a header parser, we pass it a tuple of header properties, where each entry follows the syntax:

```
('property_name', (word_index, bit_index, bit_length, default))
```

where

- property_name: name of the header property; this will be the key;
- word_index: index into the header words for this key;
- bit_index: index to the starting bit of the part used;
- bit_length: number of bits used, normally between 1 and 32, but can be 64 for adding two words together; and
- default: (optional) default value to use in initialization.

For further details, see the documentation of HeaderParser.

Once defined, we can use our new header like any other:

```
>>> myheader = vdif.header.VDIFHeader.fromvalues(
...     edv=4, seconds=14363767, nchan=1,
...     station=65532, bps=2, complex_data=False,
...     thread_id=3, validity_mask_length=60,
...     validity_mask=(1 << 59) + 1)
>>> myheader
<VDIFHeader4 invalid_data: False,
             legacy_mode: False,
             seconds: 14363767,
             _1_30_2: 0,
             ref_epoch: 0,
             frame_nr: 0,
             vdif_version: 1,
             lg2_nchan: 0,
             frame_length: 0,
             complex_data: False,
             bits_per_sample: 1,
             thread_id: 3,
             station_id: 65532,
             edv: 4,
             validity_mask_length: 60,
             sync_pattern: 0xacabfeed,
             validity_mask: 576460752303423489>
>>> myheader['validity_mask'] == 2**59 + 1
True
```

There is an easier means of instantiating the header parser. As can be seen in the class inheritance diagram for the header module, many VDIF headers are subclassed from other VDIFHeader subclasses, namely VDIFBaseHeader and VDIFSampleRateHeader. This is because many EDV specifications share common header values, and so their functions and derived properties should be shared as well. Moreover, header parsers can be appended to one another, which saves repetitious coding because the first four words of any VDIF header are the same. Indeed, we can create the same header as above by subclassing VDIFBaseHeader:

```
>>> class VDIFHeader4Enhanced(vdif.header.VDIFBaseHeader):
...     _edv = 42
...
...     _header_parser = vdif.header.VDIFBaseHeader._header_parser +\
...                      vlbi.header.HeaderParser((
...                             ('validity_mask_length', (4, 16, 8, 0)),
...                             ('sync_pattern', (5, 0, 32, 0xACABFEED)),
...                             ('validity_mask', (6, 0, 64, 0))))
...
...     _properties = vdif.header.VDIFBaseHeader._properties + ('validity',)
...
...     def verify(self):
...         """Basic checks of header integrity."""
...         super(VDIFHeader4Enhanced, self).verify()
...         assert 1 <= self['validity_mask_length'] <= 64
...
...     @property
...     def validity(self):
...         """Validity mask array with proper length.
...
...         If set, writes both ``validity_mask`` and ``validity_mask_length``.
...         """
...         bitmask = np.unpackbits(self['validity_mask'].astype('>u8')
...                                 .view('u1'))[::-1].astype(bool)
...         return bitmask[:self['validity_mask_length']]
...
...     @validity.setter
...     def validity(self, validity):
...         bitmask = np.zeros(64, dtype=bool)
...         bitmask[:len(validity)] = validity
...         self['validity_mask_length'] = len(validity)
...         self['validity_mask'] = np.packbits(bitmask[::-1]).view('>u8')
```

Here, we set `edv = 42` because `VDIFHeader`'s metaclass is designed to prevent accidental overwriting of existing entries in `VDIF_HEADER_CLASSES`. If we had used `_edv = 4`, we would have gotten an exception:

```
ValueError: EDV 4 already registered in VDIF_HEADER_CLASSES
```

We shall see how to override header classes in the next section. Except for the EDV, `VDIFHeader4Enhanced`'s header structure is identical to `VDIFHeader4`. It also contains a few extra functions to enhance the header's usability.

