**Lunar Prospector MAG/ER Instrument Telemetry Format**
98-5-5 D.W.Curtis

This document describes the Lunar Prospector MAG/ER instrument telemetry format. A detailed description of the instrument and its operation can be found in ***<TBS>***. A brief top-level description of the instrument telemetry follows in Section 1, followed by a more detailed description in Section 2. Section 3 describes the analog housekeeping sampled by the spacecraft.

## 1. Top-Level Telemetry Description

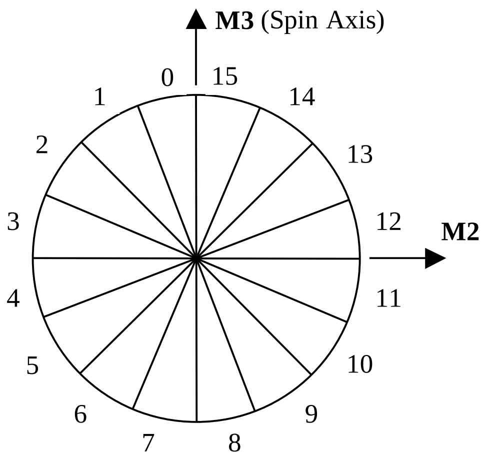
The MAG/ER instrument has a science telemetry allocation of 672 bps. This is in addition to MAG/ER analog housekeeping telemetry sampled by the spacecraft. This rate is shared approximately equally between MAG and ER science data. In addition to real-time telemetry, 'burst' telemetry will be included in the telemetry. Burst telemetry consists of enhanced time resolution data collected for a short interval. Telemetry will be formatted into two-second telemetry frames. Each 2-second frame of MAG/ER data is included in a spacecraft frame, which includes a time tag (frame counter). A group of 16 frames (starting with frame number modulo 16 equals 0) makes a 'Major Frame'.

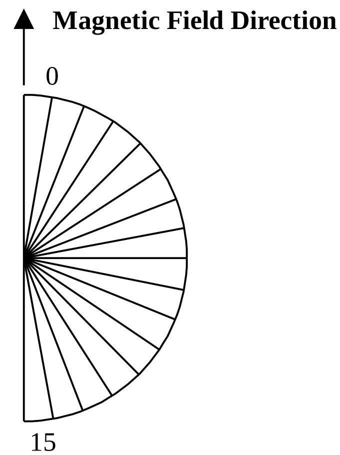
### 1.1 MAG Real-Time Telemetry

MAG telemetry will consist of raw three axis magnetometer samples, digitized to 12 bits, sampled at 18 Hz and averaged to 9Hz (telemetry-synchronous). Automatic MAG range control is exercised once a frame (to select one of 8 measurement ranges), and ranging information is included once a frame.

### 1.2 ER Real-time Telemetry

ER telemetry is collected spin-synchronous (nominal spin rate = 12 RPM). Data is accumulated in the ER instrument in two formats simultaneously: pitch angle sorted and fixed sector sorted. Pitch angle sorted data is accumulated into a 16 $\alpha$ (pitch angle) by 16 energy array, while fixed sector data is accumulated into a 16 $\theta$ (anode) by 16 energy array. The fixed sector array angular bins are equally spaced over the 360° Field-of-view (FOV), giving 22.5° resolution. Pitch angle sorting is based on the magnetic field direction provided by the magnetometer, and is done 'on the fly' for each electron count to a resolution of 1.4°. The pitch angle array angular bin spacing is programmable (default is equally spaced 11.25° bins). The figure below shows the binning schemes schematically. Note that M1 and M3 in the figure refer to instrument coordinates as described in the 'Lunar Prospector Mission Spacecraft to Science Instruments Interface Control Document', (ICD), Lockheed Martin Document LMMS/P086796F.




**Nominal ER Fixed Angle Bins Definition ($\theta$)** **Nominal ER Pitch Angle Bins Definition ($\alpha$)**

The ER energy is swept 32 times per spin (for uniform phase space coverage), and data is summed over 2 energy sweeps (1/16 spin, 22.5 degrees of rotation). The ER FOV samples all look directions in ½ spin of the spacecraft. ER fixed angle data is sampled 8 times in the ½ spin to accumulate 3D distributions with 22.5° by 22.5° resolution. This scheme over-samples the poles of the distribution (along the spin axis), so the resulting 128 angular bins are summed into 88 bins with more uniform phase space sampling (see section 2.3.2). The processor collects and accumulates data into averaged pitch angle distributions of 16 $\alpha$ by 15 energies and three dimensional distributions of 88 angular bins ($\Omega$) by 15 energies. The 16$^{th}$ energy step collected while the sweep supply ramps up is discarded.

