JUICE SCM documentation

1 SCM Overview

(Same as MMS SCM)

The tri-axial search-coil magnetometer (SCM) with its associated preamplifier provides the three-dimensional measurement of the magnetic field fluctuations. The analog magnetic waveforms measured by the SCM are digitized and processed inside the Low Frequency Receiver (LFR) together with the electric field data provided by RWI.

Both magnetic and electric field data are collected and stored by LFR. Magnetic waveforms and spectra are available at different time resolution depending on the selected mode. A full description of the design of SCM, its ground calibration results, its in-flight calibration sequence, its operational concept, and an overview of its data products can be found in the publication:

...

2 AC MAGNETIC FIELD WAVEFORMS (ACB)

2.1 Overview

The SCM waveform is sampled at 763 samples per second (S/s) in the survey mode (SID1/2), and 48800 S/s in the burst mode (SID3/7).

2.1.1 Heritage

Similar SCM have been previously flown by LPP (or formerly) on many earth-orbiting (GEOS-2, Cluster/STAFF, THEMIS/SCM, MMS/SCM) and interplanetary (Galileo, Cassini) missions. JUICE like search-coil have been also provided by LPP to equip the future Magnetospheric Mercury orbiter of the ESA/JAXA BepiColombo mission.

Search Coil Magnetometer	Cluster II (ESA)	THEMIS (NASA)	MMS (NASA)	JUICE (ESA)
SCM Instrument	STAFF-SC	SCM	SCM	SCM
SCM Onboard Spectra	STAFF-SA	DSP	DSP	LFR
Language	IDL	IDL	IDL	Python
WF Calibration method	Requency domain	Time domain	Time domain	Time domain

2.1.2 Products Overview

2.1.2.1 Exhaustive List of product types (by SID number)

SID Number	Product Name (TM_LF_xxx)	Product description	Sample Rate (S/s)
1	"Burst mode" **waveform snapshot** (periodic) (_RSWF)	Periodically collected waveform snapshots, divided into multiple	48 800

		packets	
2	“Survey mode” **waveform snapshot** (triggered) (_TSWF)	Triggered waveform snapshot sampled at 48.8 ksps or 24.4 ksps, divided into multiple packets.	48 800
3	“Burst mode” decimated **waveform** (_DWF)	Continuous waveform sampled at 763 Hz or optionally decimated down to 763/2^N Hz.	763/2^N (in current files, with N=5 → 23,84)
4	**Spectral matrix** (_SM) → *contains RW*	On-board calculated full spectral matrix	/
5	Simple spectral basic parameters (_BP0)	Simple spectral product for selective downlink. Only contains E and B power spectra calculated in software from spectral matrices. Not split in multiple packets.	/
6	Extended spectral basic parameters (_BP1)	Extended spectral product, to be used as quicklook for selective downlink, but also for science	/
7	“Burst mode” decimated **waveform snapshot** (_DWFS)	A waveform snapshot created from the DWF product	763
8	Extra reduced basic parameters (_BP2)	Another simple spectral product for selective downlink. This contains very reduced power spectra and wave polarization parameters	/
9	Trigger statistical packet, incl. Dust (_STAT)	A very short TM packet containing triggering results, including dust and wave counters, peak/RMS amplitudes etc	/

2.1.3 Product contents

2.1.3.1

2.1.3.2 *“Survey mode” waveform snapshot (periodic) cdf product (SID1 / LF_RSWF)*

Periodically collected waveform snapshots sampled at 48.8 ksps or 24.4 ksps, divided into multiple packets. Aux header only in the first packet.