The `verify` function is an optional function that runs upon header initialization to check its veracity. Ours simply checks that the validity mask length is in the allowed range, but we also call the same function in the superclass (`VDIFBaseHeader`), which checks that the header is not in 4-word "legacy mode", that the header's EDV matches that read from the words, that there are eight words, and that the sync pattern matches `0xACABFEED`.

The `validity_mask` is a bit mask, which is not necessarily the easiest to use directly. Hence, implement a derived `validity` property that generates a boolean mask of the right length (note that this is not right for cases whether the number of channels in the header exceeds 64). We also define a corresponding setter, and add this to the private `_properties` attribute, so that we can use `validity` as a keyword in `fromvalues`:

```
>>> myenhancedheader = vdif.header.VDIFHeader.fromvalues(
...     edv=42, seconds=14363767, nchan=1,
...     station=65532, bps=2, complex_data=False,
...     thread_id=3, validity=[True]+[False]*58+[True])
>>> myenhancedheader
<VDIFHeader4Enhanced invalid_data: False,
                     legacy_mode: False,
```

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```
                      seconds: 14363767,
                      _1_30_2: 0,
                      ref_epoch: 0,
                      frame_nr: 0,
                      vdif_version: 1,
                      lg2_nchan: 0,
                      frame_length: 0,
                      complex_data: False,
                      bits_per_sample: 1,
                      thread_id: 3,
                      station_id: 65532,
                      edv: 42,
                      validity_mask_length: 60,
                      sync_pattern: 0xacabfeed,
                      validity_mask: [576460752303423489]>
>>> assert myenhancedheader['validity_mask'] == 2**59 + 1
>>> assert (myenhancedheader.validity == [True]+[False]*58+[True]).all()
>>> myenhancedheader.validity = [True]*8
>>> myenhancedheader['validity_mask']
array([255], dtype=uint64)
```

Note: If you have implemented support for a new EDV that is widely used, we encourage you to make a pull request to Baseband's GitHub repository, as well as to register it (if it is not already registered) with the VDIF consortium!

14.3 Replacing an Existing EDV

Above, we mentioned that `VDIFHeader`'s metaclass is designed to prevent accidental overwriting of existing entries in `VDIF_HEADER_CLASSES`, so attempting to assign two header classes to the same EDV results in an exception. There are situations such the one above, however, where we'd like to replace one header with another.

To get `VDIFHeader` to use `VDIFHeader4Enhanced` when `edv=4`, we can manually insert it in the dictionary:

```
>>> vdif.header.VDIF_HEADER_CLASSES[4] = VDIFHeader4Enhanced
```

Of course, we should then be sure that its `_edv` attribute is correct:

```
>>> VDIFHeader4Enhanced._edv = 4
```

`VDIFHeader` will now return instances of `VDIFHeader4Enhanced` when reading headers with `edv = 4`:

```
>>> myheader = vdif.header.VDIFHeader.fromvalues(
...     edv=4, seconds=14363767, nchan=1,
...     station=65532, bps=2, complex_data=False,
...     thread_id=3, validity=[True]*60)
>>> assert isinstance(myheader, VDIFHeader4Enhanced)
```

Note: Failing to modify `_edv` in the class definition will lead to an EDV mismatch when `verify` is called during header initialization.

This can also be used to override `VDIFHeader`'s behavior *even for EDVs that are supported by Baseband*, which may prove useful when reading data with corrupted or mislabelled headers. To illustrate this, we attempt to read in a corrupted VDIF file originally from the Dominion Radio Astrophysical Observatory. This file can be imported from the baseband data directory:

```
>>> from baseband.data import SAMPLE_DRAO_CORRUPT
```

Naively opening the file with

