BRI-ACE-005-Rev3

ACE MAG
Data Formats and Algorithms

Telemetry Bits Definition
Health and Safety Monitoring
Browse and Level 1 Processing
Command Dictionary

Revision 3

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ACE MAG Formats Document Changes		
Version	Date	Changes and Comments
Draft	8/18/94	Circulated to MAG team @ BRI & GSFC and to CalTech ASC Team
Revision 1	12/11/95	Health and Safety Monitoring described
		Level 1 Processing described
		Browse File Description added
		Commands and Status updated following instrument reprogramming
		Sampling times documented
Revision 2	4/26/96	Alarm Parameters Updated
		Modes 1,2,&3 Renamed Modes 0,1,&2
		Updated description of FFT processing
Revision 3	9/30/96	Conversion formulas for alarm processing added
		Instrument calibration documented
		Command library updated

Note to the reader: This document continues to be a living document subject to revision. The data formats have been determined and are final. Additions to the format sections of this document will provide enhanced descriptions only. The algorithm sections and discussions of data processing are subject to revision as ground software is written.

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1 Instrument Description

The ACE MAG experiment is a fluxgate magnetometer design with heritage extending back to the Voyager, Mariner, and IMP missions. It is the latest generation instrument to come from the GSFC Laboratory for Extraterrestial Physics with onboard memory buffers and data processing capabilities.

The ACE MAG experiment consists of a redundant pair of two sensor boxes, denoted sensors A and B, and a redundant MFI processor which is located on the top deck of the spacecraft. The sensors are mounted on booms attached to the ends of two solar array panels at opposite sides of the spacecraft (the booms are aligned with the +Y and -Y axes of the spacecraft) and each sensor is approximately 4.3 meters from the center of the spacecraft. Sensor A is intended for mounting on the –Y-axis while Sensor B should be mounted on the +Y-axis. Each sensor measures a fully 3-dimensional magnetic field vector.

The ACE MAG instrument is the WIND flight spare with one card exchanged from the MFI in order to provide a compatible interface with the ACE spacecraft. The data collection rate, averaging intervals, and other important parameters have been changed in accordance with the telemetry rate assigned this instrument by the ACE spacecraft.

The ACE MAG instrument is fully commandable from ground and awakens in a pre-programmed and fully functioning default state when powered.

2 Telemetry Formats Legend

The ACE MAG instrument generates 4 basic data types in 3 telemetry modes. The 4 data types are designed to provide a continuous monitoring of the interplanetary magnetic field from two independent sensors while recording limited information on the high frequency fluctuations beyond the frequency range accessible to the continuous data. That high frequency information is contained in the Fast Fourier Transform of limited bands of recorded data and a circulating snapshot buffer of highest-resolution data. The 4 data types are:

1. Averages of the primary and secondary sensor measurements over time intervals that vary with the mode and sensor.
2. Fast Fourier Transforms (FFT) of the highest resolution (24 vectors/second) data generated by the instrument prior to averaging.
3. Snapshot buffer data, also at the highest time resolution, that triggers on specific interplanetary events and enable the instrument to capture a high time resolution measurement of shocks and various transient processes.
4. Housekeeping and Status information that provide a complete description of the instrument's status and functionality as well as information necessary for the interpretation of the FFT and Snapshot buffer dumps.

The ACE spacecraft telemetry has every major frame divided into 16 minor frames with a minor frame read out once per second, thereby allowing 1 major frame every 16 seconds. The ACE MAG experiment is allocated 304 bits/minor frame. We have allocated our 304 bits in such a way as to provide a standardized and systematic parcelling of the above 4 data types that does not change with telemetry mode. Only the allocation between the primary and secondary sensor averages changes with mode, as discussed below.

Throughout this document we refer to the location of each variable by the bit count. That count refers to a variable's location within the 304 bits/minor frame allocated to the MAG instrument. It **does not** *refer to a specific bit count within the spacecraft telemetry.*

The variable and bit-identification for each of the three modes is documented in this and the following two sections. The data format tables are presented following Section 3.

2.1 Sensor *A* and Sensor *B* Averages

As a result of hardware consideration and pin assignments, sensor A is logically equivalent to the "inboard" sensor of the WIND experiment. Sensor B of the ACE MAG instrument is logically equivalent to the "outboard" sensor of the WIND experiment. The ACE MAG instrument has no "inboard" or "outboard" sensors, so this fact is provided only in support of cross-comparisons between the WIND and ACE documentation.

All sensor A and sensor B averages have their MSB left-justified in all telemetry formats. Sensor A and sensor B averages together are allocated eighteen 12-bit items in each minor frame, representing six 3-component vectors. The sensor average data is located in minor frame bits 1–216 of every minor frame in each of the three telemetry modes. See Tables 1–3.

Each telemetry mode requires that either sensor A or sensor B be designated as the "Primary" sensor. The other is necessarily the "Secondary" sensor. Data allocation in telemetry, as well as data collection for the FFT and Snapshot buffers, is assigned according to Primary and Secondary sensor, not sensors A and B. Specific sensor allocations for each telemetry mode are provided in the following sections.

The default state for the instrument, and the state in which the instrument awakens when powered, is: Mode 0, Primary sensor B and Secondary sensor A.

The primary and secondary sensor averages are labelled:

P_x = Primary sensor average of vector component x.

P_y = Primary sensor average of vector component y.

P_z = Primary sensor average of vector component z.

S_x = Secondary sensor average of vector component x.

S_y = Secondary sensor average of vector component y.

S_z = Secondary sensor average of vector component z.

2.2 Spectral Data

All spectral data values are compressed to 8 bits, and are the result of one of 32 frequency bins used to group the components of a particular FFT transform output. The values are denoted by one of the symbols below to distinguish the individual transform output types. The 8-bit values are ordered in the telemetry with 4 values per minor frame, beginning the sequence with the contents of frequency bin 1 and ending with frequency bin 32, using 8 successive minor frames to transmit the 32 spectral estimates associated with each element of the spectral matrix and 5 successive major frames to completely dump the FFT dataset. Spectral data values are located in minor frame bits 217–248 of every minor frame.

The first minor frame of a particular FFT buffer dump is always minor frame 0 of the associated major frame. The first major frame of an FFT buffer dump is denoted by the bit $\mathrm{F_b} = 1$ in Status byte ST5. The Status bytes are described later in this document.

The spectral values are labelled:

F^i_{xx} = The i^{th} frequency bin value derived from the primary sensor X-axis FFT transform real output.

F^i_{yy} = The i^{th} frequency bin value derived from the primary sensor Y-axis FFT transform real output.

F^i_{zz} = The i^{th} frequency bin value derived from the primary sensor Z-axis FFT transform real output.

R^i_{xy} = The i^{th} frequency bin value derived from the primary sensor X-Y cross-spectra real output.

I^i_{xy} = The i^{th} frequency bin value derived from the primary sensor X-Y cross-spectra imaginary output.

R^i_{xz} = The i^{th} frequency bin value derived from the primary sensor X-Z cross-spectra real output.

I^i_{xz} = The i^{th} frequency bin value derived from the primary sensor X-Z cross-spectra imaginary output.

R^i_{yz} = The i^{th} frequency bin value derived from the primary sensor Y-Z cross-spectra real output.

I^i_{yz} = The i^{th} frequency bin value derived from the primary sensor Y-Z cross-spectra imaginary output.

M^i_g = The i^{th} frequency bin value derived from the primary sensor magnitude FFT transform real output.

Input for the FFT transform is obtained from the Primary sensor.

To reduce the amount of data sent to ground, and to better represent data that is exponential in nature, the linear frequency scale of the onboard FFT is converted into an approximately logarithmic frequency scale by summing adjacent FFT frequencies by groups that increase in size exponentially along the frequency axis. These groups, 32 in all, are considered compressed frequencies, and maintain a constant Q (bandwidth to center frequency ratio) throughout the spectrum. Ten summations are computed for each group; three summations for the three real diagonal terms in the covariance matrix, six summations for the three complex off-diagonal terms (separate real and imaginary sums), and one summation for the magnitude squared term.

The following table shows the original FFT normalized frequencies, the number of these frequencies summed into the compressed frequency, the compressed frequency, and the approximate center of the compressed frequency in FFT normalized frequencies. These summations are carried out in double precision (32 bits). The column labeled "Compressed Frequency" refers to the superscript "i" in the above listing where $0 \leq i \leq 31$. The column labelled "Center Frequency" gives the center of the averaging window which in turn can be used to compute the spacecraft-frame frequency ν_{sc} of the i^{th} spectral estimate according to the expression:

$$\nu_{sc} = (\text{Center Frequency} + 1) \times \Delta\nu.$$

The FFT is based on 512 samples of the magnetic field collected at 24 samples/second so $\Delta\nu = 0.046875$ Hz while the Nyquist freqency is 12 Hz.

FFT Averaging Scheme

FFT Frequency	# of FFT Frequencies	Compressed Frequency	Center Frequency	Spacecraft Frequency [Hz]
0	1	0	0	0.046875
1	1	1	1	0.093750
2	1	2	2	0.140625
3	1	3	3	0.187500
4	1	4	4	0.234375
5	1	5	5	0.281250
6-7	2	6	6	0.328125
8-9	2	7	8	0.421875
10-11	2	8	10	0.515625
12-13	2	9	12	0.609375
14-16	3	10	15	0.750000
17-19	3	11	18	0.890625
20-22	3	12	21	1.031250
23-26	4	13	24	1.171875
27-30	4	14	28	1.218750
31-35	5	15	33	1.593750
36-40	5	16	38	1.828125
41-46	6	17	43	2.062500
47-53	7	18	50	2.390625
54-61	8	19	57	2.718750
62-69	8	20	65	3.093750
70-78	9	21	74	3.515625
79-88	10	22	83	3.937500
89-100	12	23	94	4.453125
101-113	13	24	108	5.109375
114-127	14	25	120	5.671875
128-143	16	26	135	6.375000
144-161	18	27	152	7.171875
162-181	20	28	171	8.062500
182-203	22	29	192	9.046875
204-228	25	30	216	10.171875
229-255	27	31	242	11.390625

Status byte ST5 contains 2 bits to flag the first major frame of an FFT buffer readout and whether a range change occurred during the FFT data collection cycle while Status byte ST6 contains eight bits which describe the status of the onboard FFT, how the data was compressed, whether onboard averages were computed, whether the data was despun onboard, whether the auto-zeroing option was invoked, and what type of digital window was used in computing the FFT. The format of Status bytes ST5 and ST6 and specific decompression algorithms are detailed in later sections.

2.3 Snapshot Memory Samples

The Snapshot buffer is designed to record magnetic field measurements at the highest rate available, which for the ACE mission is 24 v/s. It usefullness lies in the ability to obtain and download high resolution measurements of interplanetary shocks and other structures possessing dynamically important small-scale structure. The snapshot buffer is a circulating buffer that can be programmed to trigger on a variety of magnetic field observations such as a sudden change in the field magnitude. The 256 Kbit snapshot buffer will hold a maximum of 7140 vector measurements. At 24 v/s the snapshot buffer will capture 297.5 seconds of high resolution data with the time of the trigger occurring midway within the Snapshot dataset. The trigger event halts overwriting of the buffer once it is filled in this manner until after the completed readout of the buffer or release of the SNAP-FREEZ command by the SNAP-NORM command. Input for the Snapshot buffer is obtained from the Primary sensor.

All snapshot memory samples have their MSB left-justified in all telemetry formats. Snapshot memory samples are located in minor frame bits 249–296. The entire contents of the snapshot buffer can be downloaded in 5440 minor frames of telemetry which is equivalent to 340 major frames.

The snapshot memory samples are labelled:

H_x = one 12-bit primary sensor X-axis sample at highest time resolution (24 vectors/second).

H_y = one 12-bit primary sensor Y-axis sample at highest time resolution (24 vectors/second).

H_z = one 12-bit primary sensor Z-axis sample at highest time resolution (24 vectors/second).

Status byte ST3 contains 5 bits germain to the snapshot memory readout and processing including the trigger identification bits, event or non-event identificiation bit and readout start bit. The eighth bit signifies the start of snapshot memory readout with the value RS = 1. Status byte ST4 contains 4 bits of error code and some codes are germain to the snapshot buffer. Status byte ST5 contains 4 bits of snapshot readout documentation including the buffer ID (there are 2 snapshot buffers) and trigger enable/disable bits. The format of Status bytes ST3, ST4 and ST5 are detailed in later sections.

2.4 Status and Housekeeping Bytes

Status and Housekeeping bytes are found in minor frame bits 297–304 of every minor frame in all 3 telemetry modes. The identity and interpretation of the Status and Housekeeping bytes depends on the minor frame count within the major frame (minor frame 0, minor frame 1, ...etc. through minor frame 15), but does not depend on the telemetry mode.

3 Operational Mode Formats Description

There are three operational modes for the ACE MAG instrument, referred to simply as modes 0, 1, and 2. Each mode downloads continuous vector averages of the data recorded by one or both sensors, a partial dump of the FFT buffer, a partial dump of the Snapshot buffer, and a complete dump of the Status and Housekeeping bytes for the instrument. Each major frame contains a complete record of vector averaged data, Status, and Housekeeping bytes for the 16 seconds in question. In all modes a cycle of 5 major frames is required to download the complete contents of the FFT buffer. A complete dump of the Snapshot buffer requires 340 major frames in all telemetry modes. Every major frame is 16 seconds long and consists of 16 minor frames. The telemetry allocation for the MAG instrument is 304 bits per minor frame.

