The THEMIS Digital Fields Board (DFB)

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Overview

The Digital Fields Board (DFB) performs the filtering, acquisition and signal processing for the electric field instrument (EFI) and search-coil magnetometers (SCM) onboard THEMIS.

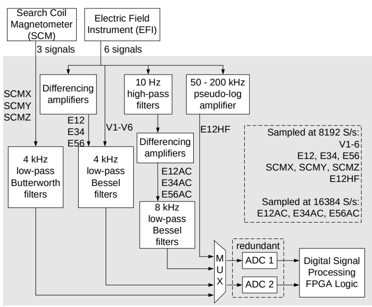
The board was designed and built at the University of Colorado, and is housed within the Instrument Data Processing Unit (IDPU). The signal processing is performed without a processor by using Field Programmable Gate Arrays (FPGAs), resulting in a robust and low-power solution.

The primary data products are time series waveforms and power spectra, available in highly flexible data products. A unique feature of the DFB is that the power spectra can be computed either on the raw signals (i.e. in a system co-rotating with the spacecraft) or in a coordinate system aligned with the local DC magnetic field. Other data products include coarse spectral power measurements for survey and triggering purposes and a measurement of the electric power in the 50kHz-200 kHz band.

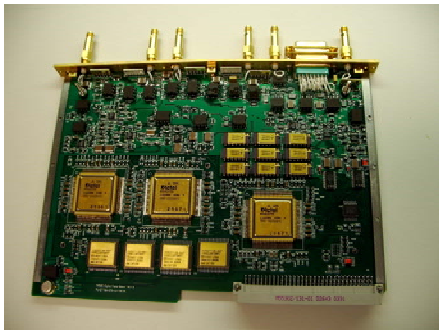
Analog Electronics

The DFB uses considerably simpler analog electronics than similar previously-flown boards. Rather than using many analog filters for many different sampling rates, we fix the sampling rate and perform most of the filtering digitally.

Mnemonic	Description
SCMX, SCMY, SCMZ	3-axis magnetic field
V1 to V6	Probe-spacecraft voltage for all 6 EFI probes
E12, E34, E56	DC-coupled electric field
E12AC, E34AC, E56AC	AC-coupled electric field
E12HF	High frequency electric field



Data Products



Waveforms

ID	Description	Burst mode	Quantities	Rate
80	Spinfit data	Slow survey	V1-4, E12, E34, E56	128 Hz
65	Voltage group A	Fast survey	Any V1-6	2 - 256 Hz
66	Voltage Group B	Fast survey	Any V1-6	2 - 256 Hz
67	Electric field	Fast survey	Any Exx or ExxAC	2 - 256 Hz
68	SCM	Fast survey	Any SCM (x,y,z)	2 - 256 Hz
69	Voltage group A	Particle burst	Any V1-6	2 - 256 Hz
70	Voltage group B	Particle burst	Any V1-6	2 - 256 Hz
71	Electric field	Particle burst	Any Exx or ExxAC	2 - 256 Hz
72	SCM	Particle burst	Any SCM (x,y,z)	2 - 256 Hz
73	Voltage group A	Wave burst	Any V1-6	2 - 8192 Hz
74	Voltage group B	Wave burst	Any V1-6	2 - 8192 Hz
75	Electric field	Wave burst	Any Exx or ExxAC	2 - 16384 Hz
76	SCM	Wave burst	Any SCM (x,y,z)	2 - 8192 Hz

Spectra

ID	Burst mode	Quantities	Frequency Bins	Rate
77	Particle burst	Any 4 signals from: V1-6, Exx, ExxAC, SCM, derived	16 to 64	1/16 - 8 Hz
78	Wave burst	Same 4 signals as above	16 to 64	1/16 - 8 Hz

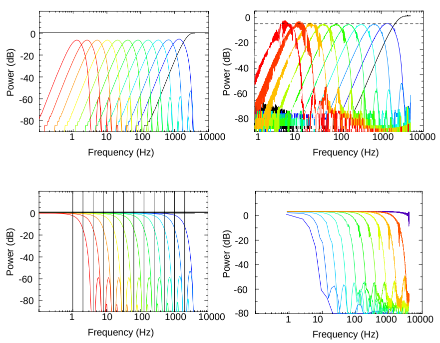
Other

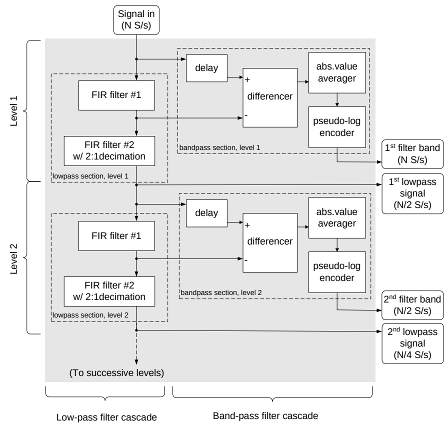
ID	Description	Burst mode	Quantities	Rate
64	Filter banks (6 bands)	Slow survey	Any 2 signals from: V1-6, Exx, ExxAC, SCM	1/16 - 8 Hz
64	50-200 kHz power	Slow survey	E12HF	Same as above
81	Filter banks (11 bands)	Triggers	Same 2 signals as above	16 Hz
81	50-200 kHz power	Triggers	E12HF	16 Hz

Digital Filters

There are 2 basic filtering operations: flexible low-pass filtering for the waveforms, and multiple bandpass filtering for the filter banks. We perform both operations using the same cascading filter.

Each level of the filter reduces the data rate by a factor of 2. Lowpass filtered data is hence available at any rate 2^{-n} times the sampling rate, and bandpass filtered data can be found by differencing the filtered and unfiltered signal within each level. Since the bandwidth shrinks at each level, the total operation count for the entire cascade is only twice the operation count for the first level.

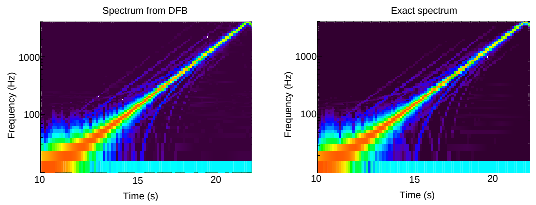




Spectra

We compute the power spectral density of 4 signals simultaneously, using 1024 point or 2048 point Fast Fourier Transforms with a Hanning window. The FFT operations are performed in fixed-point arithmetic within a dedicated FPGA. We avoid the need for lookup tables by computing the trigonometric functions with a CORDIC algorithm, which is a hardware-specific method for rotating arbitrary 2D vectors.

Binning is highly flexible both in time and frequency. Either 16, 32 or 64 logarithmically-spaced frequency bins are available, and the output cadence can be reduced from the natural 1/8 second to as low as 1/16 second by averaging together multiple spectra.



Rotation to Field-Aligned Coordinates

A unique feature of the DFB is the ability to transform SCM and/or EFI data to field-aligned coordinates before computing the spectra. Since the spectra lack phase information, this transformation cannot be performed later on the ground.

We calculate the required Euler rotation angles from the instantaneous DC magnetic field vector reported by the FGM (FluxGate Magnetometer). We then rotate the EFI or SCM vectors using a CORDIC algorithm. Euler angles are interpolated between FGM samples, and we apply calibrations to each data set (FGM, EFI, SCM).