```
>>> fh = vdif.open(SAMPLE_DRAO_CORRUPT, 'rs')  # doctest: +SKIP
```

will lead to an AssertionError. This is because while the headers of the file use EDV=0, it deviates from that EDV standard by storing additional information an: an “eud2” parameter in word 5, which is related to the sample time. Furthermore, the `bits_per_sample` setting is incorrect (it should be 3 rather than 4 – the number is defined such that a one-bit sample has a `bits_per_sample` code of 0). Finally, though not an error, the `thread_id` in word 3 defines two parts, `link` and `slot`, which reflect the data acquisition computer node that wrote the data to disk.

To accommodate these changes, we design an alternate header. We first pop the EDV = 0 entry from `VDIF_HEADER_CLASSES`:

```
>>> vdif.header.VDIF_HEADER_CLASSES.pop(0)
<class 'baseband.vdif.header.VDIFHeader0'>
```

We then define a replacement class:

```
>>> class DRAOVDIFHeader(vdif.header.VDIFHeader0):
...     """DRAO VDIF Header
...
...     An extension of EDV=0 which uses the thread_id to store link
...     and slot numbers, and adds a user keyword (illegal in EDV0,
...     but whatever) that identifies data taken at the same time.
...
...     The header also corrects 'bits_per_sample' to be properly bps-1.
...     """
...
...     _header_parser = vdif.header.VDIFHeader0._header_parser + \
...         vlbi.header.HeaderParser((('link', (3, 16, 4)),
...                                   ('slot', (3, 20, 6)),
...                                   ('eud2', (5, 0, 32))))
...
...     def verify(self):
...         pass  # this is a hack, don't bother with verification...
...
...     @classmethod
...     def fromfile(cls, fh, edv=0, verify=False):
...         self = super(DRAOVDIFHeader, cls).fromfile(fh, edv=0,
...                                                     verify=False)
...         # Correct wrong bps
...         self.mutable = True
...         self['bits_per_sample'] = 3
...         return self
```

We override `verify` because `VDIFHeader0`’s `verify` function checks that word 5 contains no data. We also override the `fromfile` class method such that the `bits_per_sample` property is reset to its proper value whenever a header is read from file.

We can now read in the corrupt file by manually reading in the header, then the payload, of each frame:

```
>>> fh = vdif.open(SAMPLE_DRAO_CORRUPT, 'rb')
>>> header0 = DRAOVDIFHeader.fromfile(fh)
```

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```
>>> header0['eud2'] == 667235140
True
>>> header0['link'] == 2
True
>>> payload0 = vdif.payload.VDIFPayload.fromfile(fh, header0)
>>> payload0.shape == (header0.samples_per_frame, header0.nchan)
True
>>> fh.close()
```

Reading a frame using VDIFFrame will still fail, since its _header_class is VDIFHeader, and so VDIFHeader.fromfile, rather than the function we defined, is used to read in headers. If we wanted to use VDIFFrame, we would need to set

```
VDIFFrame._header_class = DRAOVDIFHeader
```

before using baseband.vdif.open(), so that header files are read using DRAOVDIFHeader.fromfile.

A more elegant solution that is compatible with baseband.vdif.base.VDIFStreamReader without hacking baseband.vdif.frame.VDIFFrame involves modifying the bits-per-sample code within __init__(). Let's remove our previous custom class, and define a replacement:

```
>>> vdif.header.VDIF_HEADER_CLASSES.pop(0)
<class '__main__.DRAOVDIFHeader'>
>>> class DRAOVDIFHeaderEnhanced(vdif.header.VDIFHeader0):
...     """DRAO VDIF Header
...
...     An extension of EDV=0 which uses the thread_id to store link and slot
...     numbers, and adds a user keyword (illegal in EDV0, but whatever) that
...     identifies data taken at the same time.
...
...     The header also corrects 'bits_per_sample' to be properly bps-1.
...     """
...     _header_parser = vdif.header.VDIFHeader0._header_parser + \
...         vlbi.header.HeaderParser((('link', (3, 16, 4)),
...                                   ('slot', (3, 20, 6)),
...                                   ('eud2', (5, 0, 32))))
...
...     def __init__(self, words, edv=None, verify=True, **kwargs):
...         super(DRAOVDIFHeaderEnhanced, self).__init__(
...                 words, verify=False, **kwargs)
...         self.mutable = True
...         self['bits_per_sample'] = 3
...
...     def verify(self):
...         pass
```