The telemetry allocation is divided between the four data types (data averages, FFT, Snapshot, and Status and Housekeeping) in the same fashion in each of the three modes. Only the data average allocation for the primary and secondary sensors is changed with mode changes. The modes allocate each minor frame of telemetry between the various data elements according to the following table:

Telemetry Modes of the ACE MAG Instrument

Data Stream	Mode 0	Mode 1	Mode 2
Primary Sensor	3 vectors	4 vectors	6 vectors
Secondary Sensor	3 vectors	2 vectors	0 vectors
FFT	4 estimates	4 estimates	4 estimates
Snapshot	4 components	4 components	4 components
Status/Housekeeping	1 value	1 value	1 value

Either sensor *A* or sensor *B* can be assigned the role of Primary sensor "P" or Secondary sensor "S" depending on the performance of the instrument and the spacecraft. The three operational modes do not generally assign equal amounts of telemetry to the two sensors so that the primary sensor is allocated a greater share of the telemetry in modes 0 and 2 and thereby permitted to retain a finer time resolution. The primary sensor also provides the measurements stored in the snapshot buffer and Fourier transformed for storage in the FFT buffer. The decision of which sensor ("*A*" or "*B*") performs this enhanced role can be changed by ground command.

Each mode has the same telemetry allocation per minor frame for the data averages, FFT, Snapshot, Status and Housekeeping data. The data averages are allocated 216 bits in the form of 6 vector measurements of 3 components each. Each vector component is allocated 12 bits. The FFT is allocated 32 bits in the form of four 8-bit estimates. The snapshot buffer is allocated 48 bits (four 12-bit vector components) with the last 12 bits of the snapshot buffer allocation in the last minor frame of each major frame containing a snapshot status word. The Status and Housekeeping bytes are multiplexed across minor frames using the last 8 bits in each minor frame. The total bit count is 304 bits in all modes. The data allocation is as follows:

General Data Allocation for All Modes			
Data Averages	FFT	Snapshot	Status/House
6(X,Y,Z) vectors	4 spectral estimates	4 vector components	1 status byte
12 bits/component	8 bits/estimate	12 bits/component	8 bits/value
216 bits	32 bits	48 bits	8 bits

A total of 13 Status and Housekeeping bytes are required to completely define the state, health, and operation of the instrument. One byte is transmitted in each minor frame. The MAG sensor range status bytes are transmitted twice in every major frame. A final SYNC byte is transmitted in the last minor frame to reliably establish the identity and sequence of the transmitted bytes as seen in Tabels 1–3.

Mode 0 is the wake-up operational mode. It is to this mode that the instrument defaults when powered on. Switching to other telemetry modes is accomplished by ground command. As with each of the three modes, this mode consists of sensor A and sensor B data averages, FFT data, Snapshot data, Status and Housekeeping data. Unlike modes 1 and 2, Mode 0 allocates equal portions of telemetry to averages of Primary and Secondary data.

3.1 Mode 0 Telemetry Format

Mode 0 telemetry divides the 216 bit allocation for data averages equally between the Primary and Secondary sensors. Averaged vectors from sensors A and B are downloaded with equal allocation with each minor frame representing the observations from the previous second. Table 1 shows the detailed data format in Mode 0 for each of the 16 minor frames that constitute a major frame.

Table 1 shows five sequential major frames, starting with the first major frame of an FFT buffer dump. The 2^{nd} through 5^{th} major frames are only sketched with the 1^{st}, 7^{th}, 8^{th}, and 16^{th} minor frames shown and the remainder described in text. Five major frames constitute a complete dump of the FFT buffer. A complete dump of the Snapshot buffer cannot be similarly represented.

For the purpose of dumping the FFT buffer, five major frames are divided into 10 sets of 8 minor frames, with each set of eight minor frames used to download the 32 spectral estimates contained in F_{xx}, F_{yy}, F_{zz}, R_{xy}, I_{xy}, R_{xz}, I_{xz}, R_{yz}, I_{yz}, and M_g, in that order. Because a full dump of the FFT buffer requires 5 major frames, only the first of the five major frames is shown in complete detail in Table 1. The next 4 major frames are outlined.

The data allocation for the first major frame is given in Table 1 with that frame containing the dump of $F_{xx}^{(1-32)}$ in the first 8 minor frames and $F_{yy}^{(1-32)}$ in the second 8 minor frames. The second major frame is allocated in the same fashion, except that the 32 spectral estimates of spectrum of the z-component, $F_{zz}^{(1-32)}$, occupy bits 217–248 in each of the first 8 minor frames while the 32 spectral estimates of the real part of the x - y correlation, $R_{xy}^{(1-32)}$, occupy the same positions in the second 8 minor frames. Following the first two major frames, $I_{xy}^{(1-32)}$, $R_{xz}^{(1-32)}$, $I_{xz}^{(1-32)}$, $R_{yz}^{(1-32)}$, $I_{yz}^{(1-32)}$, and $M_g^{(1-32)}$ are transmitted in that order using the same 8-minor-frame pattern to download 32 spectral estimates.

The Snapshot buffer of high resolution data is dumped over 340 major frames. The Snapshot buffer data is located in bits 249–296 of each minor frame. All three components of the measured vector are transmitted prior to downloading the next vector in the sequence. This pattern continues until the buffer is emptied. Since a full dump of the Snapshot buffer requires 340 major frames, we can only represent this segment of the telemetry as a sequence of x, y, and z components taken from the sequential 24 v/s measurements. The timing of the individual measurments represents a level of detail not accessible to Table 1.

Status and Housekeeping data are located in bits 297–304. Their meaning is described in a later section. Status and Housekeeping data are used to reconstruct the FFT and Snapshot memory buffers from multiple major frames and they define the state of the instrument. They also monitor the health and operation of the instrument.

The designation of Primary or Secondary sensors in Mode 0 only determines which sensor is used to compute the FFT and fill the Snapshot buffer. In Modes 1 and 2, telemetry is not allocated equally between the Primary and Secondary sensors.

3.2 Mode 1 Telemetry Format

Mode 1 telemetry divides the 216 bit allocation for data averages in a 2/1 ratio between the Primary and Secondary sensors. The format is like that of Mode 0 except for the allocation of primary and secondary data. The 6 vectors are divided into 2 sets of three, with every set of three being 2 Primary vectors followed by 1 Secondary vector. The allocation for FFT buffer, Snapshot buffer, and Status and Housekeeping data is identical to Mode 0. Table 2 shows the detailed data format for Mode 1.

3.3 Mode 2 Telemetry Format

Mode 2 telemetry allocates all 216 bits of averaged data to the Primary sensor. The allocation for FFT, Snapshot buffer, and Status and Housekeeping data is identical to Modes 0 and 1. Table 3 shows the detailed data format for Mode 2.

The data format tables are double width and begin on the next page.

Table 1a: Data Format for Mode 0

Bits	0 to 11	12 to 23	24 to 35	36 to 47	48 to 59	60 to 71	72 to 83	84 to 95	96 to 107	108 to 119	120 to 131	132 to 143	144 to 155	156 to 167	168 to 179	180 to 191	192 to 203	204 to 215
Frame	Data Averages (12 bits/component)																	
0	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z
1	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z
2	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z
3	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z
4	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z
5	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z
6	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z
7	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z
8	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z
9	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z
10	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z
11	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z
12	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z
13	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z
14	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z
15	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z
16	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
23	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z
24	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
31	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z
32	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
39	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z
40	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
47	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z
48	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
55	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z
56	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
63	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z
64	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
71	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z
72	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
79	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	S_x	S_y	S_z

Table 1b: Data Format for Mode 0

Bits	216 to 223	224 to 231	232 to 239	240 to 247	248 to 259	260 to 271	272 to 283	284 to 295	296 to 303
Frame	FFT (8 bits/estimate)				Snapshot (12 bits/component)				Stat/Hous
0	F_{xx}^1	F_{xx}^2	F_{xx}^3	F_{xx}^4	H_x	H_y	H_z	H_x	ST1
1	F_{xx}^5	F_{xx}^6	F_{xx}^7	F_{xx}^8	H_y	H_z	H_x	H_y	ST2
2	F_{xx}^9	F_{xx}^{10}	F_{xx}^{11}	F_{xx}^{12}	H_z	H_x	H_y	H_z	ST3
3	F_{xx}^{13}	F_{xx}^{14}	F_{xx}^{15}	F_{xx}^{16}	H_x	H_y	H_z	H_x	ST4
4	F_{xx}^{17}	F_{xx}^{18}	F_{xx}^{19}	F_{xx}^{20}	H_y	H_z	H_x	H_y	ST5
5	F_{xx}^{21}	F_{xx}^{22}	F_{xx}^{23}	F_{xx}^{24}	H_z	H_x	H_y	H_z	ST6
6	F_{xx}^{25}	F_{xx}^{26}	F_{xx}^{27}	F_{xx}^{28}	H_x	H_y	H_z	H_x	PCTEMP
7	F_{xx}^{29}	F_{xx}^{30}	F_{xx}^{31}	F_{xx}^{32}	H_y	H_z	H_x	H_y	CMON
8	F_{yy}^1	F_{yy}^2	F_{yy}^3	F_{yy}^4	H_z	H_x	H_y	H_z	ST1
9	F_{yy}^5	F_{yy}^6	F_{yy}^7	F_{yy}^8	H_x	H_y	H_z	H_x	ST2
10	F_{yy}^9	F_{yy}^{10}	F_{yy}^{11}	F_{yy}^{12}	H_y	H_z	H_x	H_y	HK1
11	F_{yy}^{13}	F_{yy}^{14}	F_{yy}^{15}	F_{yy}^{16}	H_z	H_x	H_y	H_z	HK2
12	F_{yy}^{17}	F_{yy}^{18}	F_{yy}^{19}	F_{yy}^{20}	H_x	H_y	H_z	H_x	HK3
13	F_{yy}^{21}	F_{yy}^{22}	F_{yy}^{23}	F_{yy}^{24}	H_x	H_y	H_z	H_x	HK4
14	F_{yy}^{25}	F_{yy}^{26}	F_{yy}^{27}	F_{yy}^{28}	H_z	H_x	H_y	H_z	HK5
15	F_{yy}^{29}	F_{yy}^{30}	F_{yy}^{31}	F_{yy}^{32}	H_x	H_y	H_z	ST	SYNC
16	F_{zz}^1	F_{zz}^2	F_{zz}^3	F_{zz}^4	H_x	H_y	H_z	H_x	ST1
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
23	F_{zz}^{29}	F_{zz}^{30}	F_{zz}^{31}	F_{zz}^{32}	H_y	H_z	H_x	H_y	CMON
24	R_{xy}^1	R_{xy}^2	R_{xy}^3	R_{xy}^4	H_z	H_x	H_y	H_z	ST1
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
31	R_{xy}^{29}	R_{xy}^{30}	R_{xy}^{31}	R_{xy}^{32}	H_x	H_y	H_z	ST	SYNC
32	I_{xy}^1	I_{xy}^2	I_{xy}^3	I_{xy}^4	H_x	H_y	H_z	H_x	ST1
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
39	I_{xy}^{29}	I_{xy}^{30}	I_{xy}^{31}	I_{xy}^{32}	H_y	H_z	H_x	H_y	CMON
40	R_{xz}^1	R_{xz}^2	R_{xz}^3	R_{xz}^4	H_z	H_x	H_y	H_z	ST1
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
47	R_{xz}^{29}	R_{xz}^{30}	R_{xz}^{31}	R_{xz}^{32}	H_x	H_y	H_z	ST	SYNC
48	I_{xz}^1	I_{xz}^2	I_{xz}^3	I_{xz}^4	H_x	H_y	H_z	H_x	ST1
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
55	I_{xz}^{29}	I_{xz}^{30}	I_{xz}^{31}	I_{xz}^{32}	H_y	H_z	H_x	H_y	CMON
56	R_{yz}^1	R_{yz}^2	R_{yz}^3	R_{yz}^4	H_z	H_x	H_y	H_z	ST1
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
63	R_{yz}^{29}	R_{yz}^{30}	R_{yz}^{31}	R_{yz}^{32}	H_x	H_y	H_z	ST	SYNC
64	I_{yz}^1	I_{yz}^2	I_{yz}^3	I_{yz}^4	H_x	H_y	H_z	H_x	ST1
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
71	I_{yz}^{29}	I_{yz}^{30}	I_{yz}^{31}	I_{yz}^{32}	H_y	H_z	H_x	H_y	CMON
72	Mg^1	Mg^2	Mg^3	Mg^4	H_z	H_x	H_y	H_z	ST1
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
79	Mg^{29}	Mg^{30}	Mg^{31}	Mg^{32}	H_x	H_y	H_z	ST	SYNC

Table 2a: Data Format for Mode 1

Bits	0 to 11	12 to 23	24 to 35	36 to 47	48 to 59	60 to 71	72 to 83	84 to 95	96 to 107	108 to 119	120 to 131	132 to 143	144 to 155	156 to 167	168 to 179	180 to 191	192 to 203	204 to 215
Frame	Data Averages (12 bits/component)																	
0	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z
1	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z
2	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z
3	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z
4	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z
5	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z
6	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z
7	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z
8	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z
9	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z
10	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z
11	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z
12	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z
13	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z
14	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z
15	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z
16	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
23	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z
24	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
31	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z
32	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
39	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z
40	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
47	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z
48	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
55	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z
56	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
63	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z
64	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
71	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z
72	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
79	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z	P_x	P_y	P_z	P_x	P_y	P_z	S_x	S_y	S_z

