SOUK MKID Readout

Release souk_mkid_readout-5e2513a:souk_mkid_readout-v7.1.1-1-g5e2513a7

Jack Hickish

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CHAPTER

ONE

INSTALLATION

The SOUK MKID Readout pipeline firmware and software is available at https://github.com/realtimeradio/souk-firmware. Follow the instructions here to download and install the pipeline.

1.1 Install Prerequisites

1.1.1 Firmware Requirements

The SOUK MKID Readout firmware can be built with the CASPER toolflow, and was designed using the following software stack:

- Ubuntu 20.04.6 LTS (64-bit)
- MATLAB R2021a
- Simulink R2021a
- MATLAB Fixed-Point Designer Toolbox R2021a
- Xilinx Vivado HLx 2021.2
- Python 3.8.10

It is *strongly* recommended that the same software versions be used to rebuild the design.

1.2 Get the Source Code

Specify the repository root directory by defining the `REPOROOT` environment variable, eg:

```
export REPOROOT=~/src/
mkdir -p $REPOROOT
```

Clone the repository and its dependencies with:

```
# Clone the main repository
cd $REPOROOT
git clone https://github.com/realtimeradio/souk-firmware
# Clone relevant submodules
cd souk-firmware
git submodule init
git submodule update
```

1.3 Create a Local Environment Configuration

Create a local configuration file which specifies the location to which various tools have been installed. An example configuration is given in *$REPOROOT/firmware/startsg.local*:

```
export XILINX_PATH=/data/Xilinx/Vivado/2021.2
export COMPOSER_PATH=/data/Xilinx/Model_Composer/2021.2
export MATLAB_PATH=/data/MATLAB/R2021a
export PLATFORM=lin64
export JASPER_BACKEND=vitis
export CASPER_SKIP_STARTUP_LOAD_SYSTEM=yesplease
export XILINXD_LICENSE_FILE=/home/jackh/.Xilinx/Xilinx.lic
export XLNX_DT_REPO_PATH=/home/jackh/src/souk-firmware/firmware/lib/device-tree-xlnx

# over-ride the MATLAB libexpat version with the OS's one.
# Using LD_PRELOAD=${LD_PRELOAD}:"..." rather than just LD_PRELOAD="..."
# ensures that we preserve any other settings already configured
export LD_PRELOAD=${LD_PRELOAD}:"/usr/lib/x86_64-linux-gnu/libexpat.so"
```

When launching Simulink to modify or compile firmware, use the incantation:

```
cd $REPOROOT/firmware
./startsg <custom_startsg_local_file>
```

CHAPTER

TWO

F-ENGINE SYSTEM OVERVIEW

2.1 Overview

The SOUK MKID readout system is built around multiple instances of a single readout pipeline. Each pipeline has the following capabilities:

1. Digitize a single RF data stream at 5 Gsps (real-sampled).
2. Channelize the resulting 2.5 GHz Nyquist band into 8192 channels each of 610 kHz width, and overlapping by 50%.
3. Select 2048 of 8192 available channels.
4. Mix each channel with an independent, programmable local-oscillator before integrating and storing the result.
5. Output an RF signal with a 2.5 GHz bandwidth (generated from a 5 Gsps real-sampled stream), constructed by frequency multiplexing each of the system's 2048 LOs with a synthesis bank.

A block diagram of a single pipeline is shown in Figure Fig. 2.1.

The readout firmware is defined using the graphical MATLAB Simulink / Xilinx System Generator design tools. As such, the source code very closely resembles the high-level block diagram description of the system.

The Simulink source diagram for a single pipeline is shown in Figure A block diagram of a single pipeline is shown in Figure Fig. 2.2.

Multiple pipelines may be instantiated on a single FPGA processing board. When using an RFSoC processor such as the xczu47p – which has 8 ADC and DAC channels capable of running at 5 Gsps and 9.85 Gsps, respectively – a single chip is, in principle, capable of supporting 8 such pipelines. In practice, other processing limitations mean that a single chip can likely only service 2-3 pipelines.

The top-level Simulink source code for firmware supporting multi-pipelines is shown in Figure Fig. 2.3. Common infrastructure is shared between pipelines, in a processing block whose functionality is shown in Figure Fig. 2.4.

2.1.1 Initialization

The functionality of individual blocks is described below. However, in order to simply get the firmware into a basic working state the following process should be followed:

1. Program the FPGA
2. Initialize all blocks in the system
3. Trigger master reset and timing synchronization event.

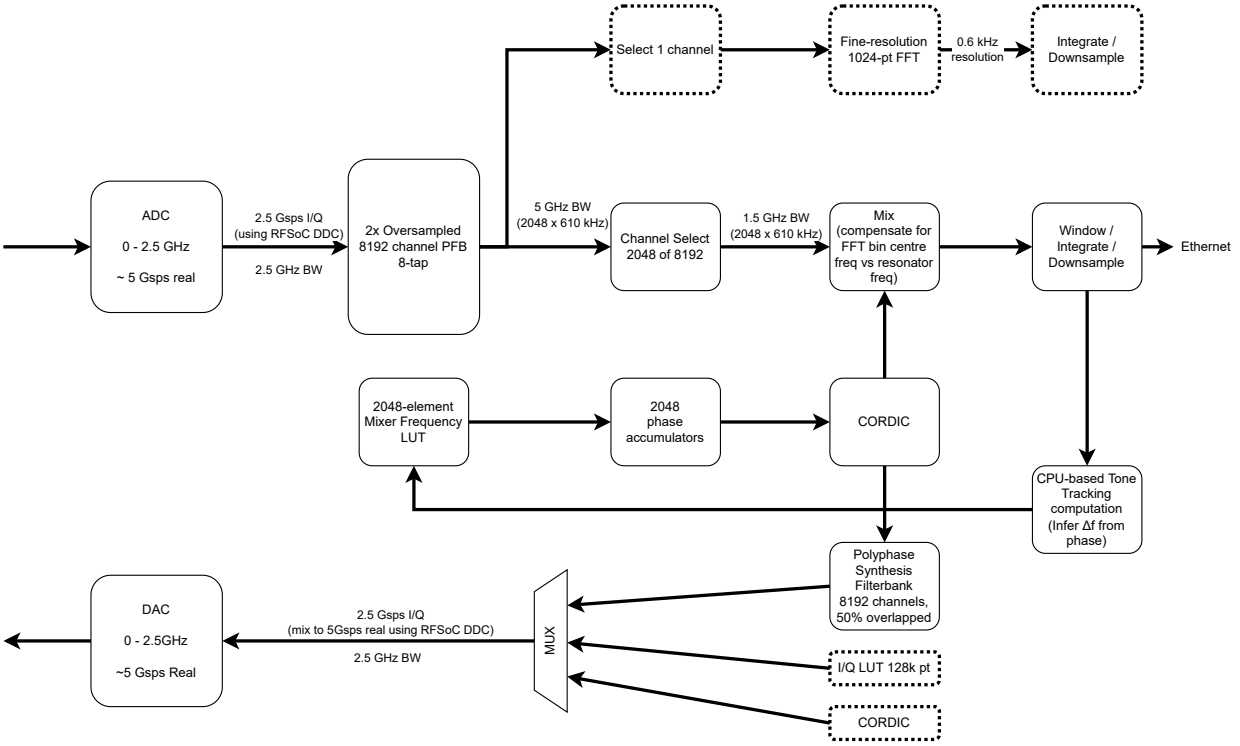

Fig. 2.1: A single SOUK MKID readout pipeline. Shown in dotted-boxes are processing features which are not required in production but may be useful for testing in a lab environment. Such features may be shared between different pipelines to save processing resources.