Offset (byte)	ID	Size in bytes	Range /type	Description
RPWI common header (6 bytes)				
0	SID	1	1/33	SID = 1/33: TM_LF_RSWF
1	Acquisition Coarse Delta Time	2		Difference in seconds between the packet coarse time and acquisition coarse time
3	Acquisition Fine Time	2		Data acquisition fine time (in units of 2^-64 sec)
5	SEQ_CNT	2	0 - 0xFFFF	Sequential counter (per SID)
7	Aux Length	1	0	
Aux header (length = 8 bytes)				
8	SWITCHES1	4	Bitmask	HW switches1
12	SWITCHES3	1	Bitmask	HW switches2
13	COMPONENT_MASK	1	Bitmask	A bitmask of components in the packet. **num_comp (number of components in data packets)** = number of nonzero bits in COMPONENT_MASK.
14	TOTAL_PACKETS	2	Unsigned <= 3072	Number of packets forming one snapshot.
Start of data (length = 4 + 2*128*num_comp. Maximum length 2052 bytes)				
16	ARTEFACTS	1	Bitmask	ADC overflow bits.
17	SNAPSHOT_NUMBER	1	Bitmask	Sequential counter incremented with each snapshot.
18	SEQ_COUNTER	2	Unsigned	Packet number within one snapshot.
20	DATA	2***num_comp** *128 (arrays of dim 128 x **num_comp**)	Signed int16	Waveform data encoded as 16b integers. 128 samples per channel, from **num_comp** channels. Currently, **num_comp** = 8 , the SCM data is in channels **[0,1,2]**

2.1.3.3 *“Survey mode” waveform snapshot (triggered) cdf product (SID2 / LF_TSWF)*

Triggered waveform snapshot sampled at 48.8 ksps or 24.4 ksps, divided into multiple packets. Aux header only in the first packet.

Offset (byte)	ID	Size in bytes	Range /type	Description
RPWI common header (6 bytes)				
0	SID	1	2/34	SID = 2/34: TM_LF_TSWF
1	Acquisition Coarse Delta Time	2		Difference in seconds between the packet coarse time and acquisition coarse time
3	Acquisition Fine Time	2		Data acquisition fine time (in units of 2^-64 sec)
5	SEQ_CNT	2	0 - 0xFFFF	Sequential counter (per SID)
7	Aux Length	1	12	Aux_len = 12
Aux header (length = 12 bytes) – only in first packet				
8	SWITCHES1	4	Bitmask	HW switches1
12	SWITCHES2	1	Bitmask	HW switches2
13	COMPONENT_MASK	1	Bitmask	A bitmask of components in the packet. **num_comp (number of components in data packets) =** number of nonzero bits in COMPONENT_MASK
14	TOTAL_PACKETS	2	Uint4 + Uint12	Low 12 bits: Number of packets forming one segment (< 3072) High 4 bits: Number of segments the packet is divided into
16	TRIGGER_INFO	2		Trigger algorithm information. See below.
18	QUALITY	2		Quality factor
Data (the following block is repeated):				
20	ARTEFACTS	1	Bitmask	ADC overflow bits.
21	SNAPSHOT_NUMBER	1	Bitmask	Sequential counter incremented with each snapshot.
22	SEQ_COUNTER	2	Unsigned	Packet number within one snapshot.
24	DATA	2***num_comp** *128 (arrays of dim 128 x **num_comp**)	Signed int16	Waveform data encoded as 16b integers. 128 samples per channel, from **num_comp** channels. Currently, **num_comp** = 8 , the SCM data is in channels **[0,1,2]**

2.1.3.4 “Burst mode” decimated waveform cdf product (SID3 / LF_DWF)

Continuous waveform sampled at 763 Hz or optionally decimated down to 763/2^N Hz.