ER data is collected into a fixed telemetry format, which is accumulated over 16 spins. The 16-spin accumulation is read out in 36 telemetry frames. At the nominal spin rate (12 RPM), 16 spins occur in 40 telemetry frame times. The extra telemetry frames are used to send Burst data or Fill. An index in each telemetry frame indicates which of the 36 frames of ER data is included (or of it is a Burst of Fill packet). If the spin rate is above nominal, the ER will produce an accumulation in less than 40 telemetry frames. This causes less Burst/fill data to be sent. If the spin rate exceeds 13.3 RPM, then there will be insufficient telemetry space to send the ER data with no Burst/Fill. Data frames will be dropped and an error will be indicated in this case. If the spin rate is below nominal, then more burst/fill data is read out.

Real-time 3D data is collected for ½ spin, and read out once every 16 spins. Real-time ER pitch angle data has different time resolutions for different energies. Two selected energies are accumulated and read out every ½ spin. The rest of the energies are accumulated and read out every 4 or 8 spins. Note that 3D data is accumulated only over ½ spin, while Pitch Angle data is typically accumulated continuously over the sample interval.

Below a certain energy, pitch angle distributions are not as useful. The distribution is significantly non-gyrotropic in the spacecraft frame even if it is in the solar wind frame. Also, electrostatic charging effects of the spacecraft and planet distort the distribution at low energies. Accumulating the data into a pitch angle distribution under these circumstances makes the angular data unusable because it mixes unrelated regions of phase space. To accommodate this, below a programmable energy step (nominally about 100eV), 'Cut' data is sent instead of pitch angle data. Cut data is the fixed sector data at a selected spin phase, corresponding to when the magnetic field is in the field of view of the instrument. Cut data is sampled, not averaged. This provides a low angular resolution pitch angle measurement without mixing different regions of phase space. Cuts are only sent in Real-time data, not burst data (where 3D data is always available). Cut data has 22.5 degree fixed resolution since it is extracted from the fixed angle data.

The ER uses the magnetic field direction measured by the magnetometer for pitch-angle sorting the electrons on-board. The magnetic field vector is propagated in the ER hardware for spacecraft rotation, and the vector is only updated from the magnetic field data four times a spin. It is important to know on the ground what magnetic field direction is used for pitch-angle sorting (in order to know the geometric factor of each pitch angle bin). The ER uses the same field vector that is in the MAG real-time telemetry, so the only uncertainty is which of the vectors in telemetry were used. Based on the spin phase timing included in the instrument telemetry, you can determine fairly accurately which sample, but there will be cases where the MAG sample time is close enough to the start of a 1/4 spin to make the determination of which MAG sample is used ambiguous. To eliminate this ambiguity, one bit per quarter spin is telemetered to indicate the LSB of the MAG sample number that was used.

### 1.3 Digital Subcom

Instrument status information is included in Digital Subcom telemetry. Digital Subcom data consists of a 16-bit word read out each Frame, subcomutated by 16 using the frame number included in the spacecraft. Digital Subcom data is sampled at the time of the start of the Major Frame.

### 1.4 Burst Operation

The burst system will be run in one of two possible modes: 'Triggered' and 'Commanded'. In Triggered mode, the burst memory will be used to attempt to capture interesting events based on a burst criterion computed from the ER data. In Commanded mode, the burst memory will be used to study a selected region on the lunar surface with enhanced spatial resolution. Most of the time, the system will be in Triggered burst mode. Commanded bursts will be collected at selected times by ground command. After the Commanded burst is collected and transmitted, the system returns to Triggered burst mode.

### 1.4.1 Triggered Burst Mode

This is the normal operating mode. In this mode, high rate data is continuously put into a piece of the burst memory called a ‘preamble’. This section is continuously over-written until the burst criteria value exceeds that of the previously recorded burst. At that time, the preamble is saved, and subsequent data is saved in the ‘ending’ block, over-writing the previous ‘best’ burst. When the ending is full, the system starts searching for an even better event using a second preamble buffer. This continues while a previously collected burst is played out through telemetry. When the transmission of the burst being telemetered is complete, its preamble and ending buffers are freed, and the current best burst preamble and ending buffers are frozen for telemetry. This system collects the ‘best’ burst once every burst read-out interval. It requires 3 preamble buffers (transmitting, collecting, and best), and two ending buffers (transmitting and best). The sizes of the preamble and ending buffers are programmable, but the total of the five buffers must fit into the 1 Mbyte burst memory.