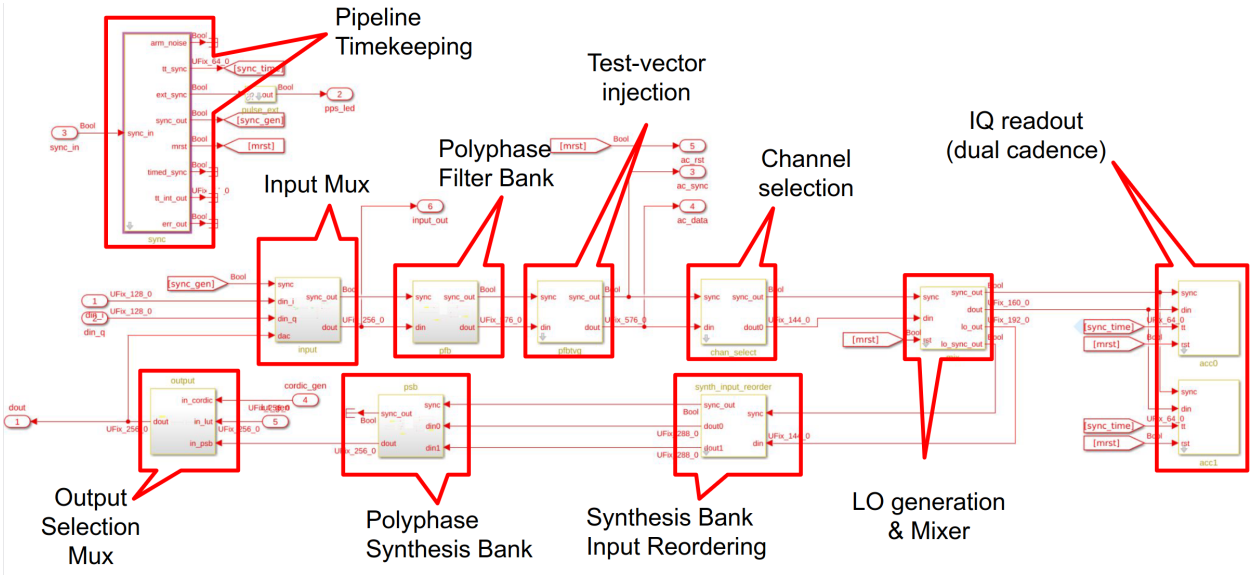

Fig. 2.2: The Simulink source code for a single SOUK MKID readout pipeline.

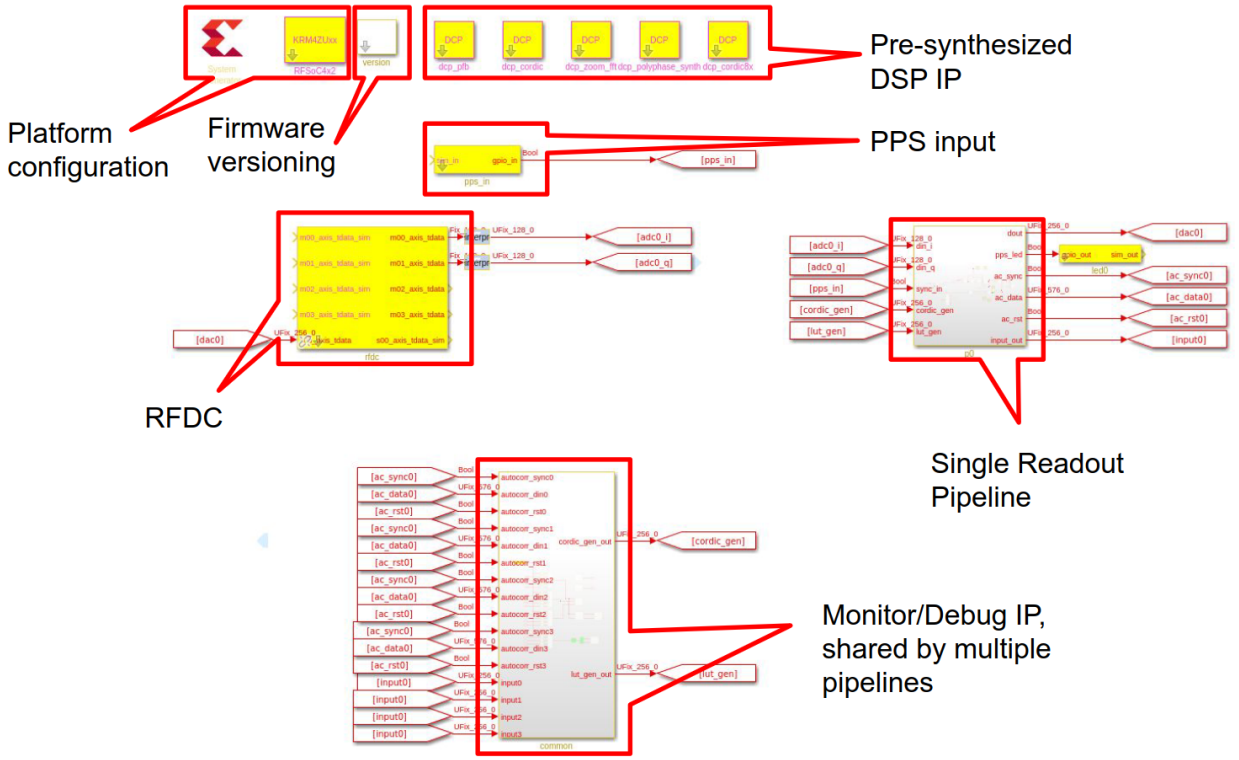

Fig. 2.3: The top-level Simulink source code for a firmware design capable of supporting multiple readout pipelines. A single RFDC instance may feed multiple pipelines. Common testing/monitoring functionality is shared between pipelines to save processing resources.