We can then use the stream reader without further modification:

```
>>> fh2 = vdif.open(SAMPLE_DRAO_CORRUPT, 'rs', sample_rate=5**12*u.Hz)
>>> fh2.header0['eud2'] == header0['eud2']
True
>>> np.all(fh2.read(1) == payload0[0])
True
>>> fh2.close()
```

Reading frames using VDIFFileReader.read_frame will now work as well, but reading frame sets using VDIFFileReader.read_frameset will still fail. This is because the frame and thread numbers that function relies on are meaningless for these headers, and grouping threads together using the `link`, `slot` and `eud2` values should be manually performed by the user.

CHAPTER

FIFTEEN

RELEASE PROCEDURE

This procedure is based off of Astropy's, and additionally uses information from the PyPI packaging tutorial.

15.1 Prerequisites

To make releases, you will need

- The twine package.
- An account on PyPI.
- Collaborator status on Baseband's repository at `mhvk/baseband` to push new branches.
- An account on Read the Docs that has access to Baseband.
- Optionally, a GPG signing key associated with your GitHub account. While releases do not need to be signed, we recommend doing so to ensure they are trustworthy. To make a GPG key and associate it with your GitHub account, see the Astropy documentation.

15.2 Versioning

Baseband follows the semantic versioning specification:

```
major.minor.patch
```

where

- `major` number represents backward incompatible API changes.
- `minor` number represents feature updates to last major version.
- `patch` number represents bugfixes from last minor version.

Major and minor versions have their own release branches on GitHub that end with "x" (eg. `v1.0.x`, `v1.1.x`), while specific releases are tagged commits within their corresponding branch (eg. `v1.1.0` and `v1.1.1` are tagged commits within `v1.1.x`).

15.3 Procedure

The first two steps of the release procedure are different for major and minor releases than it is for patch releases. Steps specifically for major/minor releases are labelled "m", and patch ones labelled "p".

15.3.1 1m. Preparing major/minor code for release

We begin in the main development branch (the local equivalent to mhvk/baseband:master). First, check the following:

- **Ensure tests pass**. Run the test suite by running python3 setup.py test in the Baseband root directory.
- **Update** CHANGES.rst. All merge commits to master since the last release should be documented (except trivial ones such as typo corrections). Since CHANGES.rst is updated for each merge commit, in practice it is only necessary to change the date of the release you are working on from "unreleased" to the current date.
- **Add authors and contributors to** AUTHORS.rst. To list contributors, one can use:

  ```
  git shortlog -n -s -e
  ```

  This will also list contributors to astropy-helpers and the astropy template, who should not be added. If in doubt, cross-reference with the authors of pull requests.

Once finished, git add any changes and make a commit:

```
git commit -m "Finalizing changelog and author list for v<version>"
```

For major/minor releases, the patch number is 0.

Submit the commit as a pull request to master.

15.3.2 1p. Cherry-pick code for a patch release

We begin by checking out the appropriate release branch:

```
git checkout v<version branch>.x
```

Bugfix merge commits are backported to this branch from master by way of git cherry-pick. First, find the SHA hashes of the relevant merge commits in the main development branch. Then, for each:

```
git cherry-pick -m 1 <SHA-1>
```

For more information, see Astropy's documentation.

Once you have cherry-picked, check the following:

- **Ensure tests pass and documentation builds**. Run the test suite by running python3 setup.py test, and build documentation by running python3 setup.py build_docs, in the Baseband root directory.
- **Update** CHANGES.rst. Typically, merge commits record their changes, including any backported bugfixes, in CHANGES.rst. Cherry-picking should add these records to this branch's CHANGES.rst, but if not, manually add them before making the commit (and manually remove any changes not relevant to this branch). Also, change the date of the release you are working on from "unreleased" to the current date.