Table 2b: Data Format for Mode 1

Bits	216 to 223	224 to 231	232 to 239	240 to 247	248 to 259	260 to 271	272 to 283	284 to 295	296 to 303
Frame	FFT (8 bits/estimate)				Snapshot (12 bits/component)				Stat/Hous
0	F^{1}_{xx}	F^{2}_{xx}	F^{3}_{xx}	F^{4}_{xx}	H_x	H_y	H_z	H_x	ST1
1	F^{5}_{xx}	F^{6}_{xx}	F^{7}_{xx}	F^{8}_{xx}	H_y	H_z	H_x	H_y	ST2
2	F^{9}_{xx}	F^{10}_{xx}	F^{11}_{xx}	F^{12}_{xx}	H_z	H_x	H_y	H_z	ST3
3	F^{13}_{xx}	F^{14}_{xx}	F^{15}_{xx}	F^{16}_{xx}	H_x	H_y	H_z	H_x	ST4
4	F^{17}_{xx}	F^{18}_{xx}	F^{19}_{xx}	F^{20}_{xx}	H_y	H_z	H_x	H_y	ST5
5	F^{21}_{xx}	F^{22}_{xx}	F^{23}_{xx}	F^{24}_{xx}	H_z	H_x	H_y	H_z	ST6
6	F^{25}_{xx}	F^{26}_{xx}	F^{27}_{xx}	F^{28}_{xx}	H_x	H_y	H_z	H_x	PCTEMP
7	F^{29}_{xx}	F^{30}_{xx}	F^{31}_{xx}	F^{32}_{xx}	H_y	H_z	H_x	H_y	CMON
8	F^{1}_{yy}	F^{2}_{yy}	F^{3}_{yy}	F^{4}_{yy}	H_z	H_x	H_y	H_z	ST1
9	F^{5}_{yy}	F^{6}_{yy}	F^{7}_{yy}	F^{8}_{yy}	H_x	H_y	H_z	H_x	ST2
10	F^{9}_{yy}	F^{10}_{yy}	F^{11}_{yy}	F^{12}_{yy}	H_y	H_z	H_x	H_y	HK1
11	F^{13}_{yy}	F^{14}_{yy}	F^{15}_{yy}	F^{16}_{yy}	H_z	H_x	H_y	H_z	HK2
12	F^{17}_{yy}	F^{18}_{yy}	F^{19}_{yy}	F^{20}_{yy}	H_x	H_y	H_z	H_x	HK3
13	F^{21}_{yy}	F^{22}_{yy}	F^{23}_{yy}	F^{24}_{yy}	H_x	H_y	H_z	H_x	HK4
14	F^{25}_{yy}	F^{26}_{yy}	F^{27}_{yy}	F^{28}_{yy}	H_z	H_x	H_y	H_z	HK5
15	F^{29}_{yy}	F^{30}_{yy}	F^{31}_{yy}	F^{32}_{yy}	H_x	H_y	H_z	ST	SYNC
16	F^{1}_{zz}	F^{2}_{zz}	F^{3}_{zz}	F^{4}_{zz}	H_x	H_y	H_z	H_x	ST1
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
23	F^{29}_{zz}	F^{30}_{zz}	F^{31}_{zz}	F^{32}_{zz}	H_y	H_z	H_x	H_y	CMON
24	R^{1}_{xy}	R^{2}_{xy}	R^{3}_{xy}	R^{4}_{xy}	H_z	H_x	H_y	H_z	ST1
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
31	R^{29}_{xy}	R^{30}_{xy}	R^{31}_{xy}	R^{32}_{xy}	H_x	H_y	H_z	ST	SYNC
32	I^{1}_{xy}	I^{2}_{xy}	I^{3}_{xy}	I^{4}_{xy}	H_x	H_y	H_z	H_x	ST1
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
39	I^{29}_{xy}	I^{30}_{xy}	I^{31}_{xy}	I^{32}_{xy}	H_y	H_z	H_x	H_y	CMON
40	R^{1}_{xz}	R^{2}_{xz}	R^{3}_{xz}	R^{4}_{xz}	H_z	H_x	H_y	H_z	ST1
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
47	R^{29}_{xz}	R^{30}_{xz}	R^{31}_{xz}	R^{32}_{xz}	H_x	H_y	H_z	ST	SYNC
48	I^{1}_{xz}	I^{2}_{xz}	I^{3}_{xz}	I^{4}_{xz}	H_x	H_y	H_z	H_x	ST1
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
55	I^{29}_{xz}	I^{30}_{xz}	I^{31}_{xz}	I^{32}_{xz}	H_y	H_z	H_x	H_y	CMON
56	R^{1}_{yz}	R^{2}_{yz}	R^{3}_{yz}	R^{4}_{yz}	H_z	H_x	H_y	H_z	ST1
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
63	R^{29}_{yz}	R^{30}_{yz}	R^{31}_{yz}	R^{32}_{yz}	H_x	H_y	H_z	ST	SYNC
64	I^{1}_{yz}	I^{2}_{yz}	I^{3}_{yz}	I^{4}_{yz}	H_x	H_y	H_z	H_x	ST1
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
71	I^{29}_{yz}	I^{30}_{yz}	I^{31}_{yz}	I^{32}_{yz}	H_y	H_z	H_x	H_y	CMON
72	Mg^{1}	Mg^{2}	Mg^{3}	Mg^{4}	H_z	H_x	H_y	H_z	ST1
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
79	Mg^{29}	Mg^{30}	Mg^{31}	Mg^{32}	H_x	H_y	H_z	ST	SYNC

Table 3a: Data Format for Mode 2

Bits	0 to 11	12 to 23	24 to 35	36 to 47	48 to 59	60 to 71	72 to 83	84 to 95	96 to 107	108 to 119	120 to 131	132 to 143	144 to 155	156 to 167	168 to 179	180 to 191	192 to 203	204 to 215
Frame	Data Averages (12 bits/component)																	
0	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z
1	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z
2	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z
3	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z
4	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z
5	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z
6	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z
7	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z
8	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z
9	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z
10	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z
11	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z
12	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z
13	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z
14	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z
15	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z
16	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
17	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z
18	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
31	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z
32	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
39	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z
40	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
47	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z
48	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
55	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z
56	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
63	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z
64	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
71	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z
72	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
79	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z	P_x	P_y	P_z

Table 3b: Data Format for Mode 2

Bits	216 to 223	224 to 231	232 to 239	240 to 247	248 to 259	260 to 271	272 to 283	284 to 295	296 to 303
Frame	FFT (8 bits/estimate)				Snapshot (12 bits/component)				Stat/Hous
0	F_{xx}^{1}	F_{xx}^{2}	F_{xx}^{3}	F_{xx}^{4}	H_x	H_y	H_z	H_x	ST1
1	F_{xx}^{5}	F_{xx}^{6}	F_{xx}^{7}	F_{xx}^{8}	H_y	H_z	H_x	H_y	ST2
2	F_{xx}^{9}	F_{xx}^{10}	F_{xx}^{11}	F_{xx}^{12}	H_z	H_x	H_y	H_z	ST3
3	F_{xx}^{13}	F_{xx}^{14}	F_{xx}^{15}	F_{xx}^{16}	H_x	H_y	H_z	H_x	ST4
4	F_{xx}^{17}	F_{xx}^{18}	F_{xx}^{19}	F_{xx}^{20}	H_y	H_z	H_x	H_y	ST5
5	F_{xx}^{21}	F_{xx}^{22}	F_{xx}^{23}	F_{xx}^{24}	H_z	H_x	H_y	H_z	ST6
6	F_{xx}^{25}	F_{xx}^{26}	F_{xx}^{27}	F_{xx}^{28}	H_x	H_y	H_z	H_x	PCTEMP
7	F_{xx}^{29}	F_{xx}^{30}	F_{xx}^{31}	F_{xx}^{32}	H_y	H_z	H_x	H_y	CMON
8	F_{yy}^{1}	F_{yy}^{2}	F_{yy}^{3}	F_{yy}^{4}	H_z	H_x	H_y	H_z	ST1
9	F_{yy}^{5}	F_{yy}^{6}	F_{yy}^{7}	F_{yy}^{8}	H_x	H_y	H_z	H_x	ST2
10	F_{yy}^{9}	F_{yy}^{10}	F_{yy}^{11}	F_{yy}^{12}	H_y	H_z	H_x	H_y	HK1
11	F_{yy}^{13}	F_{yy}^{14}	F_{yy}^{15}	F_{yy}^{16}	H_z	H_x	H_y	H_z	HK2
12	F_{yy}^{17}	F_{yy}^{18}	F_{yy}^{19}	F_{yy}^{20}	H_x	H_y	H_z	H_x	HK3
13	F_{yy}^{21}	F_{yy}^{22}	F_{yy}^{23}	F_{yy}^{24}	H_x	H_y	H_z	H_x	HK4
14	F_{yy}^{25}	F_{yy}^{26}	F_{yy}^{27}	F_{yy}^{28}	H_z	H_x	H_y	H_z	HK5
15	F_{yy}^{29}	F_{yy}^{30}	F_{yy}^{31}	F_{yy}^{32}	H_x	H_y	H_z	ST	SYNC
16	F_{zz}^{1}	F_{zz}^{2}	F_{zz}^{3}	F_{zz}^{4}	H_x	H_y	H_z	H_x	ST1
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
23	F_{zz}^{29}	F_{zz}^{30}	F_{zz}^{31}	F_{zz}^{32}	H_y	H_z	H_x	H_y	CMON
24	R_{xy}^{1}	R_{xy}^{2}	R_{xy}^{3}	R_{xy}^{4}	H_z	H_x	H_y	H_z	ST1
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
31	R_{xy}^{29}	R_{xy}^{30}	R_{xy}^{31}	R_{xy}^{32}	H_x	H_y	H_z	ST	SYNC
32	I_{xy}^{1}	I_{xy}^{2}	I_{xy}^{3}	I_{xy}^{4}	H_x	H_y	H_z	H_x	ST1
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
39	I_{xy}^{29}	I_{xy}^{30}	I_{xy}^{31}	I_{xy}^{32}	H_y	H_z	H_x	H_y	CMON
40	R_{xz}^{1}	R_{xz}^{2}	R_{xz}^{3}	R_{xz}^{4}	H_z	H_x	H_y	H_z	ST1
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
47	R_{xz}^{29}	R_{xz}^{30}	R_{xz}^{31}	R_{xz}^{32}	H_x	H_y	H_z	ST	SYNC
48	I_{xz}^{1}	I_{xz}^{2}	I_{xz}^{3}	I_{xz}^{4}	H_x	H_y	H_z	H_x	ST1
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
55	I_{xz}^{29}	I_{xz}^{30}	I_{xz}^{31}	I_{xz}^{32}	H_y	H_z	H_x	H_y	CMON
56	R_{yz}^{1}	R_{yz}^{2}	R_{yz}^{3}	R_{yz}^{4}	H_z	H_x	H_y	H_z	ST1
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
63	R_{yz}^{29}	R_{yz}^{30}	R_{yz}^{31}	R_{yz}^{32}	H_x	H_y	H_z	ST	SYNC
64	I_{yz}^{1}	I_{yz}^{2}	I_{yz}^{3}	I_{yz}^{4}	H_x	H_y	H_z	H_x	ST1
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
71	I_{yz}^{29}	I_{yz}^{30}	I_{yz}^{31}	I_{yz}^{32}	H_y	H_z	H_x	H_y	CMON
72	Mg^{1}	Mg^{2}	Mg^{3}	Mg^{4}	H_z	H_x	H_y	H_z	ST1
$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
79	Mg^{29}	Mg^{30}	Mg^{31}	Mg^{32}	H_x	H_y	H_z	ST	SYNC

3.4 Data Collection Times

The magnetic field is sampled 24 times each minor frame, which is 24 times each second. Each sample contains the full three-component magnetic field vector for both the Primary and Secondary sensors as well as two housekeeping variables, PCTEMP and CMON. These 24 samples are used to construct the Snapshot buffer and averages of these 24 samples are used to compute the data averages, P_x, P_y, P_z, S_x, S_y and S_z. Knowledge of the sampling times are necessary to despin the data. The following table lists the time of each sample in milliseconds following the start of the minor frame.

Time of Sample from Minor Frame Start

Sample #	Time [ms]	Sample #	Time [ms]
1	0	13	500.00
2	41.67	14	541.67
3	83.33	15	583.33
4	125.00	16	625.00
5	166.67	17	666.67
6	208.33	18	708.33
7	250.00	19	750.00
8	291.67	20	791.67
9	333.33	21	833.33
10	375.00	22	875.00
11	416.67	23	916.67
12	458.33	24	958.33

In mode 0 three Primary and three Secondary sensor averages are saved in telemetry. Primary sensor averages are computed by averaging samples 1–8, 9–16 and 17–24. Secondary sensor averages are computed by averaging samples 1–8, 9–16 and 17–24.

In mode 1 four Primary and two Secondary sensor averages are saved in telemetry. Primary sensor averages are computed by averaging samples 1–6, 7–12, 13–18 and 19–24. Secondary sensor averages are computed by averaging samples 1–12 and 13–24.

In mode 2 six Primary and no Secondary sensor averages are saved in telemetry. Primary sensor averages are computed by averaging samples 1–4, 5–8, 9–12, 13–16, 17–20 and 21–24.

The above averages are loaded into the minor frame telemetry sequentially: The average of samples 1–8 in mode 0 become the first Primary sensor average and first Secondary sensor averages in telemetry and occupy bits 0 through 71 of the minor frame. Averages of samples 9–16 are stored in bits 72 through 143, etc.

The time of completion for the sampling the six field components and two housekeeping variables as measured from the start of each sample interval is given below.

Time from Beginning of Sample

Variable	Time [ms]
sensor B_x	0.775
sensor B_y	1.550
sensor B_z	2.325
sensor A_x	3.100
sensor A_y	3.875
sensor A_z	4.650
PCTEMP	5.425
CMON	6.200

The time required to complete the sampling of the above eight items is 6.2 ms. Note that the above references the physical sensors A and B and not whichever is currently determined to be the Primary and Secondary sensors.

4 Status and Housekeeping Definitions

Instrument data processing provides a total of 8 Status bytes and 5 Housekeeping bytes. The status bytes are ST1, ST2, ST3, ST4, ST5, ST6, PCTEMP and CMON. The Housekeeping bytes are named similarly: HK1, HK2, HK3, HK4, and HK5. As seen in Tables 1–3, every Status byte and every Housekeeping byte is transmitted in every major frame of telemetry. Two Status bytes are transmitted twice in a major frame. A breakdown of each Status byte and Housekeeping byte is described below. Status and Housekeeping bytes are found in bits 297–394.