Offset (byte)	ID	Size in bytes	Range	Description
RPWI common header				
0	SID	1	3	SID = 3: TM_LF_DWF
1	Acquisition Coarse Delta	2		Difference in seconds between the

	Time			packet coarse time and acquisition coarse time
3	Acquisition Fine Time	2		Data acquisition fine time (in units of 2^-64 sec)
4	SEQ_CNT	2	0 - 0xFFFF	Sequential counter (per SID)
7	Aux Length	1	0	Aux len = 0
Packet header (length = 8 bytes)				
8	SWITCHES1	4	Bitmask	HW switches1
12	SWITCHES2	1	Bitmask	HW switches2
13	ARTEFACTS	1	Bitmask	ADC overflow bits.
14	COMPONENT_MASK	1	Bitmask	A bitmask of components in the packet. **num_comp (number of components in data packets) =** number of nonzero bits in COMPONENT_MASK
15	DECIMATION	1	0-5	Decimation factor.
Start of data (length = 2*128*num_comp. Maximum length 2048 bytes)				
16	DATA	16***num_comp** *128 (arrays of dim 128 x **num_comp**)	Signed int16	Waveform data encoded as 16b integers. 128 samples per channel, from **num_comp** channels. Currently, **num_comp** = 8 , the SCM data is in channels **[0,1,2]**

2.1.3.5 "Burst mode" decimated waveform snapshot cdf product (SID7 / LF_DWFS)

A waveform snapshot created from the DWF product, divided into multiple packets. Aux header only in the first packet.

Offset (byte)	**ID**	**Size in bytes**	**Range /type**	**Description**
RPWI common header				
0	SID	1	7	SID = 7: TM_LF_DWFS
1	Acquisition Coarse Delta Time	2		Difference in seconds between the packet coarse time and acquisition coarse time
3	Acquisition Fine Time	2		Data acquisition fine time (in units of 2^-64 sec)
5	SEQ_CNT	1	0 - 0xFFFF	Sequential counter (per SID)
7	Aux Length	1	8	Aux_len = 8
Aux header (length = 8 bytes)				
8	SWITCHES1	4	Bitmask	HW switches1
12	SWITCHES2	1	Bitmask	HW switches2
13	COMPONENT_MASK	1	Bitmask	A bitmask of components in the packet. **num_comp =** number of nonzero bits in COMPONENT_MASK

14	TOTAL_PACKETS	2	Unsigned <= 3072	Number of packets forming one snapshot.
Start of data (length = 4 + 2*128*num_comp. Maximum length 2052 bytes)				
16	ARTEFACTS	1	Bitmask	ADC overflow bits.
17	SNAPSHOT_NUMBER	1	Bitmask	Sequential counter incremented with each snapshot.
18	SEQ_COUNTER	2	Unsigned	Packet number within one snapshot.
20	DATA	2***num_comp** *128 (arrays of dim 128 x **num_comp**)	Signed int16	Waveform data encoded as 16b integers. 128 samples per channel, from **num_comp** channels. Currently, **num_comp** = 8 , the SCM data is in channels **[0,1,2]**

2.2 Theoretical Description of different product levels

Responsibility	**Usual Convention**	**JUICE/SCM Convention**	**Usual Files Content**	**JUICE/SCM Wave Form Products**
Mission Level ESA	Raw data		Telemetry packets	
Mission level ESA +	Level 0	L0	De-commuted data	Binary files TM counts
Instrument suite level ..	Level 1	L1A	Decompressed and time tagged data	CDF files TM counts (LONG64) Time tagged (TT2000) ..
Instrument team level SCM/LPP	Level 2	L1B	Calibrated data	CDF files nT (FLOAT) Converting counts to V to nT is a tricky process! ..
..	..	..	..	..

2.2.1 Global description of the different steps

2.2.1.1 L0 to L1a (done by ..)

Decompression:
• Takes care of data loss due to compression (need of a status flag/fillvalue)
• Also takes care of saturation (status flag/fillvalue)

Timing:
• Packet time, clock derivation, delay is taken care of at the Fields consortium level

2.2.1.2 L1a to L1b (calibrated data) (LPP)

Waveforms snapshots are divided into multiple packets, each packet having a starting epoch time and sampling period