Commit your changes:

```
git commit -m "Finalizing changelog for v<version>"
```

15.3.3 2m. Create a new release branch

Still in the main development branch, change the version keyword under the [[metadata]] section of setup.cfg to:

```
version = <version>
```

and make a commmit:

```
git commit -m "Preparing v<version>."
```

Submit the commit as a pull request to master.

Once the pull request has been merged, make and enter a new release branch:

```
git checkout -b v<version branch>.x
```

15.3.4 2p. Append to the release branch

In the release branch, prepare the patch release commit by changing the `version` keyword under the `[[metadata]]` section of `setup.cfg` to:

```
version = <version>
```

then make a new commmit:

```
git commit -m "Preparing v<version>."
```

15.3.5 3. Tag the release

Tag the commit made in step 2 as:

```
git tag -s v<version> -m "Tagging v<version>"
```

15.3.6 4. Clean and package the release

Checkout the tag:

```
git checkout v<version>
```

Clean the repository:

```
git clean -dfx
cd astropy_helpers; git clean -dfx; cd ..
```

and ensure the repository has the proper permissions:

```
umask 0022
chmod -R a+Xr .
```

Finally, package the release's source code:

```
python setup.py build sdist
```

15.3.7 5. Test the release

We now test installing and running Baseband in clean virtual environments, to ensure there are no subtle bugs that come from your customized development environment. Before creating the virtualenvs, we recommend checking if the `$PYTHONPATH` environmental variable is set. If it is, set it to a null value (in bash, `PYTHONPATH=`) before proceeding.

To create the environments:

```
python3 -m venv --no-site-packages test_release
```

Now, for each environment, activate it, navigate to the Baseband root directory, and run the tests:

```
source <name_of_virtualenv>/bin/activate
cd <baseband_directory>
pip install dist/baseband-<version>.tar.gz
pip install pytest-astropy
cd ~/
python -c 'import baseband; baseband.test()'
deactivate
```

If the test suite raises any errors (at this point, likely dependency issues), delete the release tag:

```
git tag -d v<version>
```

For a major/minor release, delete the `v<version branch>.x` branch as well. Then, make the necessary changes directly on the main development branch. Once the issues are fixed, repeat steps 2 - 6.

If the tests succeed, you may optionally re-run the cleaning and packaging code above following the tests:

```
git clean -dfx
cd astropy_helpers; git clean -dfx; cd ..
umask 0022
chmod -R a+Xr .
python setup.py build sdist
```

You may optionally sign the source as well:

```
gpg --detach-sign -a dist/baseband-<version>.tar.gz
```

15.3.8 7. Publish the release on GitHub

If you are working a major/minor release, first push the branch to upstream (assuming upstream is `mhvk/baseband`):

```
git push upstream v<version branch>.x
```

Push the tag to GitHub as well:

```
git push upstream v<version>
```

Go to the `mhvk/baseband` Releases section. Here, published releases are in shown in blue, and unpublished tags in grey and in a much smaller font. To publish a release, click on the `v<version>` tag you just pushed, then click “Edit tag” (on the upper right). This takes you to a form where you can customize the release title and description. Leave the title blank, in which case it is set to “v<version>”; you can leave the description blank as well if you wish. Finally, click on “Publish release”. This takes you back to Releases, where you should see our new release in blue.

The Baseband GitHub repo automatically updates Baseband’s Zenodo repository for each published release. Check if your release has made it to Zenodo by clicking the badge in `Readme.rst`.