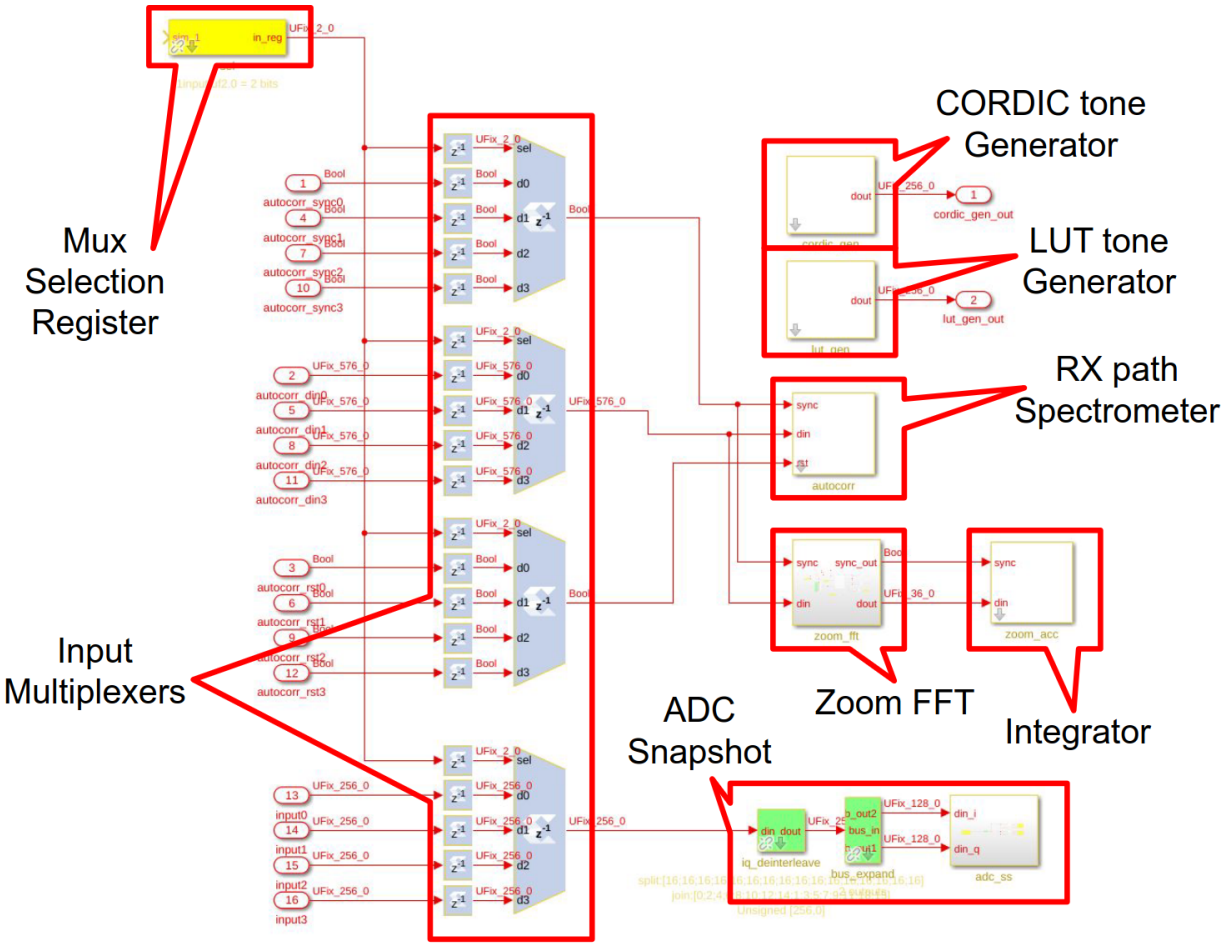

Fig. 2.4: The Simulink source code for processing functionality shared between pipelines. This includes readout of ADC snapshots, pre-mixer spectrometer powers, and high-resolution "zoom" spectra.

In a multi-board system, the process of synchronizing a board can be relatively involved. For testing purposes, using single board, a simple software reset can be used in place of a hardware timing signal to perform an artificial synchronization. A software reset is automatically issued as part of system initialization.

The following commands bring the F-engine firmware into a functional state, suitable for testing. See Section 3 for a full software API description

```
# Import the SNAP2 F-Engine library
from souk_mkid_readout import SoukFirmwareReadout

# Instantiate an SoukFirmwareReadout instance, connecting to a board with
# hostname 'my_zcu111'
f = SoukFirmwareReadout('my_rfsoc_board', config_file='my_config_file.yaml')

# Program a board
f.program() # Load whatever firmware was listed in the config file

# Initialize all the firmware blocks
# and issue a global software reset
f.initialize()
```

2.1.2 Block Descriptions

Each block in the firmware design can be controlled using an API described in Section 3.

CHAPTER

THREE

CONTROL INTERFACE

3.1 Overview

A Python class `SoukMkidReadout` is provided to encapsulate control of individual blocks in the firmware DSP pipeline. The structure of the software interface aims to mirror the hierarchy of the firmware modules, through the use of multiple `Block` class instances, each of which encapsulates control of a single module in the firmware pipeline.

In testing, and interactive debugging, the `SoukMkidReadout` class provides an easy way to probe board status for a RFSoC board on the local network.

3.2 `SoukMkidReadout` Python Interface

The `SoukMkidReadout` class can be instantiated and used to control a single RFSoC board running LWA's F-Engine firmware. An example is below:

```
# Import the RFSoC F-Engine library
from souk_mkid_readout import SoukMkidReadout

# Instantiate a SoukMkidReadout instance to a board with
# hostname 'my_zcu111'
f = SoukMkidReadout('my_zcu111', configfile='my_config.yaml')

# Program a board (if it is not already programmed)
# and initialize all the firmware blocks
if not f.fpga.is_programmed():
  f.program() # Load whatever firmware is in flash
  # Initialize firmware blocks
  f.initialize()

# Blocks are available as items in the SoukMkidReadout `blocks`
# dictionary, or can be accessed directly as attributes
# of the SoukMkidReadout.

# Print available block names
print(sorted(f.blocks.keys()))
# Returns:
# ['rfdc', 'input', 'autocorr', 'pfb', 'pfbtvg', 'chanreorder', 'mix',
# 'gen_lut', 'gen_cordic', 'output', 'accumulator0', 'accumulator1']
```