4.1 Status Bytes 1 and 2 (ST1 and ST2)

ST1 is found in minor frames 0 and 8. ST2 is found in minor frames 1 and 9. ST1 and ST2 are transmitted every 8 minor frames to match the rate at which the sensor ranges, calibrations and sensor flips can change. Status bytes ST1 and ST2 are permitted to change within a major frame and the two transmitted values of ST1 and ST2 within each major frame may differ. The Status bytes ST1 and ST2 take the format described below:

Bit Identification for Status Byte ST1

7	6	5	4	3	2	1	0
F_s	S	A	R_2	R_1	R_0	C	EF
Sensor B							

Bit Identification for Status Byte ST2

7	6	5	4	3	2	1	0
M_1	M_0	A	R_2	R_1	R_0	C	EF
Sensor A							

where the individual variable have the following interpretation:

ST1 and ST2 Variable Definitions

F_s = snapshot buffer freeze bit
S = swap bit
A = auto/manual range control bit
R_2, R_1, R_0 = range bits
C = calibration bit
EF = electronic flipper bit
M_1, M_0 = operational mode bits

The A, R_2, R_1, R_0, C, and EF of bits 0–5 of ST1 correspond to sensor *B* operation. Likewise, the A, R_2, R_1, R_0, C, and EF of bits 0–5 of ST2 correspond to sensor *A* operation.

$F_s = 1$ enables the snapshot freeze mode wherein the snapshot buffer is written to and filled one time, then retained and dumped continuously until released by $F_s = 0$ command. $F_s = 0$ corresponds to the normal mode of operation of the snapshot buffer, filling and reading out independently, refilling upon completion of readout. $F_s = 0$ is the default state.

S = 1 indicates the sensor *B* is now the Secondary sensor and sensor *A* is the Primary sensor (i.e., they are swapped relative to the awakened state). S = 0 indicates a 'no swap', or default condition.

A = 1 indicates manual range mode for the relevant sensor; A = 0 indicates auto-ranging in effect. A = 0 is the default state.

R_2, R_1, R_0 provide the 0–7 range value for that sensor, and apply to both manual and auto-ranging modes.

C = 1 indicates calibration is set "on" for that sensor; C = 0 indicates calibration is "off". C = 0 is the default state.

EF = 1 indicates the sensor is flipped (180°); EF = 0 indicates the sensor is in normal position (0°). EF = 0 is the default state.

M_1, M_0 indicate the present operational mode, as follows:

M_1	M_0	MODE
0	0	0
0	1	1
1	0	2
1	1	not used

4.2 Status Byte 3 (ST3)

ST3 occurs in frame 2 only. This status byte ST3 is formatted and defined according to:

Bit Identification for Status Byte ST3							
7	6	5	4	3	2	1	0
CMD	CM_1	CM_0	STR_2	STR_1	STR_0	EVT	RS

where:

ST3 Variable Definitions

CMD = command verification bit
CM_1, CM_0 = last command issued bits
STR_2, STR_1, STR_0 = snapshot trigger identification bits
EVT = snapshsot event/non-event mode bit
RS = snapshot readout start bit

CMD = 1 for one major frame cycle after the receipt and implementation of a spacecraft software command; CMD = 0 otherwise. CM_1, CM_0 specify the last command type issued, as follows:

CM_1	CM_0	CMD TYPE
0	0	minor mode type 0 (MAG configuration)
0	1	minor mode type 1 (FFT configuration)
1	0	memory load process started (data being received)
1	1	memory load process successfully completed

There are two types of minor mode commands: One resets the MAG configuration (sets the Primary sensor, turns on the calibration current, sets the telemetry mode, etc.) while the second resets the FFT configuration (sets the auto-zeroing option, invokes one of several filters, etc.).

The default state of (CM_1, CM_0) after a reset is minor mode cmd (0,0). This is the same state used to signal that the last command was a reprocessing of the MAG configuration. A minor mode (0,1) states that the last command reconfigured the onboard FFT analyzer.

$STR_2 = 1$ when a snapshot event has been triggered by the FFT frequency bins threshold method; $STR_2 = 0$ otherwise. $STR_1 = 1$ when a snapshot event has been triggered by the FFT magnitude ratio threshold method; $STR_1 = 0$ otherwise. $STR_0 = 1$ when a snapshot event has been triggered by the default 8086 threshold method; $STR_0 = 0$ otherwise. It is possible for both STR_2 and STR_1 to be = 1, since they are evaluated on the same data set at the same time during processing.

EVT = 1 signifies the present snapshot data being read out is event data; EVT = 0 signifies non-event data.

RS = 1 marks the first major frame in the 340 major frame sequence that makes up a snapshot buffer readout. RS = 1 for the first major frame only and RS = 0 for the remaining 339 major frames in a snapshot buffer readout.

4.3 Status Byte 4 (ST4)

ST4 occurs in minor frame 3 only. This status byte is formatted and defined according to:

Bit Identification for Status Byte ST4							
7	6	5	4	3	2	1	0
C_3	C_2	C_1	C_0	E_3	E_2	E_1	E_0

The variable quatern of C_3, C_2, C_1, C_0 serves as the 4-bit error counter for processor errors. The variable quatern of E_3, E_2, E_1, E_0 supplies the 4-bit error type that corresponds to the error count. Interpretation of the error type is as follows:

Hex Code Error Types	
01–0A	valid error types
0B–0F	unused
00	No errors
01	Interrupt service routine count incorrect after 1 major frame
02	Snapshot default trigger threshold invalid (must be 00–04 hex); forced to 02 hex (25%)
03	c10 busy port value not 73 dec. during processing (is it lost?)
04	c10 timed out (port value not = 88 dec. after max. time has elapsed)
05	c10 timed out for 4th time; c10 program reloaded from ROM and checksum computed
06	Software command opcode invalid (must be 41-45 hex); command ignored
07	Illegal memory load command address (must be between 0000–23FF or C000–DFFF hex); command ignored
08	Memory load command word count invalid (must be between 1 and 1024 words); command ignored
09	Too many memory load data words for word count; command ignored
0A	Memory load command checksum did not match computed checksum; command ignored

4.4 Status Byte 5 (ST5)

ST5 occurs in minor frame 4 only. This status byte is formatted and defined according to:

Bit Identification for Status Byte ST5							
7	6	5	4	3	2	1	0
RP	S_2	S_1	S_0	F_b	Rg	Rf	CH

where:

ST5 Variable Definitions

RP = snapshot readout page bit
S_2, S_1, S_0 = snapshot trigger enable/disable bits
F_b = FFT frame bit
Rg = range change during FFT data collection cycle
Rf = ROM bit
CH = C10 program reload checksum bit

RP = 1 signifies the present snapshot read page = 1; RP = 0 signifies snapshot page 0. Two physically distinct Snapshot memory buffers exist within the instrument to permit readout of one while recording on the other. RP is used to determine which buffer, or page, was read out. RP is used primarily for diagnostic purposes.

$S_2 = 1$ denotes the snapshot frequency bins threshold trigger is enabled; $S_2 = 0$ signifies the trigger is disabled. $S_1 = 1$ denotes the snapshot magnitude ratio threshold trigger is enabled; $S_1 = 0$ signifies the trigger is disabled. $S_0 = 1$ denotes the snapshot default 8086 method trigger is enabled; $S_0 = 0$ signifies the trigger is disabled.

$F_b = 1$ indicates the first of 5 FFT dataset major frames. $F_b = 0$ indicates any of the remaining 4 of 5 major frames.

Rg = 1 indicates that a range, cal, or EF change to the primary sensor has just occurred at the previous cycle boundary, which is during FFT input data collection; Rg = 0 otherwise. Rg = 1 serves as a notification that a discontinuity may have been introduced into the FFT data set.

4.5 Status Byte 6 (ST6)

ST6 occurs in minor frame 5 only. This status byte is formatted and defined according to:

Bit Identification for Status Byte ST6							
7	6	5	4	3	2	1	0
Ov	Z	F_5	F_4	F_3	F_2	F_1	F_0

where:

ST6 Variable Definitions

Ov = FFT data value overflow bit
Z = FFT X & Y zero values substitution bit
F_5 = FFT data compression type bit
F_4 = FFT frequency bins average /sum bit
F_3 = FFT difference filter enable/disable bit
F_2 = FFT data window type bit
F_1 = FFT dispin matrix normal/inverted bit
F_0 = FFT despin enable/disable bit

Ov = 1 indicates that an overflow condition has occurred during the collection of the FFT dataset currently displayed.

Z = 1 denotes that the substitution of the x- and y-axes zero values into the Pmag portion of the FFT data telemetry output is in effect. Z = 0 indicates no substitution.

$F_5 = 1$ signifies the FFT data output is logarithmically compressed to 8 bits. $F_5 = 0$ indicates the FFT data output is in the '7 LSB's + sign' format. $F_4 = 1$ denotes the contents of the 32 FFT frequency bins are averaged; $F_4 = 0$ signifies the contents of the frequency bins are summed (no average taken). $F_3 = 1$ indicates the application of a first-order difference filter on the FFT input data is enabled; $F_3 = 0$ indicates this option is disabled. $F_2 = 1$ denotes a Hanning window is applied to the FFT input data, while $F_2 = 0$ signifies a 10% cosine taper window is used. $F_1 = 1$ denotes an inverse matrix is used during despinning of the FFT input data. $F_1 = 0$ indicates the normal despin matrix is used. $F_0 = 1$ signifies despinning of the FFT input data is enabled. $F_0 = 0$ indicates this option is disabled.

4.6 PCTEMP and CMON Status Bytes

The PCTEMP and CMON status bytes display the power converter temperature and current monitor reading that is sampled during μP processing. The PCTEMP and CMON status bytes occur in minor frames 6 and 7, respectively. Only the 8 most significant bits of the 12-bit samples are used for PCTEMP and CMON. Truncating the 4 least significant bits of the readings allows for both measurements to fit into two 8-bit status bytes, while still retaining acceptable resolution. Values range from 0 to 255.

4.7 Housekeeping Byte 1 (HK1)

HK1 serves as an 8-bit software command counter. It is found in minor frame 10 in every major frame. The HK1 counter is incremented each time a minor mode or memory load software command is received and properly executed. It represents one form of feedback that a command was received and acted upon.

4.8 Housekeeping Byte 2 (HK2)

HK2 holds the default 8086 method Snapshot trigger percentage (DEFTHRS). It is found in minor frame 11. The HK2 Housekeeping byte is a μP parameter table value which ranges from 00 to 04 hex, and corresponds to the number of internal right shifts on the previous peak data necessary to achieve the desired percentage variation above or below the previous peak. The default threshold values and corresponding percentages are as follows:

DEFTHRS	= 00	100%	(no shift)	
	= 01	50%	(1 shift)	
	= 02	25%	(2 shifts)	(default from reset)
	= 03	12.5%	(3 shifts)	
	= 04	6.25%	(4 shifts)	

4.9 Housekeeping Byte 3 (HK3), Byte 4 (HK4) and Byte 5 (HK5)

HK3, HK4 and HK5 together form the 24-bit major frame counter. The 8 bit housekeeping variable HK3, which is located in minor frame 12, contains the 8 most-significant bits of the 24 bit major frame count generated by the MAG instrument. HK4, which is located in minor frame 13, contains the intermediate byte of the counter. HK5, which is located in minor frame 14, contains the low byte of the counter.

This counter is initiated to zero during μP post-reset processing. The count is incremented at the start of a new telemetry major frame.

4.10 ST and SYNC Bytes

ST is located in minor frame 15 and is a 12 bit word giving the snapshot status. Bits 11–9 give the last 3 bits of the major frame number of when the previous snapshot data vector was sampled (decimal values = 0 to 7). Bits 8–5 give the minor frame number (decimal values = 0 to 15), while bits 4–0 give the interrupt number within the minor frame (decimal values 0 to 23).

The SYNC byte is located in minor frame 15 and is the end-of-a-major-frame sync. It is the last byte in every major frame. It's value = E9 hex.

5 Default State (Awakening State)

The ACE MAG instrument awakens in a fully functional state once power is supplied to the instrument. No initialization commands are required. That state is defined to be:

- Telemetry Mode 0 with 3 vectors/second averages downloading from each of the two magnetometer sensors.

- Instrument in autoranging state, not fixed range.
- Sensor B serves as Primary sensor supplying measurements to the FFT and Snapshot buffers.
- Snapshot buffer filling and holding contents in normal operational mode (snapshot freeze disabled).
- Calibration current is off.
- Electronic flipper is off, or in normal operating position.

This state is equivalent to the MSTR_RESET command listed in the Command Dictionary and defines the default state of the instrument.

In order to capture the MAG boom release in the Snapshot buffer, it is necessary to activate the SNAP_FREEZ command. This will then begin filling the Snapshot buffer, overwriting the preexisting contents, until the buffer is filled. The Snapshot buffer is then preserved for multiple telemetry readouts until freed by the SNAP_NORM command for normal operation.

The ACE MAG instrument MFI has redundant processors, and **only one processor may be powered by the spacecraft at any given time**. Processor selection in no way effects the performance of the instrument, unless one processor should fail or malfunction. The data telemetry formats are uneffected by processor selection. All commands given in the Command Dictionary apply to the operation of either processor.

6 Health and Safety Monitoring

Health and Safety Monitoring is limited to 6 variables. Four are analog channels contained within the spacecraft engineering data and these are the two sensor temperatures and the two heater power levels. The final two variables are contained within the instrument data stream. These are variables PCTEMP, the power converter temperature, and CMON, the current monitor. The latter two digitized numbers are 12 bit values truncated to the leading 8 bits and saved as the last byte in minor frames 6 and 7 of every major frame of MAG telemetry.

Red/yellow alarm limits have been determined for each of the six monitored variables and are given in the following table. In the case of sensor heater power, only upper limits will be required. Alarm limits will be the same for both the MOC and I&T processing. No delta limit processing is presently anticipated. No special instrument alarm processing requirements are anticipated that cannot be achieved with limit processing.

Alarm Processing Parameters

	Red-Low	Yellow-Low	Yellow-High	Red-High
Sensor A Temp (°C)	$-30°$	$-25°$	$55°$	$60°$
Sensor B Temp (°C)	$-30°$	$-25°$	$55°$	$60°$
Sensor A Heater (Watts)	NA	NA	1.0	1.1
Sensor B Heater (Watts)	NA	NA	1.0	1.1
PCTEMP (°C)	$-10°$	$-5°$	$45°$	$50°$
CMON (mAmps)	0	10	90	100

All limits are valid only with power on.