15.3.9 8. Build the release wheel for PyPI

To build the release:

```
python setup.py bdist_wheel --universal
```

15.3.10 9. (Optional) test uploading the release

PyPI provides a test environment to safely try uploading new releases. To take advantage of this, use:

```
twine upload --repository-url https://test.pypi.org/legacy/ dist/baseband-<version>*
```

To test if this was successful, create a new virtualenv as above:

```
virtualenv --no-site-packages --python=python3 pypitest
```

Then (`pip install pytest-astropy` comes first because `test.pypi` does not contain recent versions of Astropy):

```
source <name_of_virtualenv>/bin/activate
pip install pytest-astropy
pip install --index-url https://test.pypi.org/simple/ baseband
python -c 'import baseband; baseband.test()'
deactivate
```

15.3.11 10. Upload to PyPI

Finally, upload the package to PyPI:

```
twine upload dist/baseband-<version>*
```

15.3.12 11. Check if Readthedocs has updated

Go to Read the Docs and check that the `stable` version points to the latest stable release. Each minor release has its own version as well, which should be pointing to its latest patch release.

15.3.13 12m. Clean up master

In the main development branch, add the next major/minor release to `CHANGES.rst`. Also update the `version` keyword in `setup.cfg` to:

```
version = <next major/minor version>.dev
```

Make a commmit:

```
git commit -m "Add v<next major/minor version> to the changelog."
```

Then submit a pull request to master.

15.3.14 12p. Update CHANGES.rst on master

Change the release date of the patch release in `CHANGES.rst` on master to the current date, then:

```
git commit -m "Added release date for v<version> to the changelog."
```

(Alternatively, `git cherry-pick` the changelog fix from the release branch back to the main development one.)

Then submit a pull request to master.

Part V

Project Details

CHAPTER SIXTEEN

AUTHORS AND CREDITS

If you used this package in your research, please cite it via DOI 10.5281/zenodo.1214268.

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CHAPTER

SEVENTEEN

FULL CHANGELOG

17.1 3.0 (2019-08-28)

- This version only supports python3.

17.1.1 New Features

- File information now includes whether a file can be read and decoded. The `readable()` method on stream readers also includes whether the data in a file can be decoded. [#316]

17.1.2 Bug Fixes

- Empty GUPPI headers can now be created without having to pass in `verify=False`. This is needed for astropy 3.2, which initializes an empty header in its revamped `.fromstring` method. [#314]
- VDIF multichannel headers and payloads are now forced to have power-of-two bits per sample. [#315]
- Bits per complete sample for VDIF payloads are now calculated correctly also for non power-of-two bits per sample. [#315]
- Guppi raw file info now presents the correct sample rate, corrected for overlap. [#319]
- All headers now check that `samples_per_frame` are set to possible numbers. [#325]
- Getting `.info` on closed files no longer leads to an error (though no information can be retrieved). [#326]

17.1.3 Other Changes and Additions

- Increased speed of VDIF stream reading by removing redundant verification. Reduces the overhead for verification for VDIF CHIME data from 50% (factor 1.5) to 13%. [#321]

17.2 2.0 (2018-12-12)

- VDIF and Mark 5B readers and writers now support 1 bit per sample. [#277, #278]

17.2.1 Bug Fixes

- VDIF reader will now properly ignore corrupt last frames. [#273]
- Mark5B reader more robust against headers not being parsed correctly in `Mark5BFileReader.find_header`. [#275]
- All stream readers now have a proper `dtype` attribute, not a corresponding `np.float32` or `np.complex64`. [#280]
- GUPPI stream readers no longer emit warnings on not quite FITS compliant headers. [#283]

17.2.2 Other Changes and Additions

- Added release procedure to the documentation. [#268]

17.3 1.2 (2018-07-27)

17.3.1 New Features

- Expanded support for acccessing sequences of files to VLBI format openers and `baseband.open`. Enabled `baseband.guppi.open` to open file sequences using string templates like with `baseband.dada.open`. [#254]
- Created `baseband.helpers.sequentialfile.FileNameSequencer`, a general-purpose filename sequencer that can be passed to any format opener. [#253]