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```
# Grab some ADC data from the ADC
adc_data = f.input.get_adc_snapshot()
```

Details of the methods provided by individual blocks are given in the next section.

3.2.1 Top-Level Control

The Top-level `SoukMkidReadout` instance can be used to perform high-level control of the firmware, such as programming and de-programming FPGA boards. It can also be used to apply configurations which affect multiple firmware subsystems, such as configuring channel selection and packet destination.

Finally, a `SoukMkidReadout` instance can be used to initialize, or get status from, all underlying firmware modules.

class souk_mkid_readout.**SoukMkidReadout**(*host*, *fpgfile=None*, *configfile=None*, *logger=None*, *pipeline_id=0*, *local=False*)

A control class for SOUK MKID Readout firmware on a single board

Parameters

- **host** (*str*) – Hostname/IP address of FPGA board
- **fpgfile** (*str*) – Path to .fpg file running on the board
- **configfile** (*str*) – Path to configuration YAML file for system
- **logger** (*logging.Logger*) – Logger instance to which log messages should be emitted.
- **pipeline_id** (*int*) – Pipeline number within a single RFSoC board.
- **local** (*bool*) – If True, use local memory accesses rather than katcp. Only works as root!

configfile

configuration YAML file

fpgfile

fpgfile currently in use

get_rx_tx_skew()

Get the difference in arrival time of a sync pulse at the start of the RX chain and at the end of the TX chain, in units of FPGA clock cycles. Depending on the *mix* block signal sharing settings, this is either the total latency (when the TX pipeline sync is shared with the RX pipeline sync) or is the residual skew when the RX pipeline sync is a delayed copy of the TX sync.

Returns
Sync time difference, in FPGA clock cycles

Return type
int

get_status_all()

Call the `get_status` methods of all blocks in `self.blocks`. If the FPGA is not programmed with F-engine firmware, will only return basic FPGA status.

Returns
(status_dict, flags_dict) tuple. Each is a dictionary, keyed by the names of the blocks in `self.blocks`. These dictionaries contain, respectively, the status and flags returned by the `get_status` calls of each of this F-Engine's blocks.

hostname

hostname of FPGA board

initialize(*read_only=False*)

Call the `initialize methods of all underlying blocks, then optionally issue a software global reset.

Parameters
read_only (*bool*) – If True, call the underlying initialization methods in a read_only manner, and skip software reset.

is_connected()

Returns
True if there is a working connection to a board. False otherwise.

Return type
bool

logger

Python Logger instance

print_status_all(*use_color=True*, *ignore_ok=False*)

Print the status returned by `get_status` for all blocks in the system. If the FPGA is not programmed with F-engine firmware, will only print basic FPGA status.

Parameters

- **use_color** (*bool*) – If True, highlight values with colors based on error codes.
- **ignore_ok** (*bool*) – If True, only print status values which are outside the normal range.

program(*fpgfile=None*)

Program an .fpg file to an FPGA.

Parameters
fpgfile (*str*) – The .fpg file to be loaded. Should be a path to a valid .fpg file. If None is given, *self.fpgfile* will be loaded. If this is None, RuntimeError is raised

reset_psb_outputs()

Zero out all synthesis bank outputs.

set_multi_tone(*freqs_hz*, *phase_offsets_rads=None*, *amplitudes=None*)

Configure both TX and RX paths for `i` tones at frequencies `freqs_hz[i]`. Disables all tones except those provided.

Parameters

- **freqs_hz** (*list of float*) – Tone frequencies, in Hz.
- **phase_offsets_rads** (*list of float*) – Phase offset of tones, in radians. If none is provided, offsets of 0 are used.
- **amplitudes** (*list of float*) – Relative amplitude of tones, provided as a list of floats between 0 and 1. If none is provided, amplitudes of 1.0 are used.

set_output_psb_scale(*nshift*, *scale=1.0*, *check_overflow=True*)

Set the PSB to scale down by 2^nshift in amplitude.

Parameters

- **nshift** (*int*) – Number of shift down stages in the PSB FFTs
- **scale** (*float*) – Post PSB scaling factor

- **check_overflow** (*bool*) – If True, warn about PSB overflow before returning.

Returns
If check_overflow is set, return FENG_OK if no overflows are detected, of FENG_ERROR otherwise. Return FENG_OK if check_overflow is not set.

Return type
int

`set_tone`(*tone_id*, *freq_hz*, *phase_offset_rads=0.0*)

Configure both TX and RX paths for a tone at frequency `freq_hz` with ID `tone_id`.

Parameters

- **tone_id** (*int*) – Index number of tone to set
- **freq_hz** (*float*) – Tone frequency, in Hz. Or, use `None` to disable this tone index.
- **phase_offset_rads** (*float*) – Phase offset of tone, in radians.

3.2.2 FPGA Control

The `FPGA` control interface allows gathering of FPGA statistics such as temperature and voltage levels. Its methods are functional regardless of whether the FPGA is programmed with an LWA F-Engine firmware design.

`class souk_mkid_readout.blocks.fpga.Fpga`(*host*, *name*, *logger=None*)

Instantiate a control interface for top-level FPGA control.

Parameters

- **host** (*casperfpga.CasperFpga*) – CasperFpga interface for host.
- **name** (*str*) – Name of block in Simulink hierarchy.
- **logger** (*logging.Logger*) – Logger instance to which log messages should be emitted.

`check_firmware_support`()

Check the software packages firmware support version against the running firmware version.

Returns
True if firmware is supported, False otherwise.

Rtype bool

`get_build_time`()

Read the UNIX time at which the current firmware was built.

Returns
Seconds since the UNIX epoch at which the running firmware was built.

Return type
int

`get_connected_antname`()

Fetch the connected antenna name.

Returns
The name of the connected antennna.

Return type
str

`get_firmware_type()`

Read the firmware type register and return the contents as an integer.

Returns
Firmware type

Return type
str

`get_firmware_version()`

Read the firmware version register and return the contents as a string.

Returns
major_version.minor_version.revision.bugfix

Rtype str

`get_fpga_clock()`

Estimate the FPGA clock, by polling the `sys_clkcounter` register.

Returns
Estimated FPGA clock in Hz

Return type
float

`get_status()`

Get status and error flag dictionaries.

Status keys:

- programmed (bool) : `True` if FPGA appears to be running DSP firmware. `False` otherwise, and flagged as a warning.
- flash_firmware (str) : The name of the firmware file currently loaded in flash memory.
- flash_firmware_md5 (str) : The MD5 checksum of the firmware file currently loaded in flash memory.
- timestamp (str) : The current time, as an ISO format string.
- host (str) : The host name of this board.
- antname (str) : The name of the antenna connected to this board.
- sw_version (str) : The version string of the control software package. Flagged as warning if the version indicates a build against a dirty git repository.
- fw_version (str): The version string of the currently running firmware. Available only if the board is programmed.
- fw_type (int): The firmware type ID of the currently running firmware. Available only if the board is programmed.
- fw_supported (bool) : True if the running firmware is supported by this software. False (and flagged as an error) otherwise.
- fw_build_time (int): The build time of the firmware, as an ISO format string. Available only if the board is programmed.
- sys_mon (str) : `'reporting'` if the current firmware has a functioning system monitor module. Otherwise `'not reporting'`, flagged as an error.
- temp (float) : FPGA junction temperature, in degrees C. (Only reported is system monitor is available). Flagged as a warning if outside the recommended operating conditions. Flagged as an error if outside the absolute maximum ratings. See DS892.

- vccaux (float) : Voltage of the VCCAUX FPGA power rail. (Only reported is system monitor is available). Flagged as a warning if outside the recommended operating conditions. Flagged as an error if outside the absolute maximum ratings. See DS892.