Two distinct sets of Red-High limit responses are requested, depending upon the parameter monitored. The Red-High limit response for Sensor A and B Temperatures, PCTEMP and CMON is (1) turn off the instrument and (2) notify the MAG team. The Red-High limit response for Sensor A and B Heater power is simply to (1) notify the MAG team (do not turn off the MAG instrument for Red-High limits of Sensor Heater power).

The proper response for Red-Low limits is (1) turn off the instrument and (2) notify the MAG team. (Note that Red-Low limits are not applicable to Sensor Heater power.)

The computation of the sensor temperatures from the applied voltage uses a linear expression with parameters that vary with each sensor. The parameters are determined empirically in thermal vacuum. The expressions are:

$$\begin{aligned}\text{Sensor } A \text{ Temp } [^\circ\text{C}] &= [\text{Analog Signal } (0 - 5\text{Volts})] \times 23.83 - 42.6\\ \text{Sensor } B \text{ Temp } [^\circ\text{C}] &= [\text{Analog Signal } (0 - 5\text{Volts})] \times 25.44 - 48.4\end{aligned}$$

As stated earlier, Sensor A is intended to be mounted on the –Y-axis of the spacecraft while Sensor B is expected to be mounted on the +Y-axis.

The heaters will range in value from 0 to 1 watt in normal operation: In full sun the heaters should be off while they will draw 1 watt (5 volts) if the spacecraft is in shadow for an extended period of time. The Yellow-High limit will be achieved if the spacecraft enters Earth shadow, but extended output at the Red-High limit indicates a malfunction of the heater circuitry. The heater power can be expected to achieve the Yellow-High limit during thermal vacuum testing of the spacecraft. The conversion of the measured analog voltage to heater power is performed in the same manner for both heaters according to:

$$\text{Sensor Heater [Watts]} = 0.004 \times [\text{Analog Signal } (0 - 5\text{Volts})].$$

Conversion of the telemetry variable PCTEMP to physical units is dependent upon which side of the processor is active. The conversion is accomplished by the following formulae:

$$\text{Side A Power Converter Temperature } [^\circ\text{C}] = 0.4829 \times [\text{PCTEMP } (0 - 255)] - 43.8$$

$$\text{Side B Power Converter Temperature } [^\circ\text{C}] = 0.5330 \times [\text{PCTEMP } (0 - 255)] - 54.5.$$

Conversion of the telemetry variable CMON to physical units is also dependent upon which side of the processor is active. The conversion is accomplished by the following formulae:

$$\text{Side A Current Monitor [mAmps]} = 1.96 \times [\text{CMON } (0 - 255)] - 244.7$$

$$\text{Side B Current Monitor [mAmps]} = 1.35 \times [\text{CMON } (0 - 255)] - 150.5.$$

Any one of the three methods for engineering unit conversion of analog parameters (linear interpolation, polynomial conversion, and table lookup) should be adequate for the MAG instrument, but the above formulas are minor simplifications of reality in order to more simply facilitate conversion. We do not anticipate any elaborate algorithms for variable conversion beyond simple polynomial conversion.

No decommutation of telemetry is needed beyond (1) the need to obtain the minor frame count for obtaining PCTEMP and CMON, and (2) whatever requirements are placed on monitoring the four analog signals within the spacecraft engineering data.

7 Sensor Mounting and Alignment Information

Once received on ground according to the formats described in this document, the data must be converted from 12 bit values (8 bits in the case of the FFT buffer) to digital values representing the physical measurement. The offsets of the measurements must be computed and applied to the data, the mounting orientation of the sensors must be taken into account, the alignment matrix for the sensors must be applied to convert the measurements into spacecraft coordinates and the data must be despun. This section describes how those tasks are accomplished.

7.1 Sensor Mounting Information

The two sensor are mounted on boom extending along the $\pm Y$ axes of the spacecraft to a distance of 165 inches (4.2 meters) from the center of the spacecraft. Sensor A is mounted on the -Y boom and sensor B is mounted on the +Y boom. Both sensors are mounted so that the +Z axis of the sensor is directed along the +Z axis of the spacecraft and sensor B is mounted so that sensor axes X and Y are aligned with the corresponding spacecraft axes, subject to mounting errors and uncertainties. Sensor A is mounted so that axes X and Y are rotated 180° relative to the corresponding spacecraft axes. A more precise mounting orientation and the mounting alignment matrix will be determined prior to flight.

7.2 Sensor Alignment Information

The sensor alignment must be addressed at two points in the construction of the spacecraft. First, alignment of the 3 sensor axes within each sensor must be determined. Although the goal is to produce 3 sensor axes at right angles to each other, a perfectly orthogonal sensor is never achieved. These alignment matrices remain TBD at this time.

Second, alignment of the sensor with the spacecraft axes must be determined. While preliminary values will be determined at the time that the MAG booms are installed on the spacecraft for the final time, the final orientation of the sensors will not be determined until after launch. Therefore, these matrices also remain TBD.

7.3 Primary and Secondary Sensor Calibration

The digital telemetry format for the Primary and Secondary sensor data and Snapshot data requires conversion to physical units. The conversion parameters are range dependent and are determined empirically during calibration of the instrument in the GSFC magnetics facility. Each sensor axis of each sensor requires individual calibration. The ideal, or theoretical, measurement range for each specified range of the instrument is given below.

Idealized Sensor Ranges	
Instrument Range	Measurement Range
0	± 4 nT
1	± 16 nT
2	± 64 nT
3	± 256 nT
4	± 1024 nT
5	± 4096 nT
6	± 16,384 nT
7	± 65,536 nT

There is no sign bit in the telemetry data so that the measured value of zero falls approximately midway in the range of digital values for the 12 bit number. Simple linear interpolation of the digital values, scaled by the measurement range provides the measured magnetic field component.

Actual conversion requires that each sensor axis be calibrated following fabrication. That calibration is range dependent and specific to each sensor axis. The calibration parameters follow.

Conversion from raw telemetry values to physical units is accomplished by the following formula:

$$\text{Magnetic Field Component [nT]} = (\text{Telemetry Count} - B_i^{zero}) \times \Delta B_i^{slope}$$

where the telemetry count may be a 12 bit value from the Primary or Secondary sensor averages or a 12 bit snapshot value. B_i^{zero} is the raw telemetry value corresponding to the zero field. In an idealized sensor this would be 2048, $\frac{1}{2}$ of the full range of the 12 bit value, but in reality it varies. ΔB_i^{slope} the scaling parameter from raw telemetry to nanoTeslas for the i^{th} component of the sensor in question. The measured values of the zeroes and slopes are given below.

Measured Sensor Zeroes

	Sensor A (x,y,z)			Sensor B (x,y,z)		
Range	B_x^{zero}	B_y^{zero}	B_z^{zero}	B_x^{zero}	B_y^{zero}	B_z^{zero}
0	0992	2480	2107	1408	2112	2234
1	1779	2154	2061	1811	1810	2089
2	1999	2087	2062	2022	2007	2066
3	2035	2057	2051	2040	2037	2051
4	2066	2064	2064	2059	2063	2072
5	2052	2052	2052	2051	2051	2053
6	2067	2060	2063	2062	2067	2072
7	2052	2051	2051	2051	2052	2053

Measured Sensor Slopes

	Sensor A (x,y,z)			Sensor B (x,y,z)		
Range	ΔB_x^{slope}	ΔB_y^{slope}	ΔB_z^{slope}	ΔB_x^{slope}	ΔB_y^{slope}	ΔB_z^{slope}
0	0.002024975	0.0020245513	0.002016807	0.001953125	0.001953125	0.002048765
1	0.00792668	0.007976072	0.00789474	0.0078125	0.0078125	0.007928642
2	0.0321884	0.3262643	0.0321285	0.03125	0.03125	0.032208712
3	0.126678	0.1282709	0.126678	0.125	0.125	0.127356088
4	0.50075	0.501756	0.49975	0.5	0.5	0.500713517
5	1.969996	1.972873	1.969473	2	2	1.97872866
6	8.01402	8.0402	7.996	8	8	8.0100125
7	31.5457	31.5789	31.4796	32	32	31.678986

From the above parameters the true range limits for each sensor can be determined if desired by using the above equation and noting that the 12 bit telemetry value can vary from 0 to 4096.

8 FFT Buffer Decompression and Analysis

For the covariance matrix terms, the phase shift due to the lagging window have no effect, since the covariance matrix retains only the differences in phase among the x, y, and z terms. For the magnitude series however, if the magnitudes were not squared before summing in frequency, the phase shift will, under certain circumstances, cause the sums to collapse.

8.1 Square Root

Whenever two numbers are multiplied, the dynamic range (the ratio of the largest number that can be represented to the smallest) of the product will be greater than either multiplicand. The covariance computations contain products, where the multiplicands have a dynamic range of 22 bits, but will be accurate to only 11 bits plus a sign, just as the original values were. Since it is unacceptable to send 22 bits down to the ground when only 11 of these bits are accurate, the square root of the product is used.

The square root of the product is as good a representation of the product as the product itself, and the dynamic range is reduced to that of the original multiplicands, that is, 11 bits, all of which are accurate.

The multiplicands in the covariance computations are contained in single 16-bit words in the TMS320C10's memory. The products are stored in 32 bit double words and the compression in frequency is carried out using 32-bit operations. The square-root operation reduces the amplitudes so they can be stored in single 16-bit words again.

8.2 Renormalization (Averaging)

If the energy in the input signal is equally divided in frequency, the logarithmic frequency scale will show an exponential increase in energy as frequency increases since more and more frequencies are summed. Like multiplication, the sum of two numbers also has a greater dynamic range than the numbers summed, so it is possible to overflow the allotted dynamic range. To renormalize or "whiten" the frequency scale and at the same time prevent overflows, an option is available to divide each compressed frequency bin by the number of FFT frequencies summed to create it. At the same time, the data of interest is expected to be relatively small; so small that even summing large numbers of FFT frequencies may not overflow the 11 bits of dynamic range allotted. Scaling by the number of FFT frequencies summed might reduce the data below the lowest resolvable level. Either case is covered by the option to renormalize.

When the F_4 bit of Status byte ST6 = 1, each compressed frequency is divided by the number of FFT frequencies summed to create it. This division should take place before the square root; however, compressed frequency bins are instead divided by the square root of the number of FFT frequencies summed after the square-root operation, which mathematically has the same effect as dividing by the number of FFT frequencies before the square root. The scale reduction mentioned above is removed by shifting the data back to the left three bit positions.

8.3 Frequency Trigger

The frequency trigger attempts to detect wide-band disturbances in the data by monitoring three well-spaced FFT frequencies for excessive energy levels. If in the magnitude data, all three FFT frequencies exceed their preset thresholds, then the frequency trigger bit is set.

The three threshold values are 8-bit unsigned values, while the data to which it is being compared are 11 bits long plus a sign bit. The thresholds are doubled (shifted left one bit) prior to comparison so that the maximum threshold is one-fourth of full scale. Since the magnitude spectrum was squared, the magnitude data will always be positive.

8.4 Amplitude Compressions

To further reduce the amount of data sent to the ground, the amplitudes of the compressed frequency bins are compressed using one of two methods: μ-law and 7-LSB. Both methods reduce the amplitudes to seven bits plus a sign bit. A single bit in the Status byte ST6, F_5, determines which method was used. If $F_5 = 1$, the μ-law method is used; if $F_5 = 0$, the 7-LSB method is used.

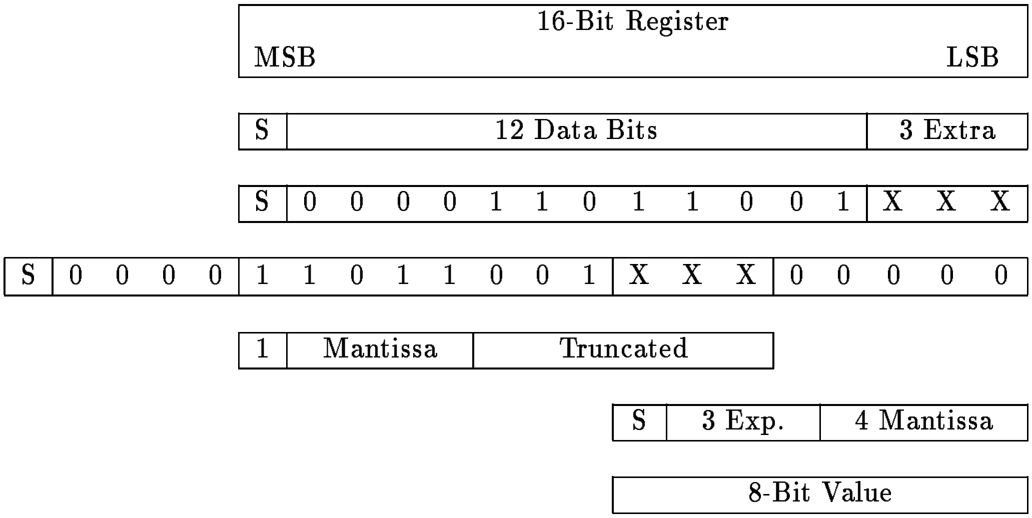
8.5 μ-Law Compression

The μ-law compression scheme is a piece-wise linear approximation to the standard μ-255 companding law used in telecommunications and it is almost an exact implementation of the μ-law companding standard given in CCITT Recommendation G.711, Pulse Code Modulation of Voice Frequencies. μ-255 companding transmits the base-256 logarithm of a number instead of the number itself, to keep the percentage error (and signal-to-noise ratio) relatively constant over a wide range of input amplitudes. 13-bit signed numbers are compressed to eight-bit signed μ-255 code words.

The compression algorithm might best be explained using an example. As in the first step of the diagram, all numbers start out as the contents of a 16-bit register. The upper 13 bits are compressed; the lower three are truncated. The most significant bit in the register reflects the sign of its contents. This sign bit, S, is copied into the most significant bit of the compressed code word. The contents of the register are now replaced with their absolute value, since the sign has been saved, and the sign bit is discarded by shifting each bit left one position, as shown in the second step.