Waveform : from 'snapshot' Counts to 'continuous' Counts

- Waveforms snapshots packets are appended into one continuous waveform, with corresponding epoch array computed using packets starting epoch time and sampling frequency :

$$for\ t_i \in [0, n_{time\_points}], for\ t_{pi} \in [t_{p0}, .., t_{p\_n\_packets}],$$
$$epoch(t_i) = epoch(t_{px}) + (t_i - t_{px}) / sampling\_freq(t_{px}), for\ t_{px} \leq t_i \leq t_{px+1}$$

Waveform: from Counts to Volts

• ADC conversion ±2.5V on 16bits with an input DSP gain of 0.403 to fit the ±6.25V output to DSP:
• [Optional] Centering of Waveform (removing DC)

Waveform: from Volts to nT

- Performed continuously in time domain by convolution

$\text{in}(t) = \text{out}(t) * c(t)$ where $c(t) = FT^{-1}[1/h(f)]$ is called **kernel**
(n_k is the size of the kernel) and $h(f)$ is the transfer function or **frequency response** of the antenna, Bessel low-pass filter and digital filter.

A large n_k gives better calibration, but is time consuming

- Get kernel suitable for use by shifting by nk/2, applying one convolution window (Hanning, ..).

- Different edge behavior (zero, wrap, truncate, mirror).

2.2.1.2.1 Frequency responses

The different responses are taken into account to construct the tranfer function:
$h(f) = Antenna\_resp(f)\ x\ DFB(f)\ x\ Bessel\_filter\_resp(f)$ (+filter between f_min and f_max)

2.2.1.2.1.1 Antenna frequency response

Put frequency frequence figure

2.2.1.2.1.2 DFB filter frequency response

Put frequency frequence figure

2.2.1.2.1.3 Bessel filter frequency response

Put frequency frequence figure

2.2.2 Calibration parameters

2.2.2.1 Kernel size (n_k) + f_min + f_max

Lower limit depends on the frequency resolution we want.

Criteria : $\frac{\Delta f}{f} < 1 \; at \, f_{min}, \; where \frac{\Delta f}{f} = \frac{f_s}{(n_k * f)}, \; n_{k\_min} > \frac{f_s}{f_{min}}$

Higher limit depends on the computing time and the loss of the first half and last half of the convolution window we can afford.

Our choice for L1b production:

Mode	Name	f_s = sample rate (S/s)	f_min (Hz)	f_max = f_nyquist (Hz)	n_k
Survey	SID7	763	0,5	381,5	1024
Burst	SID2	48800	0,5	24400	1024

2.2.2.2 Convolution window type

The convolution window types available are :

- Hanning
- Coscub with a flat portion of 1/10
- Coscub with a flat portion of 1/3
- Gaussian
- Trapezoid

Mode	Name	Default Convolution window type
Survey	SID7	Hanning
Burst	SID2	Hanning

2.2.2.3 Padding edges type

The padding edges behavior available are :

- Zero
- Truncate
- Wrap
- Mirror

Mode	Name	Default Padding edges

		behaviour
Survey	SID7	Mirror
Burst	SID2	Mirror

2.2.3 Waveform calibration algorithm

- Instrument and filter responses: $kernel_{complex}(i_f) = h_{ant}(i_f) * h_{DFB}(i_f) * h_{Bessel}(i_f)$ with $f(i_f) = i_f * df, if = 0 \ldots nk \wedge df = f_{Nyquist}/nk$
- Filter f<fmin: $kernel_{complex}(i_f < i_{fmin}) = 0$
- Filter f>fmax: $kernel_{complex}(i_f > i_{fmax}) = 0$
- Obtain kernel: $kernel_{real}(i_t) = Real(FT^{-1}[kernel_{complex}(i_f)])$ (Check that Imaginary part is 0)
- Zero time of the kernel is at index it=0, shift that to index nk/2 to get a kernel suitable for linear convolution and to allow application of the window
- Hanning windowing (As this is a continuous calibration, the window must be applied to kernel, rather than to the waveform): $kernel(i_t) = kernel_{real}(i_t) * Hanning(nk)$ (Other possibilities, coscub, trapez, etc.)
- Normalize kernel: $kernel(i_t) = kernel(i_t)/nk$
- Convol signal with kernel: $in(t) = out_{+edge_{mirror}}(t) * kernel(i_t)$ (Don't forget to shift back -nk/2)
- Remove average from signal.