- vccbram (float) : Voltage of the VCCBRAM FPGA power rail. (Only reported is system monitor is available). Flagged as a warning if outside the recommended operating conditions. Flagged as an error if outside the absolute maximum ratings. See DS892.
- vccint (float) : Voltage of the VCCINT FPGA power rail. (Only reported is system monitor is available). Flagged as a warning if outside the recommended operating conditions. Flagged as an error if outside the absolute maximum ratings. See DS892.

Returns
(status_dict, flags_dict) tuple. *status_dict* is a dictionary of status key-value pairs. flags_dict is a dictionary with all, or a sub-set, of the keys in *status_dict*. The values held in this dictionary are as defined in *error_levels.py* and indicate that values in the status dictionary are outside normal ranges.

`is_programmed()`
Check to see if a board is programmed. If the Katcp command *listdev* fails, assume that it isn't

Returns
True if programmed, False otherwise.

Return type
bool

`set_connected_antname(antname)`
Set the connected antenna name.

Parameters
antname (*str*) – The antenna name.

3.2.3 Timing Control

The Sync control interface provides an interface to configure and monitor the multi-RFSoC timing distribution system.

`class souk_mkid_readout.blocks.sync.Sync(host, name, clk_hz=None, sync_delay=1, logger=None)`
The Sync block controls internal timing signals.

Parameters
- **host** (*casperfpga.CasperFpga*) – CasperFpga interface for host.
- **name** (*str*) – Name of block in Simulink hierarchy.
- **clk_hz** (*int*) – The FPGA clock rate at which the DSP fabric runs, in Hz.
- **sync_delay** (*int*) – The initial delay to load for the delayed sync output in FPGA clock cycles
- **logger** (*logging.Logger*) – Logger instance to which log messages should be emitted.

`arm_noise()`
Arm noise generator resets.

`arm_sync`(*wait=True*)

Arm sync pulse generator, which passes sync pulses to the design DSP.

Parameters
`wait` (*bool*) – If True, wait for a sync to pass before returning.

`count_ext`()

Returns
Number of external sync pulses received.

Rtype int

`disable_error_flag`()

Disable error flag.

`enable_error_flag`()

Enable error flag.

`get_delay`()

Get the delay of the delayed sync output, in FPGA clock cycles

Returns
Delay in FPGA clock cycles

Return type
int

`get_error_count`()

Returns
Number of sync errors.

Return type
int

`get_pipeline_latency`()

Get the difference in arrival time of a sync pulse at the start of the RX chain and at the end of the TX chain, in units of FPGA clock cycles. Depending on the *mix* block signal sharing settings, this is either the total latency (when the TX pipeline sync is shared with the RX pipeline sync) or is the residual skew when the RX pipeline sync is a delayed copy of the TX sync.

Returns
Sync time difference, in FPGA clock cycles

Return type
int

`get_status`()

Get status and error flag dictionaries.

Status keys:

- uptime_fpga_clks (int) : Number of FPGA clock ticks (= ADC clock ticks) since the FPGA was last programmed.
- period_fpga_clks (int) : Number of FPGA clock ticks (= ADC clock ticks) between the last two internal sync pulses.
- ext_count (int) : The number of external sync pulses since the FPGA was last programmed.
- int_count (int) : The number of internal sync pulses since the FPGA was last programmed.

- sync_delay (int) : The number of FPGA clock cycles between the RX and TX sync pulses.

Returns
(status_dict, flags_dict) tuple. *status_dict* is a dictionary of status key-value pairs. flags_dict is a dictionary with all, or a sub-set, of the keys in *status_dict*. The values held in this dictionary are as defined in *error_levels.py* and indicate that values in the status dictionary are outside normal ranges.

`get_tt_of_ext_sync()`
Get the internal TT at which the last sync pulse arrived.

Returns
(tt, sync_number). `tt` is the internal TT of the last sync. `sync_number` is the sync pulse count corresponding to this TT.

Rtype int

`get_tt_of_sync()`
Get the internal TT of the last system sync event.

Returns
tt. The internal TT of the last sync.

Return type
int

`initialize`(*read_only=False*)
Initialize block.

Parameters
read_only (*bool*) – If False, initialize system control register to 0 and reset error counters. If True, do nothing.

`load_internal_time`(*tt*, *software_load=False*)
Load a new starting value into the _internal_ telescope time counter on the next sync.

Parameters

- **tt** (*int*) – Telescope time to load
- **software_load** (*bool*) – If True, immediately load via a software trigger. Else load on the next external sync pulse arrival.

`period()`

Returns
The number of FPGA clock ticks between the last two external sync pulses.

Rtype int

`reset_error_count()`
Reset internal error counter to 0.

`set_delay`(*delay*)
Set the delay of the delayed sync output

Parameters
delay (*int*) – Delay in FPGA clock cycles

`set_sync_active_high()`
Set the sync pulse to active on a positive edge.

`set_sync_active_low()`

Set the sync pulse to active on a negative edge.

`sw_sync()`

Issue a sync pulse from software. This will only do anything if appropriate arming commands have been made in advance.

`update_internal_time(clk_hz=None, sync_period=None, offset_ns=0.0, sync_clock_factor=1)`

Arm sync trigger receivers, having loaded an appropriate telescope time.

Parameters

- **clk_hz** (*int*) – The FPGA DSP clock rate, in Hz. Used to set the telescope time counter. If None is provided, self.clk_hz will be used.
- **sync_period** – Sync pulse period, in FPGA clock ticks. If None, read period from FPGA counters.
- **offset_ns** (*float*) – Nanoseconds offset to add to the time loaded into the internal telescope time counter.

Returns

next_sync_clocks: The value of the TT counter at the arrival of the next sync pulse. Or, *None*, if the TT counter was loaded late.

Rtype int

`uptime()`

Returns

Time in FPGA clock ticks since the FPGA was last programmed.

Return type

int

`wait_for_sync()`

Block until a sync has been received.

3.2.4 RFDC Control

The `Rfdc` control interface allows control of the RFSoC's ADCs and DACs.

`class souk_mkid_readout.blocks.rfdc.Rfdc(host, name, logger=None, lmkfile=None, lmxfile=None)`

Instantiate a control interface for an RFDC firmware block.

Parameters

- **host** (*casperfpga.CasperFpga*) – CasperFpga interface for host.
- **name** (*str*) – Name of block in Simulink hierarchy.
- **logger** (*logging.Logger*) – Logger instance to which log messages should be emitted.
- **lmkfile** (*str*) – LMK configuration file to load to board's PLL chip
- **lmxfile** (*str*) – LMX configuration file to load to board's PLL chip

`get_lo(adc_sample_rate_hz, tile, block)`

Get current LO frequency.

Parameters

- **adc_sample_rate_hz** (*float*) – ADC sample rate in Hz
- **tile** (*int*) – Zero-indexed tile ID of this ADC.
- **block** (*int*) – Zero-indexed block ID of this ADC.

Returns
LO frequency in Hz

Return type
float

`get_status()`

Get status and error flag dictionaries.

Status keys:

- lmkfile (str) : The name of the LMK configuration file being used.
- lmxfile (str) : The name of the LMX configuration file being used.

Returns
(status_dict, flags_dict) tuple. *status_dict* is a dictionary of status key-value pairs. flags_dict is a dictionary with all, or a sub-set, of the keys in *status_dict*. The values held in this dictionary are as defined in *error_levels.py* and indicate that values in the status dictionary are outside normal ranges.

`initialize(read_only=False)`

Parameters
read_only (*bool*) – If False, initialize the RFDC core and PLL chips. If True, do nothing.

3.2.5 Input Control

`class souk_mkid_readout.blocks.input.Input(host, name, logger=None)`

`disable_loopback()`

Set pipeline to feed pipeline from ADC inputs

`enable_loopback()`

Set pipeline to internally loop-back DAC stream into ADC.

`get_status()`

Get status and error flag dictionaries.

Status keys:

- loopback (book) : True is system is in internal loopback mode. If True this is flagged with "WARNING".

Returns
(status_dict, flags_dict) tuple. *status_dict* is a dictionary of status key-value pairs. flags_dict is a dictionary with all, or a sub-set, of the keys in *status_dict*. The values held in this dictionary are as defined in *error_levels.py* and indicate that values in the status dictionary are outside normal ranges.

initialize(*read_only=False*)