The third step is to shift the contents left, bit-by-bit, until the most significant bit becomes a 1 (or equivalently, the contents of the register appear negative). The number of shifts required for this to happen is subtracted from seven, and saved as the exponent in the code word. As will be explained below, a 1 bit must be found, and since the number of shifts will be encoded into a three-bit-wide exponent field in the code word, it must be found within zero to seven bits.

μ-Law Amplitude Compression



The five most significant bits in the register are the mantissa, but since the most significant bit is guaranteed to be a 1, there is no need to store it in the code word. It is the "implied bit", and during decompression, it is re-appended to the upper end of the mantissa. Requiring this 1 bit to be found in zero to seven shifts allows the five-bit mantissa to be stored in the four-bit-wide mantissa field.

If the number initially stored in the register is small enough, a 1 bit won't be found in zero to seven shifts. To ensure that one will be found, a bias is added to the register's contents before compression begins. This bias is just large enough to provide the needed 1-bit when the original contents are zero. This bias is 128 (or 80 hex) to be added to the register, or, 16 (or 10 hex) to be added to the 13 bits of data. If the initial number is already close to the maximum the register can hold, the bias cannot be added. If this occurs, the contents are replaced with the largest number the register can hold. The error introduced by this saturation, as compared to the error due to the compression, is insignificant. It's a very small loss compared to the gain of another bit of accuracy in the uncompressed word.

All bits beyond the mantissa are truncated as shown in the last step. During decompression, these bits are assigned a value equal to the mid-point of all possible values they might have had. This gives the truncation error a zero-mean.

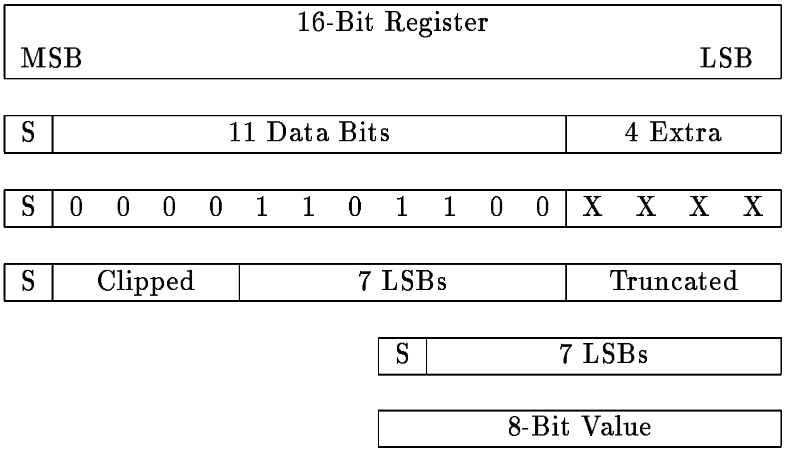
The sign bit, the number of shifts, and the mantissa are put together to form the code word. The number of shifts corresponds to the slope of a line in the piece-wise linear approximation, and the mantissa corresponds to the slope of a line in the piece-wise linear approximation, and the mantissa corresponds to how far along the line the point is. The only difference between this implementation and the CCITT G.771 implementation is in the bias. The CCITT G.711 μ-law companding standard, and the corresponding algorithm, use a bias of 16.5 to ensure a zero-level output when the input is less than one. This reduces the noise at the output when the input is near zero (idle channel noise), but it distorts the quantizer's characteristic. Since the noise is not a concern here, the correct bias of 16 was used.

Another way of looking at this process is as a conversion from a fixed-point format to a floating-point format; and as in most floating-point formats, there is a distinction between positive and negative zero.

8.6 7-LSB Compression

The data is expected to be very low in amplitude and therefore the full dynamic range of the registers may never be used. When this is the case, it would be better to send as many of the least significant bits as possible and retain their full accuracy. This is what the 7-LSB compression scheme does.

7-LSB Amplitude Compression



Since the data is only accurate to 11 bits, the lower seven of the 11 most significant data bits are saved in the compressed code word, as in the third step above. If the value in the register goes beyond these seven bits, then all 1s are stored in the 7-LSB field in the code word. The compressed value saturates at 7F hex. The sign bit is always saved, just as in the μ-law compression, and the four least significant bits in the original 16-bit word are truncated.

8.7 Output Formatting for Auto-Zero Option

The three highest-frequency magnitude terms (M_g^{29}, M_g^{30} and M_g^{31}) are overwritten with the 12-bit mean field values for the x- and y-axes when the auto-zeroing option is enabled (when Z = 1 in ST6). Since the TMS320C10 manipulates words, not bytes, two compressed-frequency values are combined to make a word. The lower frequency goes in the high byte of the word and the higher frequency goes in the lower byte.

8.8 Decompression

The μ-law decompression algorithm is much more straightforward than the compression algorithm. To decompress any μ-law compressed code word, substitute the values from the three fields into the equation below, where S is the sign field, M is the mantissa field, and E is the exponent field:

$$\mu - \text{law decompressed value} = \frac{(-1)^S \cdot \left[(16 + M + 0.5) \cdot 2^E - 16\right]}{2}.$$

The 16 added to the mantissa is the implied bit. The 0.5 factor added to the mantissa gives the decompressed value a zero-mean error. The 16 was the bias added to the original number before compression to ensure that the algorithm would work, so it is subtracted here. The μ-law compresses 12-bit plus sign numbers. Since the original data was only accurate to 11 bits, the decompressed value is divided by two.

If the sign field contains a zero, the value is positive; if it contains a one, the value is negative. Notice that the decompressed value 0 can be either positive or negative, corresponding to very small positive or negative values being truncated to zero by the compression algorithm.

There is no need for a 7-LSB decompression algorithm; the number returned is not actually compressed, but is simply limited to the range -127 to $+127$. Numbers outside this range will be compressed to ± 127, and will be unrecoverable.

It is not possible to decompress the frequency scale and go back to a linear frequency scale again. If the power spectrum is desired, each term from the spectral matrix will have to be squared. Dynamic range considerations made it necessary to return the energy spectrum, not the power spectrum. The center frequencies of the logarithmically scaled spectral estimates can be computed using the table presented earlier.

9 Browse File Description

Averages of the Primary sensor observations computed at several pre-determined resolutions and associated power spectragrams will constitute the browse file data for the MAG instrument.

The time-resolution of the browse file data remains TBD, but will approximate minute, hourly, and daily averages of the IMF. Data will be provided in spacecraft inertial and heliographic (RTN) coordinates and may be provided in other coordinate systems if the ACE project commits to providing the necessary rotation matices and ephemeris.

Coodination of MAG averaging intervals with SWEPAM instrument browse data is possible.

Automated badpoint filtering of browse data is planned.

Color spectragrams are planned and may vary in frequency interval depending on the length of time represented. Nominally, individual daily spectragrams may represent fluctuations with periods between seconds and minutes while weekly spectragrams may represent periods between minutes and hours.

10 Level 1 Processing

We define the following: Level 0 MAG data is data as transmitted by the MAG instrument to the spacecraft. No analysis has been performed on this data except for the extraction of this data from the overall ACE telemetry stream and time ordering of the telemetry into the proper time sequence as provided to the spacecraft by the instrument. The database pointers to associated engineering data may be inserted at this time. Level 1 MAG data is the product of health and safety monitoring, offset-correction, sensor-alignment rotation, conversion to physical units, rotation to heliospheric inertial coordinates, interpretation of data quality flags, and the organization of buffer dumps into self-contained logical units in the data base when operating upon Level 0 data.

We consider it imperative that Level 0 data be transmitted to the Bartol Research Institute along with the Level 1 product without requiring reversable Level-1-to-Level-0 analyses to produce the original instrument data. This data will be used to check offsets, instrument performance, and general data quality and must be reliably obtained without post-processing intervention. If reprocessing of the data is required for any reason, that reprocessing will begin with the Level 0 data.

10.1 Level 1 Product

Sequencing of the Primary and Secondary data averages according to the time when the measurement was made is desired. The time tag for data trasmission to ground may also be useful, but reconstruction of the measurement time is essential. During every minor frame the instrument sends to the spacecraft those measurements made at prescribed times during the previous minor frame where the measurement times are determined by a clock that is internal to the instrument and synchronized to the spacecraft sun pulse. The data collection time is dependent on the instrument's operating mode. If each minor frame dump is time-tagged with the minor frame count, the time of each measurement can be reconstructed. A time tag for each minor frame should be sufficient to reconstruct the time of each measurement.

The Status and Housekeeping data contained in a given major frame describes the instrument's state in that same major frame and are sampled at the beginning of the major frame. Status and Housekeeping information should be retained within the associated major frame data. For this reason, the minimum logical entry in the ACE MAG database of Primary and Secondary averages might be a major frame of data so as to minimize redundant storage of the Status and Housekeeping bits. A shift of 1 minor frame to sychronize data averages with the associated Status and Housekeeping bits is TBD.

FFT and Snapshot buffer dumps should be decommuted from multiple major frames and each should be saved as individual items in the ACE database. The individual minor frame time tags must be preserved with the Snapshot buffer dump so that range changes, instrument states, spacecraft rotation phase, etc. as represented in the engineering data and Status and Housekeeping bits can be reconstructed for the period captured in the buffer. Snapshot buffers require health and safety monitoring, offset-correction, sensor-alignment rotation, conversion to physical units, rotation to heliosperic inertial coordinates and interpretation of data quality flags in the same manner as do Primary and Secondary data. Similar reconstruction of Status and Housekeeping data is desirable for the FFT buffer, but dedicated Status bits will determine whether range changes, etc. occured during the collection and averaging period of the FFT buffer. FFT measurements require only that FFT-specific quality flags be checked, the data decompressed and converted to physical units, and rotation from the spacecraft inertial frame to a heliospheric inertial frame.

At the present time, the MAG instrument does not provide a time tag for the Snapshot buffer data capture. The time associated with these measurements is provided by comparing the Snapshot buffer with the Primary and Secondary data stream. An independent time tag may be provided as the instrument is reprogrammed during the coming year. Minimally, the time associated with the first minor frame of the buffer dump must be retained in the Level 0 to Level 1 processing.

The four MAG analog channels carried by the spacecraft (2 sensor temperatures and 2 heater power levels) will be needed within the Level 0 and Level 1 datasets. For convenience, they might be added to the Status and Housekeeping data in each major frame entry of the database.

The pointing direction of the spacecraft spin axis and the phase angle of the spacecraft's rotation must be available for rotation of the measurement to inertial coordinates.

The time intervals over which the data are segmented for storage as individual items in the database are not presently recognized as an important consideration so long as the necessary information is available for reconstrucing long intervals of data.

Missing data must be determinable so as not to lead to ambiguity regarding the timing or spin phase angle of any measurement. Data flags relating to telemetry errors must be available.

10.2 Level 1 Formats

TBD.

11 Command Dictionary

All MAG instrument commands and memory loads are based on a 40-bit word length. There are no hazardous commands and no commands are capable of placing the instrument into a state which might lead to its destruction. Likewise, no commands can jeopardize the spacecraft or other experiments.

The basic syntax for commands and memory loads consists of an 8-bit opcode prefix starting with the most significant bit in the 40-bit word, followed by 32 bits of data. There are three types of instrument software commands: MAG configuration, FFT configuration, and memory loads. For the MAG and FFT configuration commands, the 8-bit opcode is 41 hex. For memory load commands, the opcodes range from 42 through 45 hex (see memory loads section for more detail). The MAG and FFT configuration commands share the same opcode, but are uniquely recognized by the instrument with the use of the most significant data bit as a qualifier. When this qualifier bit = 0, the command is a MAG configuration command; when this qualifier bit = 1, the command is an FFT configuration command (see following discussions for more detail).

11.1 MAG Configuration Commands

MAG configuration commands control the basic operation of the magnetometer sensors. This includes the determination of which sensor is Primary, whether a calibration current is on, the orientation of an electronic flip, the range of the instrument or whether it is autoranging, etc.

A single MAG configuration command is executed midway through and at the end of every major frame. At least 8 minor frames must elapse between commands in order for both to be executed and 2 MAG configuration commands may be executed in each major frame.

The general structure of a MAG configuration command is as follows:

MSB				LSB
39 32	31 24	23 16	15 8	7 0
01000001	QDDDDDDD	DDDDDDDD	1xxx1xxx	xxxxxxxx

where: x = don't care
D = command data bits
Q = minor mode type qualifier bit = 0

Bits 32 to 39 are the command opcode, 41 hex. Bits 16 to 31 comprise the 16 bits of command data. Bits 11 and 15 must = 1 to prevent invoking a hardware command. Bits 0 to 7 can accept calues 00 through FF hex.

The MAG configure command (type"0" command, or qualifier bit Q = 0) data word syntax is as follows:

MAG Configuration Command Data Word Syntax

MSB															LSB
Bit 15							8	7							0 Bit
0	S	A	R_2	R_1	R_0	C	EF	M_1	M_0	A	R_2	R_1	R_0	C	EF
—— (Sensor B) ——								—— (Sensor A) ——							

where:

S = swap bit
A = auto/manual range control bit
R_2, R_1, R_0 = range bits
C = calibration bit
EF = electronic flipper bit
M_1, M_0 = operational mode bits.

Bit 15 is the qualifier bit for an opcode 41 hex command and is set = 0 for a MAG configuration command.

The A, R_2, R_1, R_0, C and EF variables of bits 8 to 13 correspond to sensor B operation while variables A, R_2, R_1, R_0, C and EF variables of bits 0 to 5 correspond to sensor A operation. The M_1, M_0 variables of bits 6 and 7 indicate the desired operational mode.

All of these bits have been defined in the telemetry section of this document. To briefly review:

- S = 1 indicates that the role of primary sensor is swapped with Sensor A now the primary. S = 0 indicates a "no swap" condition with Sensor B primary.
- A = 1 indicates manual range mode for the MAG instrument, A = 0 indicates auto-ranging is in effect.