2.3 Calibration and Validation (Pre-flight / In-flight / Confidence in measurements / etc)

2.3.1 Calibration

2.3.1.1 Pre-Flight / On-Ground Calibration

2.3.1.2 In-Flight Calibration

2.3.2 Confidence in Measurements

2.3.3 Comparison of Other Measurements

2.3.4 Quality Control and Diagnostics

3 AC MAGNETIC FIELD POWER SPECTRAL DENSITY (BPSD)

3.1 Overview

3.1.1 Heritage

3.2 Product description

3.3 Theoretical description

3.4 Calibration and validation

4 Quicklooks

4.1 ACB Frequency Spectra

4.1.1 Overview

For a ACB waveform (nT) of length n_time_points, the frequency spectrum matrix (nT/sqrt(Hz)) is of dimensions (*n_fft* x **fft_n_p**), where **fft_n_p** is the number of FFT points, and *n_fft* is the number of FFT computed for the n_time_points (i.e. n_fft = n_time_points // fft_n_p)

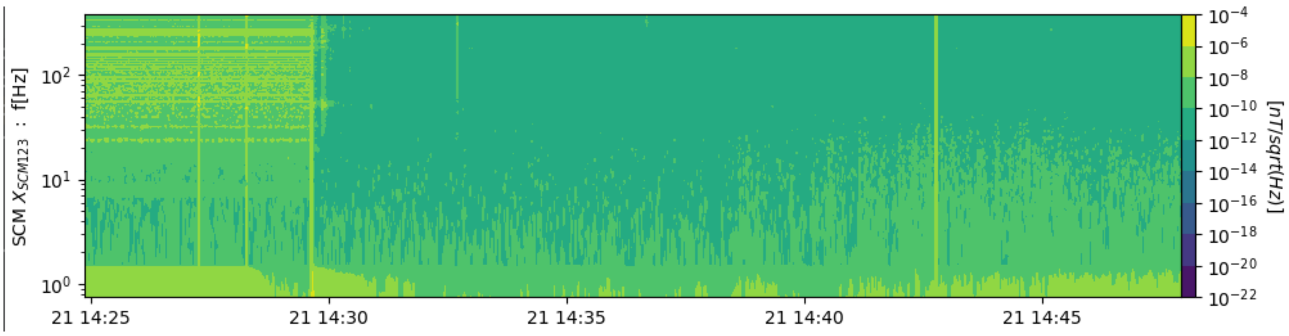


Figure 1: Example of Frequency spectrum of SID7/Survey mode waveform

4.1.2 Parameters

4.1.2.1 fft_n_p

The number of FFT points for the spectra computation will greatly influence the spectra density distribution.
Our choice for L1b production:

Mode	Name	fft_n_p
Survey	SID7	1024
Burst	SID2	1024

4.2 ACB frequency spectral densities

4.2.1 Overview

For a ACB waveform (nT) of length n_time_points, the frequency spectrum density (PSD) array (nT/sqrt(Hz)), derived from the frequency spectrum, is of dimensions (**fft_n_p**), where **fft_n_p** is the number of FFT points.