Parameters
read_only (*bool*) – If False, disable loopback mode. If True, do nothing.

loopback_enabled()

Get the current loopback state.

Returns
True if internal loopback is enabled. False otherwise.

Return type
bool

3.2.6 PFB Control

class souk_mkid_readout.blocks.pfb.**Pfb**(*host*, *name*, *logger=None*, *fftshift=4294967295*)

get_fftshift()

Get the currently applied FFT shift schedule. The returned value takes into account any hardcoding of the shift settings by firmware.

Returns
Shift schedule

Return type
int

get_overflow_count()

Get the total number of FFT overflow events, since the last statistics reset.

Returns
Number of overflows

Return type
int

get_status()

Get status and error flag dictionaries.

Status keys:

- overflow_count (int) : Number of FFT overflow events since last statistics reset. Any non-zero value is flagged with "WARNING".
- fftshift (str) : Currently loaded FFT shift schedule, formatted as a binary string, prefixed with "0b".

Returns
(status_dict, flags_dict) tuple. *status_dict* is a dictionary of status key-value pairs. flags_dict is a dictionary with all, or a sub-set, of the keys in *status_dict*. The values held in this dictionary are as defined in *error_levels.py* and indicate that values in the status dictionary are outside normal ranges.

initialize(*read_only=False*)

Parameters
read_only (*bool*) – If False, set the FFT shift to the default value, and reset the overflow count. If True, do nothing.

`reset_overflow_count()`

Reset overflow counter.

`set_fftshift(shift)`

Set the FFT shift schedule.

Parameters
shift (*int*) – Shift schedule to be applied.

3.2.7 PFB TVG Control

`class souk_mkid_readout.blocks.pfbtvg.PfbTvg(host, name, n_inputs=2, n_chans=4096, n_serial_inputs=1, n_rams=2, n_samples_per_word=4, sample_format='h', logger=None)`

Instantiate a control interface for a post-PFB test vector generator block.

Parameters

- **host** (*casperfpga.CasperFpga*) – CasperFpga interface for host.
- **name** (*str*) – Name of block in Simulink hierarchy.
- **logger** (*logging.Logger*) – Logger instance to which log messages should be emitted.
- **n_inputs** (*int*) – Number of independent inputs which may be emulated
- **n_serial_inputs** (*int*) – Number of independent inputs sharing a data bus
- **n_rams** (*int*) – Number of independent bram blocks per input. If 0, block has no RAMs, and just contains counter-based test vectors.
- **n_samples_per_word** (*int*) – Number of complex samples per word in RAM
- **n_chans** (*int*) – Number of frequency channels.
- **sample_format** (*str*) – Struct type code (eg. 'h' for 16-bit signed) for each of the real/imag parts of the TVG data samples.

`get_status()`

Get status and error flag dictionaries.

Status keys:

- tvg_enabled: Currently state of test vector generator. `True` if the generator is enabled, else `False`.

Returns
(status_dict, flags_dict) tuple. *status_dict* is a dictionary of status key-value pairs. flags_dict is a dictionary with all, or a sub-set, of the keys in *status_dict*. The values held in this dictionary are as defined in *error_levels.py* and indicate that values in the status dictionary are outside normal ranges.

`initialize(read_only=False)`

Initialize the block.

Parameters
read_only (*bool*) – If True, do nothing. If False, load frequency-ramp test vectors, but disable the test vector generator.

read_input_tvg(*input*)

Read the test vector loaded to an ADC input.

Parameters
input (*int*) – Index of input from which test vectors should be read.

Returns
Test vector array

Return type
numpy.ndarray

tvg_disable()

Disable the test vector generator

tvg_enable()

Enable the test vector generator.

tvg_is_enabled()

Query the current test vector generator state.

Returns
True if the test vector generator is enabled, else False.

Return type
bool

write_const_per_input()

Write a constant to all the channels of a input, with input *i* taking the value *i*.

write_freq_ramp()

Write a frequency ramp to the test vector that is repeated for all ADC inputs. Data are wrapped to fit into 8 bits. I.e., the test vector value for channel 257 takes the value 1.

write_input_tvg(*input*, *test_vector*)

Write a test vector pattern to a single signal input.

Parameters

- **input** (*int*) – Index of input to which test vectors should be loaded.
- **test_vector** (*list or numpy.ndarray*) – *self.n_chans*-element test vector. Values should be representable in 16-bit integer format, and may be complex.

3.2.8 Auto-correlation Control

class souk_mkid_readout.blocks.autocorr.**AutoCorr**(*host*, *name*, *acc_len=32768*, *logger=None*, *n_chans=4096*, *n_signals=64*, *n_parallel_streams=8*, *n_cores=4*, *is_descrambled=False*, *use_mux=True*)

Instantiate a control interface for an Auto-Correlation block. This provides auto-correlation spectra of post-FFT data.

In order to save FPGA resourece, the auto-correlation block may use a single correlation core to compute the auto-correlation of a subset of the total number of ADC channels at any given time. This is the case when the block is instantiated with `n_cores > 1` and `use_mux=True`. In this case, auto-correlation spectra are captured `n_signals / n_cores` channels at a time.

Parameters

- **host** (*casperfpga.CasperFpga*) – CasperFpga interface for host.
- **name** (*str*) – Name of block in Simulink hierarchy.
- **logger** (*logging.Logger*) – Logger instance to which log messages should be emitted.
- **acc_len** (*int*) – Accumulation length initialization value, in spectra.
- **n_chans** (*int*) – Number of frequency channels.
- **n_signals** (*int*) – Number of individual data streams.
- **n_parallel_streams** (*int*) – Number of streams processed by the firmware module in parallel.
- **n_cores** (*int*) – Number of accumulation cores in firmware design.
- **is_descrambled** (*bool*) – If False, apply descrable map to channel ordering on read.
- **use_mux** (*bool*) – If True, only one core is instantiated and a multiplexer is used to switch different inputs into it. If False, multiple cores are instantiated simultaneously in firmware.

Variables
n_signals_per_block – Number of signal streams handled by a single correlation core.

get_acc_cnt()

Get the current accumulation count.

Returns
Current accumulation count

Return type
int

get_acc_len()

Get the currently loaded accumulation length in units of spectra.

Returns
Current accumulation length

Return type
int

get_freqs(*adc_srate_hz*, *lo_hz=0.0*)

Get the center frequencies of each spectral channel.

Parameters

- **adc_srate_hz** (*float*) – ADC sample rate in Hz.
- **lo_hz** (*float*) – LO frequency, in Hz, implemented within the ADC.

get_new_spectra(*signal_block=0*, *flush_vacc='auto'*, *filter_ksize=None*, *return_list=False*)

Get a new average power spectra.

Parameters

- **signal_block** (*int*) – If using multiplexing, read data for this signal block. If not using multiplexing, this parameter does nothing, and data from all inputs will be returned. When multiplexing, Each call will return data for inputs `self.n_signals_per_block x signal_block` to `self.n_signals_per_block x (signal_block+1) - 1`.
- **flush_vacc** (*Bool or string*) – If `True`, throw away a spectra before grabbing a valid one. This can be useful if the upstream analog settings may have changed during the last

integration. If `False`, return the first spectra available. If `'auto'` perform a flush if the input multiplexer has changed positions.

- **filter_ksize** (*int*) – If not None, apply a spectral median filter with this kernel size. The kernel size should be odd.
- **return_list** (*Bool*) – If True, return a list else numpy.array

Returns
Float32 2D list of dimensions [POLARIZATION, FREQUENCY CHANNEL] containing autocorrelations with accumulation length divided out.

Return type
list

`get_status()`

Get status and error flag dictionaries.

Status keys:

- acc_len (int) : Currently loaded accumulation length in number of spectra.

Returns
(status_dict, flags_dict) tuple. *status_dict* is a dictionary of status key-value pairs. flags_dict is a dictionary with all, or a sub-set, of the keys in *status_dict*. The values held in this dictionary are as defined in *error_levels.py* and indicate that values in the status dictionary are outside normal ranges.