- Variables R_2, R_1, and R_0 provide the 0-7 range value and are applicable as commands only when $A = 1$ (manual range mode).
- $C = 1$ indicates calibration is set on; $C = 0$ indicates calibration is off.
- $EF = 1$ indicates the MAG sensor is flipped (180 degrees); $EF = 0$ indicates the MAG sensor is in normal position (0 degrees).
- (M_1, M_0) indicates the instrument telemetry mode according to:

(M_1, M_0)	Mode
(0,0)	0
(0,1)	1
(1,0)	2

It is convenient to think in terms of a default state for the instrument as the state in which the instrument awakens. Commands are described below with mnemonics that assume this default state for functions not otherwise addressed. In reality, all functionality of the instrument is addressed with every command. New commands can be written with other permutations of the instrument's functionality by setting the appropriate bits in the 16 bit command data word.

There is no accumulative effect of multiple commands. For instance, M1_CAL_ON turns on the calibration current and sets the telemetry mode to Mode 1, but does not fix a range, leaving the instrument to autorange since autoranging is thought of as the default state of the instrument's range function. The instrument will autorange regardless of what command preceeded M1_CAL_ON. This command also leaves sensor *B* to serve as the Primary sensor and leaves the electronic flipper in the "off" position. In reality, the M1_CAL_ON command explicitly sets the range feature to autorange, sets the electronic flippers to the normal position, and directs sensor *B* to serve as Primary sensor, but these functions are conveniently thought of as the default state. Likewise, the command M2_A_PRM sets the *A* sensor to the role of primary sensor and the telemetry mode to Mode 2, leaving the autoranging on, the calibration current off, and the electronic flipper off in both sensors.

Logically, the "B" sensor on ACE is equivalent to the outboard sensor on WIND. Therefore, the role of Primary sensor falls to the "B" sensor unless otherwise commanded.

The following is an incomplete listing of the MAG command dictionary. Further documentation will be provided as the mission proceeds. Additional 32 bit command words can be developed using the data fields and their assigned instrument functionality.

MAG Configuration Command Word Examples:

Command Mnemonic	32 bit Command (8 Hex characters)	Action Taken
M0_CNFG_DF	0000FFFF	Mode M0, All Else to Default State
M1_CNFG_DF	0040FFFF	Mode M1, All Else to Default State
M2_CNFG_DF	0080FFFF	Mode M2, All Else to Default State
M0_RANGE_0	2020FFFF	Mode M0, Fixed Range 0
M0_RANGE_1	2424FFFF	Mode M0, Fixed Range 1

M0_RANGE_2	2828FFFF	Mode M0, Fixed Range 2
M0_RANGE_3	2C2CFFFF	Mode M0, Fixed Range 3
M0_RANGE_4	3030FFFF	Mode M0, Fixed Range 4
M0_RANGE_5	3434FFFF	Mode M0, Fixed Range 5
M0_RANGE_6	3838FFFF	Mode M0, Fixed Range 6
M0_RANGE_7	3C3CFFFF	Mode M0, Fixed Range 7
M1_RANGE_0	2060FFFF	Mode M1, Fixed Range 0
M1_RANGE_1	2464FFFF	Mode M1, Fixed Range 1
M1_RANGE_2	2868FFFF	Mode M1, Fixed Range 2
M1_RANGE_3	2C6CFFFF	Mode M1, Fixed Range 3
M1_RANGE_4	3070FFFF	Mode M1, Fixed Range 4
M1_RANGE_5	3474FFFF	Mode M1, Fixed Range 5
M1_RANGE_6	3878FFFF	Mode M1, Fixed Range 6
M1_RANGE_7	3C7CFFFF	Mode M1, Fixed Range 7
M2_RANGE_0	20A0FFFF	Mode M2, Fixed Range 0
M2_RANGE_1	24A4FFFF	Mode M2, Fixed Range 1
M2_RANGE_2	28A8FFFF	Mode M2, Fixed Range 2
M2_RANGE_3	2ACAFFFF	Mode M2, Fixed Range 3
M2_RANGE_4	30B0FFFF	Mode M2, Fixed Range 4
M2_RANGE_5	34B4FFFF	Mode M2, Fixed Range 5
M2_RANGE_6	38B8FFFF	Mode M2, Fixed Range 6
M2_RANGE_7	3CBCFFFF	Mode M2, Fixed Range 7
M0_CAL_ON	0202FFFF	Mode M0, Calib. Current On, (Autorange)
M0_CAL_R0	2222FFFF	Mode M0, Calib. Current On, Fixed Range 0
M0_CAL_R1	2626FFFF	Mode M0, Calib. Current On, Fixed Range 1
M0_CAL_R2	2A2AFFFF	Mode M0, Calib. Current On, Fixed Range 2
M0_CAL_R3	2E2EFFFF	Mode M0, Calib. Current On, Fixed Range 3
M0_CAL_R4	3232FFFF	Mode M0, Calib. Current On, Fixed Range 4
M0_CAL_R5	3636FFFF	Mode M0, Calib. Current On, Fixed Range 5
M0_CAL_R6	3A3AFFFF	Mode M0, Calib. Current On, Fixed Range 6
M0_CAL_R7	3E3EFFFF	Mode M0, Calib. Current On, Fixed Range 7
M1_CAL_R0	2262FFFF	Mode M1, Calib. Current On, Fixed Range 0
M1_CAL_R1	2666FFFF	Mode M1, Calib. Current On, Fixed Range 1
M1_CAL_R2	2A6AFFFF	Mode M1, Calib. Current On, Fixed Range 2
M1_CAL_R3	2E6EFFFF	Mode M1, Calib. Current On, Fixed Range 3
M1_CAL_R4	3272FFFF	Mode M1, Calib. Current On, Fixed Range 4
M1_CAL_R5	3676FFFF	Mode M1, Calib. Current On, Fixed Range 5
M1_CAL_R6	3A7AFFFF	Mode M1, Calib. Current On, Fixed Range 6
M1_CAL_R7	3E7EFFFF	Mode M1, Calib. Current On, Fixed Range 7
M2_CAL_R0	22A2FFFF	Mode M2, Calib. Current On, Fixed Range 0
M2_CAL_R1	26A6FFFF	Mode M2, Calib. Current On, Fixed Range 1
M2_CAL_R2	2AAAFFFF	Mode M2, Calib. Current On, Fixed Range 2
M2_CAL_R3	2EAEFFFF	Mode M2, Calib. Current On, Fixed Range 3

M2_CAL_R4	32B2FFFF	Mode M2, Calib. Current On, Fixed Range 4
M2_CAL_R5	36B6FFFF	Mode M2, Calib. Current On, Fixed Range 5
M2_CAL_R6	3ABAFFFF	Mode M2, Calib. Current On, Fixed Range 6
M2_CAL_R7	3EBEFFFF	Mode M2, Calib. Current On, Fixed Range 7
M0_FLIP_ON	0101FFFF	Mode M0, Electronic Flip On, (Autorange)
M0_FLIP_R0	2121FFFF	Mode M0, Elec. Flip On, Fixed Range 0
M0_FLIP_R1	2525FFFF	Mode M0, Elec. Flip On, Fixed Range 1
M0_FLIP_R2	2929FFFF	Mode M0, Elec. Flip On, Fixed Range 2
M0_FLIP_R3	2D2DFFFF	Mode M0, Elec. Flip On, Fixed Range 3
M0_FLIP_R4	3131FFFF	Mode M0, Elec. Flip On, Fixed Range 4
M0_FLIP_R5	3535FFFF	Mode M0, Elec. Flip On, Fixed Range 5
M0_FLIP_R6	3939FFFF	Mode M0, Elec. Flip On, Fixed Range 6
M0_FLIP_R7	3D3DFFFF	Mode M0, Elec. Flip On, Fixed Range 7
M1_FLIP_R0	2161FFFF	Mode M1, Elec. Flip On, Fixed Range 0
M1_FLIP_R1	2565FFFF	Mode M1, Elec. Flip On, Fixed Range 1
M1_FLIP_R2	2969FFFF	Mode M1, Elec. Flip On, Fixed Range 2
M1_FLIP_R3	2D6DFFFF	Mode M1, Elec. Flip On, Fixed Range 3
M1_FLIP_R4	3171FFFF	Mode M1, Elec. Flip On, Fixed Range 4
M1_FLIP_R5	3575FFFF	Mode M1, Elec. Flip On, Fixed Range 5
M1_FLIP_R6	3979FFFF	Mode M1, Elec. Flip On, Fixed Range 6
M1_FLIP_R7	3D7DFFFF	Mode M1, Elec. Flip On, Fixed Range 7
M2_FLIP_R0	21A1FFFF	Mode M2, Elec. Flip On, Fixed Range 0
M2_FLIP_R1	25A5FFFF	Mode M2, Elec. Flip On, Fixed Range 1
M2_FLIP_R2	29A9FFFF	Mode M2, Elec. Flip On, Fixed Range 2
M2_FLIP_R3	2DADFFFF	Mode M2, Elec. Flip On, Fixed Range 3
M2_FLIP_R4	31B1FFFF	Mode M2, Elec. Flip On, Fixed Range 4
M2_FLIP_R5	35B5FFFF	Mode M2, Elec. Flip On, Fixed Range 5
M2_FLIP_R6	39B9FFFF	Mode M2, Elec. Flip On, Fixed Range 6
M2_FLIP_R7	3DBDFFFF	Mode M2, Elec. Flip On, Fixed Range 7
M0_A_PRM	4000FFFF	Mode M0, A Sensor Set to Primary
M1_CAL_ON	0242FFFF	Mode M1, Calibration Current On, (Autorange)
M1_FLIP_ON	0141FFFF	Mode M1, Elec. Flip On, (Autorange)
M1_A_PRM	4040FFFF	Mode M1, A Sensor Set to Primary
M2_CAL_ON	0282FFFF	Mode M2, Calibration Current On, (Autorange)
M2_FLIP_ON	0181FFFF	Mode M2, Elec. Flip On, (Autorange)
M2_A_PRM	4080FFFF	Mode M2, A Sensor Set to Primary
M0_A_R_0	0020FFFF	Mode M0, A Sensor Only into Fixed Range 0
M0_A_R_1	0024FFFF	Mode M0, A Sensor Only into Fixed Range 1
M0_A_R_2	0028FFFF	Mode M0, A Sensor Only into Fixed Range 2
M0_A_R_3	002CFFFF	Mode M0, A Sensor Only into Fixed Range 3
M0_A_R_4	0030FFFF	Mode M0, A Sensor Only into Fixed Range 4
M0_A_R_5	0034FFFF	Mode M0, A Sensor Only into Fixed Range 5
M0_A_R_6	0038FFFF	Mode M0, A Sensor Only into Fixed Range 6

M0_A_R_7	003CFFFF	Mode M0, A Sensor Only into Fixed Range 7
M1_A_R_0	0060FFFF	Mode M1, A Sensor Only into Fixed Range 0
M1_A_R_1	0064FFFF	Mode M1, A Sensor Only into Fixed Range 1
M1_A_R_2	0068FFFF	Mode M1, A Sensor Only into Fixed Range 2
M1_A_R_3	006CFFFF	Mode M1, A Sensor Only into Fixed Range 3
M1_A_R_4	0070FFFF	Mode M1, A Sensor Only into Fixed Range 4
M1_A_R_5	0074FFFF	Mode M1, A Sensor Only into Fixed Range 5
M1_A_R_6	0078FFFF	Mode M1, A Sensor Only into Fixed Range 6
M1_A_R_7	007CFFFF	Mode M1, A Sensor Only into Fixed Range 7
M2_A_R_0	00A0FFFF	Mode M2, A Sensor Only into Fixed Range 0
M2_A_R_1	00A4FFFF	Mode M2, A Sensor Only into Fixed Range 1
M2_A_R_2	00A8FFFF	Mode M2, A Sensor Only into Fixed Range 2
M2_A_R_3	00ACFFFF	Mode M2, A Sensor Only into Fixed Range 3
M2_A_R_4	00B0FFFF	Mode M2, A Sensor Only into Fixed Range 4
M2_A_R_5	00B4FFFF	Mode M2, A Sensor Only into Fixed Range 5
M2_A_R_6	00B8FFFF	Mode M2, A Sensor Only into Fixed Range 6
M2_A_R_7	00BCFFFF	Mode M2, A Sensor Only into Fixed Range 7
M0_A_CAL	0002FFFF	Mode M0, A Sensor Calib. Current On, (Autorange)
M0_A_FLIP	0001FFFF	Mode M0, A Elec. Flip On, (Auotrange)
M1_A_CAL	0042FFFF	Mode M1, A Sensor Calib. Current On, (Autorange)
M1_A_FLIP	0041FFFF	Mode M1, A Elec. Flip On, (Auotrange)
M2_A_CAL	0082FFFF	Mode M2, A Sensor Calib. Current On, (Autorange)
M2_A_FLIP	0081FFFF	Mode M2, A Elec. Flip On, (Auotrange)
M0_B_R_0	2000FFFF	Mode M0, B Sensor Only into Fixed Range 0
M0_B_R_1	2400FFFF	Mode M0, B Sensor Only into Fixed Range 1
M0_B_R_2	2800FFFF	Mode M0, B Sensor Only into Fixed Range 2
M0_B_R_3	2C00FFFF	Mode M0, B Sensor Only into Fixed Range 3
M0_B_R_4	3000FFFF	Mode M0, B Sensor Only into Fixed Range 4
M0_B_R_5	2400FFFF	Mode M0, B Sensor Only into Fixed Range 5
M0_B_R_6	3800FFFF	Mode M0, B Sensor Only into Fixed Range 6
M0_B_R_7	3C00FFFF	Mode M0, B Sensor Only into Fixed Range 7
M1_B_R_0	2040FFFF	Mode M1, B Sensor Only into Fixed Range 0
M1_B_R_1	2440FFFF	Mode M1, B Sensor Only into Fixed Range 1
M1_B_R_2	2840FFFF	Mode M1, B Sensor Only into Fixed Range 2
M1_B_R_3	2C40FFFF	Mode M1, B Sensor Only into Fixed Range 3
M1_B_R_4	3040FFFF	Mode M1, B Sensor Only into Fixed Range 4
M1_B_R_5	3440FFFF	Mode M1, B Sensor Only into Fixed Range 5
M1_B_R_6	3840FFFF	Mode M1, B Sensor Only into Fixed Range 6
M1_B_R_7	3C40FFFF	Mode M1, B Sensor Only into Fixed Range 7
M2_B_R_0	2080FFFF	Mode M2, B Sensor Only into Fixed Range 0
M2_B_R_1	2480FFFF	Mode M2, B Sensor Only into Fixed Range 1
M2_B_R_2	2880FFFF	Mode M2, B Sensor Only into Fixed Range 2

M2_B_R_3	2C80FFFF	Mode M2, B Sensor Only into Fixed Range 3
M2_B_R_4	3080FFFF	Mode M2, B Sensor Only into Fixed Range 4
M2_B_R_5	3480FFFF	Mode M2, B Sensor Only into Fixed Range 5
M2_B_R_6	3880FFFF	Mode M2, B Sensor Only into Fixed Range 6
M2_B_R_7	3C80FFFF	Mode M2, B Sensor Only into Fixed Range 7
M0_B_CAL	0200FFFF	Mode M0, B Sensor Calib. Current On, (Autorange)
M0_B_FLIP	0100FFFF	Mode M0, B Sensor Elec. Flip On, (Autorange)
M1_B_CAL	0240FFFF	Mode M1, B Sensor Calib. Current On, (Autorange)
M1_B_FLIP	0140FFFF	Mode M1, B Sensor Elec. Flip On, (Autorange)
M2_B_CAL	0280FFFF	Mode M2, B Sensor Calib. Current On, (Autorange)
M2_B_FLIP	0180FFFF	Mode M2, B Sensor Elec. Flip On, (Autorange)

If we combine the command opcode with the 32 bit commands listed above, we can present two examples of a complete MAG instrument configure command:

Using the first command in the library, we set readout mode to M0 and all else to default (M0_CNFG_DF), so that the command is 410000FFFF hex. Likewise, if we wish instead to adopt telemetry mode M2, flip sensor B, and autorange without a calibration current (M2_B_FLIP), the command is 410180FFFF hex.