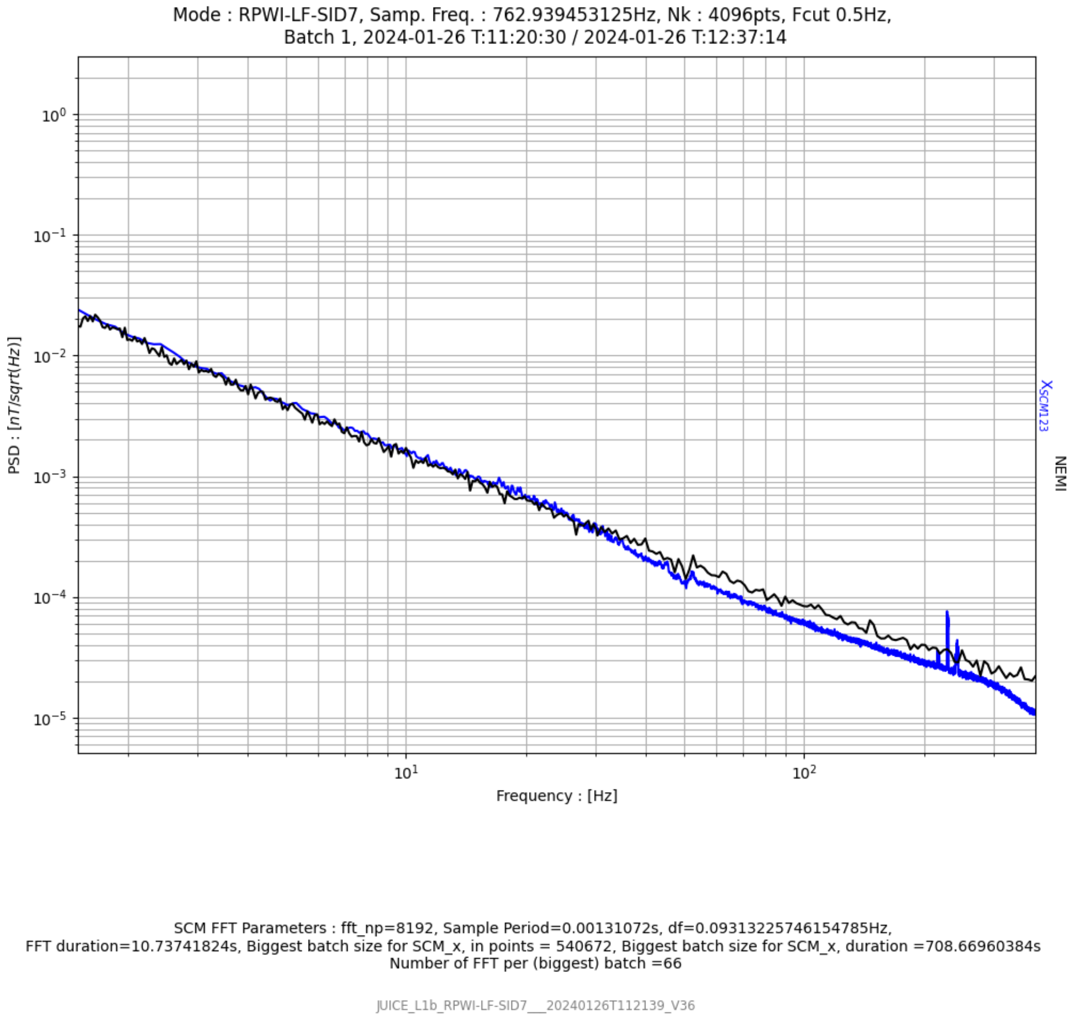


Figure 2: Example of spectral density plot of SID7/Survey Mode waveform

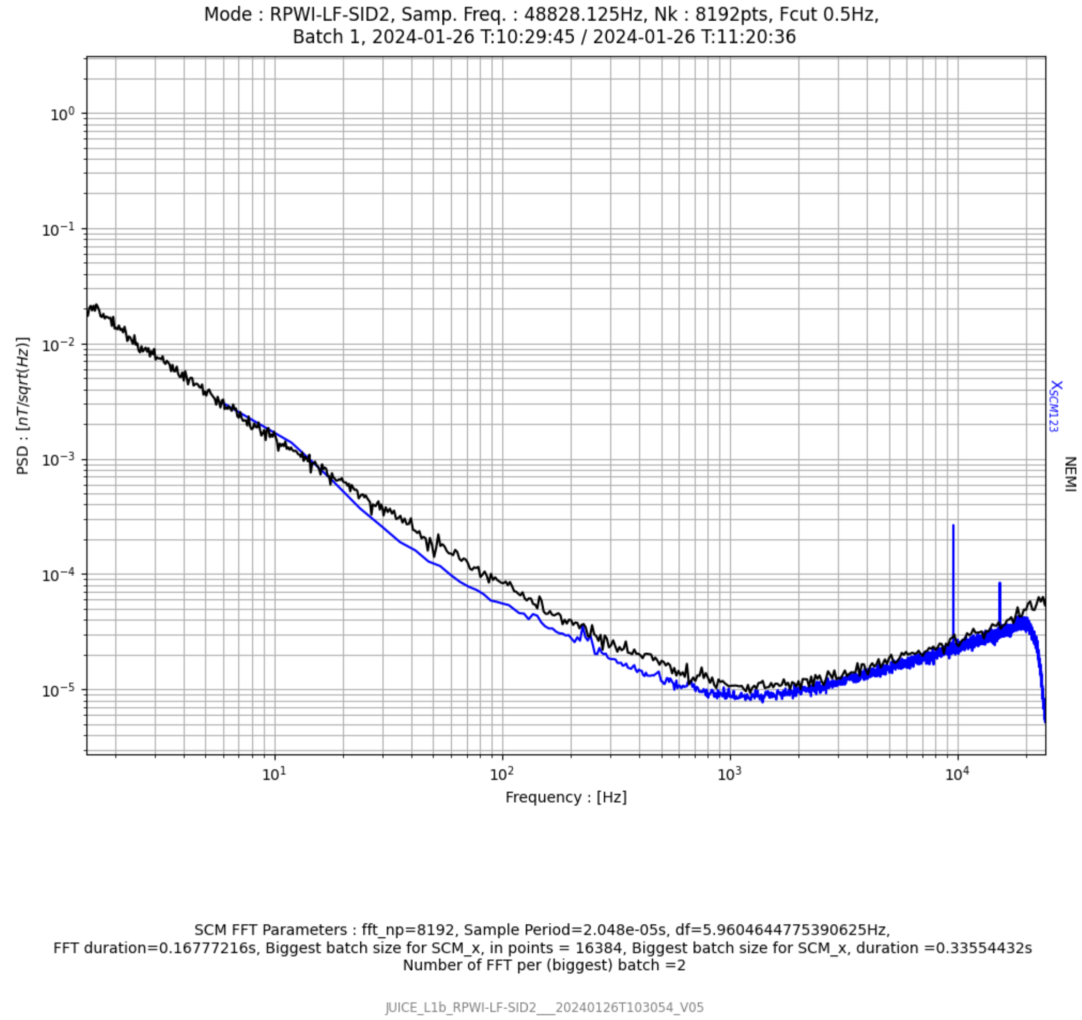
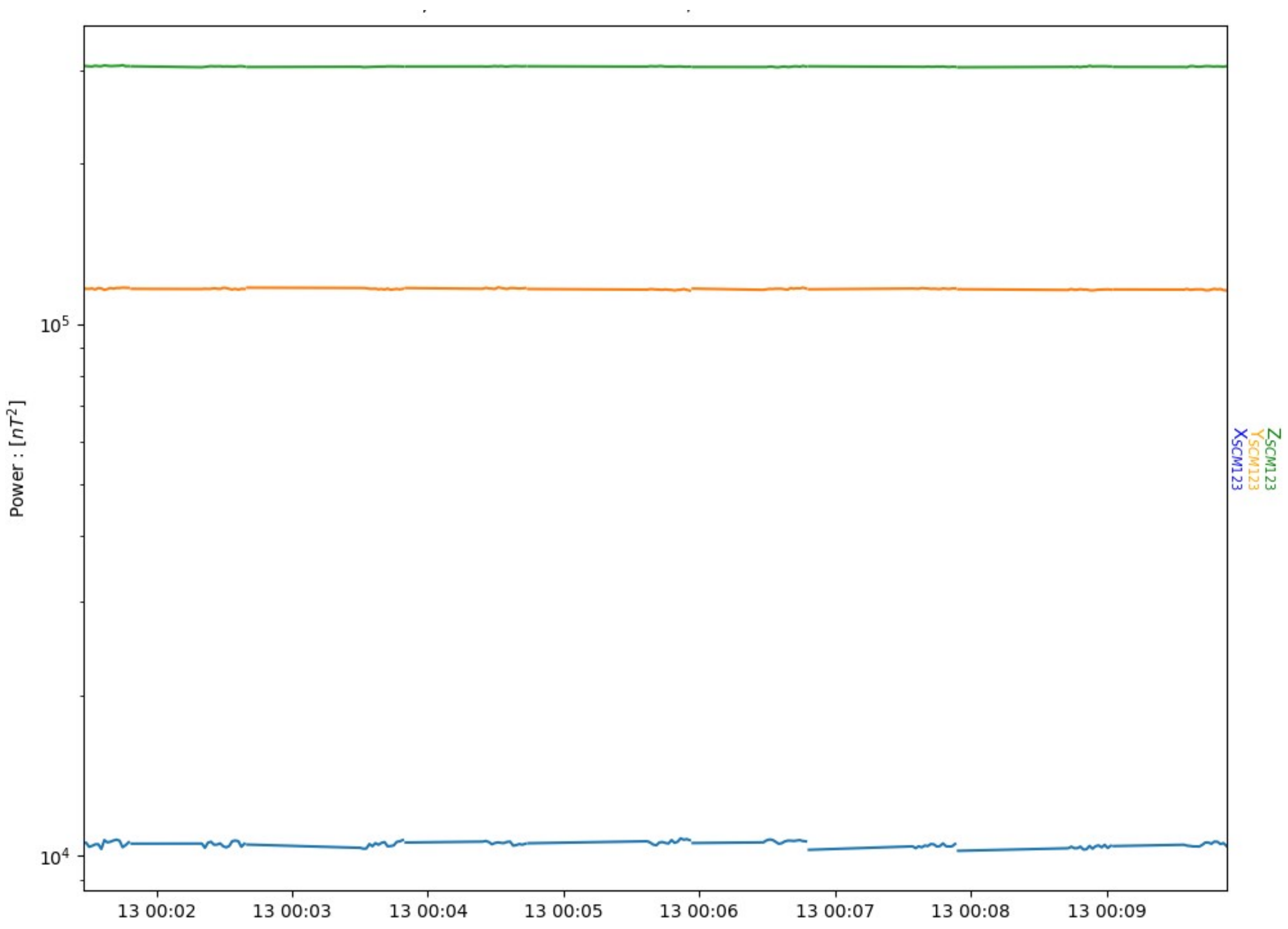


Figure 3: Example of Spectral Density plot of SID2 / Burst Mode waveform

4.3 ACB frequency spectral powers

For a ACB waveform (nT) of length n_time_points, the frequency spectrum powers array (nT/sqrt(Hz)), derived from the frequency spectrum, is of dimensions (*n_fft*), where **fft_n_p** is the number of FFT points, and *n_fft* is the number of FFT computed for the n_time_points (i.e. n_fft = n_time_points // **fft_n_p**)



4.3.1 Overview

4.3.2 Parameters

4.4 Quicklooks content

The quicklook contains the ACB waveforms, frequency spectra, frequency spectral densities and frequency spectral powers, with in addition information about parameters (f_min, f_max, n_k, fft_n_p), metadata (sampling frequency and other information computed by the code).