`initialize(read_only=False)`

Initialize the block, setting (or reading) the accumulation length.

Parameters
read_only (*bool*) – If False, set the accumulation length to the value provided when this block was instantiated. If True, use whatever accumulation length is currently loaded.

`plot_all_spectra(db=True, show=True, filter_ksize=None, adc_srate_hz=None, lo_hz=0.0)`

Plot the spectra of all signals, with accumulation length divided out

Parameters

- **db** (*bool*) – If True, plot 10log10(power). Else, plot linear.
- **show** (*bool*) – If True, call matplotlib's *show* after plotting
- **filter_ksize** (*int*) – If not None, apply a spectral median filter with this kernel size. The kernet size should be odd.
- **adc_srate_hz** (*float*) – ADC sample rate in Hz. If provided, plot with an appropriate frequency scale on the X-axis.
- **lo_hz** (*float*) – LO frequency, in Hz, implemented within the ADC.

Returns
matplotlib.Figure

`plot_spectra(signal_block=0, db=True, show=True, filter_ksize=None, adc_srate_hz=None, lo_hz=0.0)`

Plot the spectra of all signals in a single signal_block, with accumulation length divided out

Parameters

- **signal_block** (*int*) – If using multiplexing, plot data for this signal block. If not using multiplexing, this parameter does nothing, and data from all inputs will be plotted.

When multiplexing, Each call will plot data for inputs `self.n_signals_per_block x signal_block` to `self.n_signals_per_block x (signal_block+1) - 1`.

- **db** (*bool*) – If True, plot 10log10(power). Else, plot linear.
- **show** (*bool*) – If True, call matplotlib's *show* after plotting
- **filter_ksize** (*int*) – If not None, apply a spectral median filter with this kernel size. The kernet size should be odd.
- **adc_srate_hz** (*float*) – ADC sample rate in Hz. If provided, plot with an appropriate frequency scale on the X-axis.
- **lo_hz** (*float*) – LO frequency, in Hz, implemented within the ADC.

Returns
matplotlib.Figure

set_acc_len(*acc_len*)

Set the number of spectra to accumulate.

Parameters
acc_len (*int*) – Number of spectra to accumulate

3.2.9 Channel Sub-Select Control

class souk_mkid_readout.blocks.chanreorder.**ChanReorder**(*host*, *name*, *n_chans_in=4096*, *n_chans_out=2048*, *n_parallel_chans_in=4*, *support_zeroing=False*, *parallel_first=False*, *logger=None*)

Instantiate a control interface for a Channel Reorder block.

Parameters

- **host** (*casperfpga.CasperFpga*) – CasperFpga interface for host.
- **name** (*str*) – Name of block in Simulink hierarchy.
- **logger** (*logging.Logger*) – Logger instance to which log messages should be emitted.
- **n_chans_in** (*int*) – Number of channels input to the reorder
- **n_chans_out** (*int*) – Number of channels output to the reorder
- **n_parallel_chans_in** (*int*) – Number of channels handled in parallel at the input
- **support_zeroing** (*bool*) – If True, allow the use of channel index `-1` to mean "zero out this channel"
- **parallel_first** (*bool*) – If True, the firmware reorders in the parallel signal dimension before the serial dimension.

get_channel_outmap()

Read the currently loaded reorder map.

Returns
The reorder map currently loaded. Entry *i* in this map is the channel number which emerges in the `i`th output position.

Return type
list

initialize(*read_only=False*)

Initialize the block.

Parameters
read_only (*bool*) – If True, this method is a no-op. If False, initialize the block with the identity map. I.e., map channel *n* to channel *n*.

set_channel_outmap(*outmap*)

Remap the channels such that the channel outmap[i] emerges out of the reorder map in position i.

The provided map must be *self.n_chans_out* elements long, else *ValueError* is raised

Parameters
outmap (*list of int*) – The outmap to which data should be mapped. I.e., if *outmap[0] = 16*, then the first channel out of the reorder block will be channel 16.

set_single_channel(*outidx*, *inidx*)

Set output channel number `outidx` to input number `inidx`. Do this by reading the total channel map, modifying a single entry, and writing back.

Example usage:
Set the first channel out of the reorder to 33 `set_single_channel(0, 33)`

Parameters

- **outidx** (*int*) – Index of output channel to set.
- **inidx** (*int*) – Input channel index to select.

3.2.10 Mixer Control

class souk_mkid_readout.blocks.mixer.**Mixer**(*host*, *name*, *n_chans=4096*, *n_upstream_chans=8192*, *upstream_oversample_factor=2*, *n_parallel_chans=4*, *phase_bp=31*, *phase_offset_bp=31*, *n_scale_bits=8*, *n_ri_step_bits=16*, *logger=None*)

Instantiate a control interface for a Mixer block.

Parameters

- **host** (*casperfpga.CasperFpga*) – CasperFpga interface for host.
- **name** (*str*) – Name of block in Simulink hierarchy.
- **logger** (*logging.Logger*) – Logger instance to which log messages should be emitted.
- **n_chans** (*int*) – Number of channels this block processes
- **n_upstream_chans** (*int*) – Number of channels in the upstream PFB prior to downselection
- **upstream_oversample_factor** (*int*) – Oversampling factor of upstream system. This, with the number of upstream channels, should allow this block to figure out how wide channels are.
- **n_parallel_chans** (*int*) – Number of channels this block processes in parallel
- **phase_bp** (*int*) – Number of phase fractional bits
- **n_ri_step_bits** (*int*) – Number of bits in each of the real/image per-sample rotation values.

`disable_power_mode()`

Use phase rotation, rather than power.

`enable_power_mode()`

Instead of applying a phase rotation to the data streams, calculate their power.

`get_phase_offset(chan, lo='rx')`

Get the currently loaded phase increment being applied to channel *chan*.

Parameters
lo (*str*) – Which LO to read. 'rx' or 'tx'

Returns
(phase_step, phase_offset, scale) A tuple containing the phase increment (in radians) being applied to channel *chan* on each successive sample, the start phase in radians, and the scale factor being applied to this channel.

Return type
float

`get_status()`

Get a dictionary of status values, with optional warning of error flags. To be overridden by individual blocks

Returns
(status_dict, flags_dict) tuple. *status_dict* is a dictionary of status key-value pairs, defined on a per-block basis. flags_dict is a dictionary with all, or a sub-set, of the keys in *status_dict*. The values held in this dictionary should be as defined in *error_levels.py*.

`get_tx_independence()`

Get the current sharing state of TX LO control signals.

Returns a dictionary, keyed by signal name, whose value is True if the signal is independent from the RX pipeline. False if it is shared.

Returns
independence dictionary

Return type
dict

`initialize(read_only=False)`

Initialize the block.

Parameters
read_only (*bool*) – If True, this method is a no-op. If False, set this block to phase rotate mode, but initialize with each channel having zero phase increment.

`is_power_mode()`

Get the current block mode.

Returns
True if the block is calculating power, False if it is applying phase rotation.

Return type
bool

`set_amplitude_scale(chan, scale=1.0, los=['rx', 'tx'])`

Apply an amplitude scaling <=1 to an output channel.

Parameters

- **chan** (*int*) – The channel index to which this phase-rate should be applied

- **scaling** (*float*) – optional scaling (<=1) to apply to the output tone amplitude.
- **los** (*list*) – List of LOs to write to. Can be ['rx'], ['tx'] or ['rx', 'tx']

set_chan_freq(*chan*, *freq_offset_hz=None*, *phase_offset=0*, *sample_rate_hz=2500000000*)

Set the frequency of output channel *chan*.

Parameters

- **chan** (*int*) – The channel index to which this phase-rate should be applied
- **freq_offset_hz** (*float*) – The frequency offset, in Hz, from the channel center. If None, disable this oscillator.
- **phase_offset** – The phase offset at which this oscillator should start in units of radians.
- **sample_rate_hz** (*float*) – DAC sample rate, in Hz

set_dependent_tx(*sync=True*, *offset=True*, *scale=True*, *step=True*)

Set the TX LOs to use dependent control signals from the RX LOs.

Parameters

- **sync** (*bool*) – If True, use a shared time sync input
- **offset** (*bool*) – If True, use a shared phase offset
- **scale** (*bool*) – If True, use a shared amplitude scale