17.3.2 Other Changes and Additions

- Moved the Getting Started section to *"Using Baseband"*, and created a new quickstart tutorial under *Getting Started* to better assist new users. [#260]

17.4 1.1.1 (2018-07-24)

17.4.1 Bug Fixes

- Ensure gsb times can be decoded with astropy-dev (which is to become astropy 3.1). [#249]
- Fixed rounding error when encoding 4-bit data using `baseband.vlbi_base.encoding.encode_4bit_base`. [#250]
- Added GUPPI/PUPPI to the list of file formats used by `baseband.open` and `baseband.file_info`. [#251]

17.5 1.1 (2018-06-06)

17.5.1 New Features

- Added a new `baseband.file_info` function, which can be used to inspect data files. [#200]
- Added a general file opener, `baseband.open` which for a set of formats will check whether the file is of that format, and then load it using the corresponding module. [#198]

- Allow users to pass a `verify` keyword to file openers reading streams. [#233]
- Added support for the GUPPI format. [#212]
- Enabled `baseband.dada.open` to read streams where the last frame has an incomplete payload. [#228]

17.5.2 API Changes

- In analogy with Mark 5B, VDIF header time getting and setting now requires a frame rate rather than a sample rate. [#217, #218]
- DADA and GUPPI now support passing either a `start_time` or `offset` (in addition to `time`) to set the start time in the header. [#240]

17.5.3 Bug Fixes

17.5.4 Other Changes and Additions

- The `baseband.data` module with sample data files now has an explicit entry in the documentation. [#198]
- Increased speed of VLBI stream reading by changing the way header sync patterns are stored, and removing redundant verification steps. VDIF sequential decode is now 5 - 10% faster (depending on the number of threads). [#241]

17.6 1.0.1 (2018-06-04)

17.6.1 Bug Fixes

- Fixed a bug in `baseband.dada.open` where passing a `squeeze` setting is ignored when also passing header keywords in 'ws' mode. [#211]
- Raise an exception rather than return incorrect times for Mark 5B files in which the fractional seconds are not set. [#216]

17.6.2 Other Changes and Additions

- Fixed broken links and typos in the documentation. [#211]

17.7 1.0.0 (2018-04-09)

- Initial release.

CHAPTER

EIGHTEEN

LICENSES

18.1 Baseband License

Baseband is licensed under the GNU General Public License v3.0. The full text of the license can be found in `LICENSE` under Baseband's root directory.

Part VI

Reference/API

CHAPTER

NINETEEN

BASEBAND PACKAGE

Radio baseband I/O.

19.1 Functions

`file_info`(name[, format])	Get format and other information from a baseband file.
`open`(name[, mode, format])	Open a baseband file (or sequence of files) for reading or writing.
`test`(**kwargs)	Run the tests for the package.

19.1.1 file_info

`baseband.`**`file_info`**(*name*, *format=('dada', 'mark4', 'mark5b', 'vdif', 'guppi', 'gsb')*, ***kwargs*)

Get format and other information from a baseband file.

The keyword arguments will only be used if needed, so if one is unsure what format a file is, but knows it was taken recently and has 8 channels, one would put in `ref_time=Time('2015-01-01'), nchan=8`. Alternatively, and perhaps easier, one can first call the function without extra arguments in which case the result will describe what is missing.

Parameters

name
[str or filehandle, or sequence of str] Raw file for which to obtain information. If a sequence of files is passed, returns information from the first file (see Notes).

format
[str, tuple of str, optional] Formats to try. If not given, try all standard formats.

****kwargs**
Any arguments that might help to get information. For instance, Mark 4 and Mark 5B do not have complete timestamps, which can be addressed by passing in `ref_time`. Furthermore, for Mark 5B, it is needed to pass in `nchan`. Arguments are checked for consistency with the file even if not used (see notes below).