11.2 FFT Configure Commands

The instrument executes FFT configuration commands at the end of a major frame. Changes specific to FFT data collection are reflected in the first new FFT data set that is acquired after this time.

The general structure of an FFT configuration command is as follows:

MSB				LSB
39 32	31 24	23 16	15 8	7 0
01000001	QDDDDDDD	DDDDDDDD	1xxx1xxx	xxxxxxxx

where: x = don't care
D = command data bits
Q = minor mode type qualifier bit = 1

Bits 32 to 39 are the command opcode, 41 hex. Bits 16 to 31 comprise the 16 bits of command data. Bits 11 and 15 must = 1 to prevent invoking a hardware command. Bits 0 to 7 can accept calues 00 through FF hex.

The FFT configure (type "1", or qualifier bit Q = 1) command word syntax is as follows:

FFT Configuration Command Word Syntax

MSB Bit 15															LSB 0 Bit
1	u	u	u	S_2	S_1	S_0	F_s	u	Z	F_5	F_4	F_3	F_2	F_1	F_0

where:

u = unused bit
S_2, S_1, S_0 = snapshot trigger enable/disable bits
F_s = snapshot freeze command bit
Z = FFT X and Y axis zero values substitution bit
F_5 = FFT data compression type bit
F_4 = FFT frequency bins average/sum bit
F_3 = FFT difference filter enable/disable bit
F_2 = FFT data window type bit
F_1 = FFT despin matrix normal/inverted bit
F_0 = FFT despin enable/disable bit.

Note that the FFT configure command also controls the snapshot trigger operation and snapshot freeze mode.

Bit 15 (the MSB in the command word) is set = 1 for an FFT configure command.

The function of each of these variables is discussed in detail within the telemetry sections of this document. To review briefly:

- Setting any of the S_2, S_1, S_0 = 1 enables the snapshot trigger(s), while any of the bits = 0 disables the trigger. S_2 controls the snapshot frequency bins threshold trigger. S_1 controls the snaphot magnitude ratio threshold trigger. S_0 controls the snapshot default method trigger.
- Setting F_s = 1 enables the snaphot freeze mode while setting the bit = 0 provides normal snapshot buffer operation.
- Setting Z = 1 enables the substitution of the X and Y axis zero values into the Pmag portion of the FFT data telemetry output. Setting Z = 0 disables this option.
- Setting F_5 = 1 causes the FFT data output to be logarithmically compressed to 8 bits. Setting F_5 = 0 causes the FFT data output to be in the '7 LSB's + sign' format.
- Setting F_4 = 1 will result in the contents of the 32 FFT frequency bins being averaged. Setting F_4 = 0 will cause the contents of the frequency bins to be summed, with no average taken (so that small signals can be preserved, averaging here may eliminate the detection of small signals that are present).
- Setting F_3 = 1 enables the implementation of a first-order difference filter on the FFT input data. Setting F_3 = 0 disables this option.

- Setting $F_2 = 1$ causes a Hanning window to be applied to the FFT input data, while setting $F_2 = 0$ causes a 10% cosine taper window to be used.
- Setting $F_1 = 1$ causes the coefficients of the matrix to be inverted, while setting $F_1 = 0$ results in the normal despin matrix used during despinning of the FFT input data.
- Setting $F_0 = 1$ enables the FFT input data to be despun, while setting $F_0 = 0$ disables this option.

As with MAG configure commands, a complete listing of all commands would be too extensive to be practical here. Instead, we list the two commands that freeze and release the snapshot buffer followed by an example of an FFT buffer command.

FFT Configuration Command Word Examples:

Command Mnemonic	32 bit Command (8 Hex characters)	Action Taken
FFT_DFLT	8000FFFF	Sets All FFT Command Function Bits to Zero
SNAP_FREQ	8800FFFF	Enables Shapshot Frequency Bins Threshold Trigger
SNAP_RATIO	8400FFFF	Enables Snapshot Magnitude Ratio Trigger
SNAP_DFLT	8200FFFF	Enables Snapshot Default Method Trigger
SNAP_FREEZ	8125FFFF	Freezes Snapshot Buffer Overwrite to Capture Deployment
SNAP_NORM	8E25FFFF	Returns Snapshot Buffer to Triggered Overwrite
FFT_ZERO	8040FFFF	Substitutes X,Y Axis Zeroes in Pmag
FFT_LOG	8020FFFF	Enables FFT Log Compression
FFT_AVG	8021FFFF	Enables FFT Bin Averaging
FFT_DIFF	8008FFFF	Enables FFT First-Order Difference Dilter
FFT_HANN	8004FFFF	Enables FFT Hanning Window
FFT_INV	8002FFFF	Enables FFT Matrix Coefficient Inversion
FFT_DSPN	8001FFFF	Enables Despinning of FFT

As a further example of a compound FFT configure command addressing several functions of the FFT buffer, we may select to enable the snapshot magnitude ratio trigger ($S_1 = 1$), disable the other two snapshot triggers (S_2 and $S_0 = 0$), disable the snapshot freeze ($F_s = 0$) so that the snapshot buffer fills and downloads automatically, disable the FFT X and Y axis zero value substitution ($Z = 0$), adopt the FFT logarithmic compression scheme ($F_5 = 1$), average the contents of the 32 FFT frequency bins ($F_4 = 1$), disable the first-order difference filter ($F_3 = 0$), enable the Hanning window ($F_2 = 1$), adopt the inverse matrix for despinning ($F_1 = 1$), and enable the despinning algorithm ($F_0 = 1$). The resulting binary code is: "`01000001 1xxx0100 x0110111 1xxx1xxx xxxxxxxx`" where "x" can be either "0" or "1". If we take all x = 1, the resulting hex command is 41F4B7FFFF hex but this hex form is not unique since 18 binary values are unprescribed.

11.3 Memory Load Commands

There are four types of commands associated with a memory load procedure: a memory load *start* command, a memory load *word count* command, a memory load *data* command, and a memory load *checksum* command. The memory load start command is used once to start the memory load process, and supplies the start address of where to load into memory the data that follows. The memory load word count command is uploaded next, and contains the number of command data words that are to be transferred. The memory load data command is used as many times as necessary to send the desired block of data, containing 16 bits of data for each command transfer. The memory load checksum is the final command of the memory load procedure, and contains the 16-bit checksum of the preceeding start address, word count, and data words that were transferred.

The memory load *start* command format is as follows:

MSB				LSB
39 32	31 24	23 16	15 8	7 0
01000010	SSSSSSSS	SSSSSSSS	xxxxxxxx	xxxxxxxx

where: x = don't care
S = memory load start address bits

Bits 32 to 39 are the memory load start command opcode, 42 hex. Bits 16 to 31 are the 16-bit RAM memory load address. Bits 0 to 15 are not used and can accept values 00 through FF hex. Valid memory load addresses are as follows:

0000–33FF hex	contains interrupt vectors, μP parameter tables, μP scratchpad, and free space.
C000–DFFF hex	contains C10 program and C10 parameter tables.

The memory load *word count* command format is as follows:

MSB				LSB
39 32	31 24	23 16	15 8	7 0
01000011	CCCCCCCC	CCCCCCCC	xxxxxxxx	xxxxxxxx

where: x = don't care
C = memory load word count bits

Bits 32 to 39 are the memory load word count command opcode, 43 hex. Bits 16 to 31 are the 16-bit memory load word count of the data words only. Bits 0 to 15 are not used and can accept values from 00 through FF hex. Valid memory load word counts are from 1 to 1024 per memory load transfer procedure.

The memory load *data* command format is as follows:

MSB				LSB
39 32	31 24	23 16	15 8	7 0
01000100	DDDDDDDD	DDDDDDDD	xxxxxxxx	xxxxxxxx

where: x = don't care
D = memory load data bits

Bits 32 to 39 are the memory load data command opcode, 44 hex. Bits 16 to 31 are the 16-bits of load data. Bits 0 to 15 are not used and can accept values from 00 through FF hex.

The memory load *checksum* command format is as follows:

MSB				LSB
39 32	31 24	23 16	15 8	7 0
01000101	SSSSSSSS	SSSSSSSS	xxxxxxxx	xxxxxxxx

where: x = don't care
S = memory load checksum bits

Bits 32 to 39 are the memory load checksum opcode, 44 hex. Bits 16 to 31 contain the 16-bit checksum. Bits 0 to 15 are not used and can accept values from 00 through FF hex. Note that the checksum command must be the final command of the memory load transfer procedure; the instrument software uses it to recognize that the transfer procedure is complete and processing can begin on the memory load commands stored in the software command buffer. Memory loads are implemented at the end of a major frame.

11.4 Emergency Program Loads

The emergency program load procedure uses memory load commands to upload a new μP program into μP RAM. However, a checksum word is not used, and two hardware commands (ROM flag = 1 and master reset) must precede the memory laod sequence. The steps required to successfully execute an emergency program load are as follows:

1. *Issue a 'ROM flag = 1' hardware command.* This sets up the hardware ROM flag to a state which causes the instrument to avoid normal program initialization after a reset, and instead enter the emergency program load routine.
2. *Issue a 'Master Reset' hardware command.* The causes program execution to reset and enter the emergency program load routine.
3. *Issue a memory load START command with the desired program start address as the command data word.* This command contains an opcode = 42 hex, and its data is the address of the new program's first instruction that will execute following the completion of the load into RAM.

4. *Issue a memory load WORD COUNT command with the word count as the command data word.* This command contains an opcode = 43 hex, and its data is the count of the program data words to follow.

5. *Issue memory load DATA commands to complete the transfer procedure.* Each memory load data command contains an opcode = 44 hex, and transfers one program data word to the instrument. The program data words must be sent in sequential order, as they are to be stored into RAM, including 'filler' data words for gaps that exist in between modules of the total program.

When the last program data word is received by the instrument, processing is still busy with the diagnostic readout of the new contents of RAM into the telemetry stream. This is due to the memory load command transfers occurring at a rate significantly faster than the diagnostic output rate (a data word is received by a 40-bit command transfer every 64 msec; a data word is read out into the telemetry stream once per minor frame, which is every second. When the last data word that had been loaded into RAM by the emergency program load procedure is read out into the telemetry stream, program execution automatically jumps to RAM at the specified program start address.

11.5 Hardware Commands

Three hardware commands exist for the instrument: a master reset to the μP, setting the ROM program load flag = 0, and setting the ROM program flag = 1. Hardware commands make use of the MAG and FFT configuration commands opcode, 41 hex. Like the MAG and FFT configuration commands, hardware commands require only one 40-bit transmission. Bits 6 and 7 of the command data word (bits 22 and 23 of the 40-bit transfer) are set = 1 to signify a hardware command to the μP software. Since the transmission sets the command flag which in turn causes the μP to read in the command data as a configuration command type, mode = 3 alerts the software that the transmission is a hardware command and its data can be ignored. *However, if bits 22 and 23 are not set to mode 3 status, the hardware command will still be implemented, and the software will process the data. This can result in undesirable MAG or FFT configuration command action.*

Hardware command transmissions take on the following format:

MSB				LSB
39 32	31 24	23 16	15 8	7 0
01000001	xxxxxxxx	11xxxxxx	JxxxKxxx	xxxxxxxx

where: x = don't care
J,K = hardware command invoke bits

Bits 32 to 39 are the minor mode command opcode, 41 hex. Bits 24 to 32 and bits 0 to 7 can accept values from 00 through FF hex. Bits 16 to23 have the two MSBs = 1 for mode 3 status, and as a result, can accept values C0 through FF hex.

The following patterns for J and K of bits 8 to 15 are:

J	K	Command
0	0	master reset
0	1	ROM flag = 1
1	0	ROM flag = 0
1	1	not used

The Three Emergency Program Load Commands Are:

Command Mnemonic	32 bit Command (8 Hex characters)	Action Taken
MSTR_RESET	00C00000	Master Reset to Awakening State
ROM_FLAG_1	00C00800	Set Program Run Flag to Accept Emergency Program Load Upon Processor Reset
ROM_FLAG_2	00C08000	Reset Program Run Flag to Run Default Program Upon Processor Reset

The above commands must be preceeded by 41 hex to form a 40-bit hardware command.