- **step** (*bool*) – If True, use a shared phase step

set_freqs(*freqs_hz*, *phase_offsets*, *scaling=1.0*, *sample_rate_hz=2500000000*, *los=['rx', 'tx']*)

Configure the amplitudes, phases, and frequencies of multiple tones.

Parameters

- **freqs_hz** (*numpy.ndarray*) – The frequencies, in Hz, to emit.
- **phase_offsets** (*np.ndarray*) – The phase offsets at which oscillators should start, in units of radians.
- **scaling** (*np.ndarray*) – optional scaling (<=1) to apply to the output tone amplitudes. If a single number, apply this scale to all tones.
- **sample_rate_hz** (*float*) – DAC sample rate, in Hz
- **los** (*list*) – List of LOs to write to. Can be ['rx'], ['tx'] or ['rx', 'tx']

set_independent_tx(*sync=True*, *offset=True*, *scale=True*, *step=True*)

Set the TX LOs to use independent control signals from the RX LOs.

Parameters

- **sync** (*bool*) – If True, use an independent time sync input
- **offset** (*bool*) – If True, use an independent phase offset
- **scale** (*bool*) – If True, use an independent amplitude scale
- **step** (*bool*) – If True, use an independent phase step

set_phase_step(*chan*, *phase=None*, *phase_offset=0.0*, *los=['rx', 'tx']*)

Set the phase increment to apply on each successive sample for channel *chan*.

Parameters

- **chan** (*int*) – The channel index to which this phase-rate should be applied

- **phase** (*float*) – The phase increment to be added each successive sample in units of radians. If None, disable this oscillator.
- **phase_offset** – The phase offset at which this oscillator should start in units of radians.
- **los** (*list*) – List of LOs to write to. Can be ['rx'], ['tx'] or ['rx', 'tx']

3.2.11 Accumulator Control

class souk_mkid_readout.blocks.accumulator.**Accumulator**(*host*, *name*, *logger=None*, *acc_len=32768*, *n_chans=4096*, *n_parallel_chans=8*, *n_parallel_samples=1*, *is_complex=True*, *dtype='>i4'*, *has_dest_ip=False*)

Instantiate a control interface for an Accumulator Block. This provides a vector accumulation of post-FFT data.

Parameters

- **host** (*casperfpga.CasperFpga*) – CasperFpga interface for host.
- **name** (*str*) – Name of block in Simulink hierarchy.
- **logger** (*logging.Logger*) – Logger instance to which log messages should be emitted.
- **acc_len** (*int*) – Accumulation length initialization value, in spectra.
- **n_chans** (*int*) – Number of frequency channels.
- **n_parallel_chans** (*int*) – Number of chans processed by the firmware module in parallel.
- **n_parallel_samples** (*int*) – Number of samples processed by the firmware module in parallel.
- **is_complex** (*Bool*) – If True, block accumulates complex-valued data.
- **dtype** (*str*) – Data type string (as recognised by numpy's *frombuffer* method) for accumulated data. If data are complex, this is the data type of one of a single real/imag component.

get_acc_cnt()

Get the current accumulation count.

Returns
Current accumulation count

Return type
int

get_acc_len()

Get the currently loaded accumulation length in units of spectra.

Returns
Current accumulation length

Return type
int

get_new_spectra(*gpio_count=[]*)

Wait for a new accumulation to be ready then read it.

Parameters
gpio_count – List of GPIO counter registers to return with the accumulator data. E.g., [0,1,3] will return counters for pulse edges on GPIOs 0, 1, and 3.

Returns
If gpio_count=[], an array of *self.n_chans* complex-values. If gpio_count is not an empty list, return the tuple (data, gpio_counters), with gpio_values a list of the same length as gpio_count.

Return type
numpy.ndarray[, gpio_counters]

`get_status()`

Get status and error flag dictionaries.

Status keys:

- acc_len (int) : Currently loaded accumulation length in number of spectra.

Returns
(status_dict, flags_dict) tuple. *status_dict* is a dictionary of status key-value pairs. flags_dict is a dictionary with all, or a sub-set, of the keys in *status_dict*. The values held in this dictionary are as defined in *error_levels.py* and indicate that values in the status dictionary are outside normal ranges.

`initialize(read_only=False)`

Initialize the block, setting (or reading) the accumulation length.

Parameters
read_only (*bool*) – If False, set the accumulation length to the value provided when this block was instantiated. If True, use whatever accumulation length is currently loaded.

`plot_spectra(power=True, db=True, show=True, fftshift=False, sample_rate_hz=None)`

Plot the spectra of all signals in a single signal_block, with accumulation length divided out

Parameters

- **power** (*bool*) – If True, plot power, else plot complex
- **db** (*bool*) – If True, plot 10log10(power). Else, plot linear.
- **show** (*bool*) – If True, call matplotlib's *show* after plotting
- **fftshift** (*bool*) – If True, fftshift data before plotting.
- **sample_rate_hz** (*float*) – Effective FFT input sampling rate, in Hz. If provided, generate an appropriate frequency axis

Returns
matplotlib.Figure

`read_gpio_counter(n)`

Read GPIO counter n

Parameters
n (*int*) – GPIO counter to read

`set_acc_len(acc_len)`

Set the number of spectra to accumulate.

Parameters
acc_len (*int*) – Number of spectra to accumulate

3.2.12 Generator

class souk_mkid_readout.blocks.generator.**Generator**(*host*, *name*, *logger=None*)

get_cordic_overflows()

Get the number of overflow events in the CORDIC pipeline since the last phase reset. Return 0 if no CORDIC generators exist.

Returns
Overflows since last reset

Return type
bool

get_lut_output(*n*)

Get waveform stored in LUT output *n*.

Parameters
n (*int*) – Which generator to target.

Returns
waveform

Return type
numpy.ndarray

initialize(*read_only=False*)

Parameters
read_only (*bool*) – If True, do nothing. If False, reset phase and generator contents

reset_phase()

Reset the phase of the output(s).

set_cordic_output(*n*, *p*, *amplitude=None*)

Set CORDIC output *n* to increment by phase *p* every sample.

Parameters

- **n** (*int*) – Which generator to target.
- **p** (*float*) – phase increment, in units of radians
- **amplitude** (*float*) – Set the output of amplitude of the CW signal. If not provided, use maximum scale.

set_lut_output(*n*, *x*, *scale=True*)

Set LUT output *n* to sample array *x*.

Parameters

- **n** (*int*) – Which generator to target.
- **x** (*list or numpy.array*) – Array (or list) of complex sample values
- **scale** (*bool*) – If True, scale to the maximum possible amplitude range in event of overflow. Otherwise, saturate overflowing values.

set_output_freq(*n*, *freq_hz*, *sample_rate_hz=2457600000*, *amplitude=None*, *round_freq=True*, *window=False*)

Set an output to a CW tone at a specific frequency.

Parameters

- **n** (*int*) – Which generator to target. Use -1 to mean "all"
- **freq_hz** (*float*) – Output frequency, in Hz
- **sample_rate_hz** (*float*) – DAC sample rate, in Hz
- **amplitude** (*float*) – Set the output of amplitude of the CW signal. If not provided, use maximum scale.
- **round_freq** (*bool*) – If True, round `freq_hz` to the nearest frequency which can be represented with a `self.n_samples` circular buffer. This option affects only LUT generators.
- **window** (*bool*) – If True, apply a Hann (a.k.a. Hanning) window to data samples. This option affects only LUT generators.

3.2.13 Output

class souk_mkid_readout.blocks.output.**Output**(*host*, *name*, *logger=None*)

get_mode()

Get the current output mode.

Returns
string describing output mode, eg. "CORDIC"

Return type
str

get_status()

Get status and error flag dictionaries.

Status keys:

- mode (str) : 'CORDIC' or 'LUT' or 'PSB'

Returns
(status_dict, flags_dict) tuple. *status_dict* is a dictionary of status key-value pairs. flags_dict is a dictionary with all, or a sub-set, of the keys in *status_dict*. The values held in this dictionary are as defined in *error_levels.py* and indicate that values in the status dictionary are outside normal ranges.

initialize(*read_only=False*)

Parameters
read_only (*bool*) – If True, do nothing. If False, initialize to LUT mode.

use_cordic()

Set output pipeline to use CORDIC generators

use_lut()

Set output pipeline to use LUT generators

use_psb()

Set output pipeline to use Polyphase Synthesis generators

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