Returns

info
[`VLBIFileReaderInfo` or `VLBIStreamReaderInfo`] The information on the file. Can be turned info a `dict` by calling it (i.e., `info()`).

Notes

All keyword arguments passed in are classified, ending up in one of the following (mostly useful if the file could be opened as a stream):

- `used_kwargs`: arguments that were needed to open the file.
- `consistent_kwargs`: not needed to open the file, but consistent.
- `inconsistent_kwargs`: not needed to open the file, and inconsistent.
- `irrelevant_kwargs`: provide information irrelevant for opening.

19.1.2 open

`baseband.open`(*name*, *mode='rs'*, *format=('dada', 'mark4', 'mark5b', 'vdif', 'guppi', 'gsb')*, ***kwargs*)

Open a baseband file (or sequence of files) for reading or writing.

Opened as a binary file, one gets a wrapped filehandle that adds methods to read/write a frame. Opened as a stream, the handle is wrapped further, and reading and writing to the file is done as if the file were a stream of samples.

Parameters

name
[str or filehandle, or sequence of str] File name, filehandle, or sequence of file names. A sequence may be a list or str of ordered filenames, or an instance of `FileNameSequencer`.

mode
[{'rb', 'wb', 'rs', or 'ws'}, optional] Whether to open for reading or writing, and as a regular binary file or as a stream. Default: 'rs', for reading a stream.

format
[str or tuple of str] The format the file is in. For reading, this can be a tuple of possible formats, all of which will be tried in turn. By default, all supported formats are tried.

****kwargs**
Additional arguments needed for opening the file as a stream. For most formats, trying without these will raise an exception that tells which arguments are needed. Opening will not succeed if any arguments are passed in that are inconsistent with the file, or are irrelevant for opening the file.

19.1.3 test

`baseband.test`(***kwargs*)

Run the tests for the package.

This method builds arguments for and then calls `pytest.main`.

Parameters

package
[str, optional] The name of a specific package to test, e.g. 'io.fits' or 'utils'. Accepts comma separated string to specify multiple packages. If nothing is specified all default tests are run.

args
: [str, optional] Additional arguments to be passed to `pytest.main` in the `args` keyword argument.

docs_path
: [str, optional] The path to the documentation .rst files.

open_files
: [bool, optional] Fail when any tests leave files open. Off by default, because this adds extra run time to the test suite. Requires the `psutil` package.

parallel
: [int or 'auto', optional] When provided, run the tests in parallel on the specified number of CPUs. If parallel is `'auto'`, it will use the all the cores on the machine. Requires the `pytest-xdist` plugin.

pastebin
: [('failed', 'all', None), optional] Convenience option for turning on py.test pastebin output. Set to 'failed' to upload info for failed tests, or 'all' to upload info for all tests.

pdb
: [bool, optional] Turn on PDB post-mortem analysis for failing tests. Same as specifying `--pdb` in `args`.

pep8
: [bool, optional] Turn on PEP8 checking via the pytest-pep8 plugin and disable normal tests. Same as specifying `--pep8 -k pep8` in `args`.

plugins
: [list, optional] Plugins to be passed to `pytest.main` in the `plugins` keyword argument.

remote_data
: [{'none', 'astropy', 'any'}, optional] Controls whether to run tests marked with @pytest.mark.remote_data. This can be set to run no tests with remote data (`none`), only ones that use data from http://data.astropy.org (`astropy`), or all tests that use remote data (`any`). The default is `none`.

repeat
: [`int`, optional] If set, specifies how many times each test should be run. This is useful for diagnosing sporadic failures.

skip_docs
: [`bool`, optional] When `True`, skips running the doctests in the .rst files.

test_path
: [str, optional] Specify location to test by path. May be a single file or directory. Must be specified absolutely or relative to the calling directory.

verbose
: [bool, optional] Convenience option to turn on verbose output from py.test. Passing True is the same as specifying `-v` in `args`.

PYTHON MODULE INDEX

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