The burst criterion is based on changes in the ER count rate in a programmable energy range. The counts over the selected interval are summed and log-compressed once each ½ spin. A simple filter is used to compute the baseline value for this measurement (in log counts). The absolute value of the difference between the current value and the baseline value is the burst criteria. If the burst criterion is better that the criteria for the current ‘best’ burst, then a new ‘best’ burst is saved. Note that the criterion for a ‘best’ burst is the maximum value of the criterion taken over the whole burst.

Burst telemetry shall include MAG samples at 18 Hz, and both fixed angle (88 $\Omega$ by 15 E) and pitch angle (16 $\alpha$ by 15 E) ER data sampled typically every 1/2 spin (the sample rate is programmable). With some additional context data, this produces 5997 bps. At this rate the burst memory can hold a total of 23 minutes of data (divided amongst the 3 preamble and 2 ending buffers).

The nominal telemetry allocation is:

MAG Science: ............... 328.0 bps
ER Science: .................... 302.8 bps (at 12 RPM)
Digital Subcom: .................. 8.0 bps
Burst Playback:................. 33.2 bps (at 12 RPM)

Total: .............................. 672.0 bps

At this rate, 6 minutes of burst data (at about 6Kbps collect rate) will play out in about 18 hours.

### 1.4.2 Commanded Burst Mode

Commanded burst mode is initiated by command. At a selected time, the burst memory contents are erased (the current Triggered bursts are lost), and the burst memory is filled with burst data. When the selected burst buffer size has been reached, all data collection is suspended, and the full telemetry stream is used to play out the burst memory contents. When the memory playback is complete, the system returns to normal (Triggered burst) mode and real-time data. A series of periodic Commanded bursts may be set up, for example once per orbit as the spacecraft passes over the desired location on the planet (or perhaps every second orbit so that some context data is collected at the normal rate).

Commanded bursts contain the same data as triggered bursts. Since the playback rate is considerably higher (about 20x), the playback time is shorter. If we limit the playback time to one orbit (118 minutes), the burst size is 580 Kbytes, and the record time is about 13 minutes (at 6 Kbps collect rate).

### 1.5 Timing

Instrument timing is tied to the frame and major frame pulses received by the instrument. These pulses are generated by the spacecraft at the beginning of each frame and major frame. The time of these frame pulses can be reconstructed on the ground based on Earth receive time, minus light time, and minus known delays in the data through the spacecraft data system (2 seconds for regular data, 3200 seconds for ‘delayed’ data).

ER data is collected spin-synchronous, based on a sun pulse provided by the spacecraft which drives a phase-locked loop in the ER. When there is no sun pulse, the ER continues to ‘fly-wheel’ using the last measured spin period. The timing of the ER data accumulation relative to the Major Frame time can be reconstructed from the Mag/ER telemetry (see section 2.3.5).

## 2. Detailed Telemetry Format

MAG/ER has 672bps*2s/8bits = 168 bytes per 2 second telemetry frame. The first 3 bytes of every frame is the same in all modes:

| Byte | Contents |
|---|---|
| 0 | Frame Code (see section 2.1) |
| 1,2 | Digital Subcom (see section 2.5) |

The format of the remaining bytes depends on the Frame Code as described in section 2.1 below.

## 2.1 Frame Code

The Frame Code indicates the format of the remaining data in the frame. The 6 LSB of the Frame Code are the Frame Type, with the two MSB containing ancillary information, depending on the Frame Type.

### 2.1.1 Real-time Frames (Frame Type 0-35)

These frames contain real-time MAG and ER data. The Frame Type indicates which of the 36 ER packets making up a 16-spin sample are included (see section 2.3). For these frames, the 2 MSBs of the Frame Code are used for ancillary ER data (see Section 2.3.3). The frame format is:

| Byte | Contents |
|---|---|
| 3-84 | Real-time Mag data (Section 2.2) |
| 85-167 | Real-time ER data (Section 2.3) |

### 2.1.2 Half Burst Frames (Frame Type 36-62, with Frame Code MSB = 0)

These frames contain real-time MAG data, plus burst playback data. The MSB of the Frame Code for these frames are zero. The Frame Type number indicates which of the 22 Burst packet types is included (see section 2.4). This format is typically used for Triggered burst playback data.

| Byte | Contents |
|---|---|
| 3-84 | Real-time Mag data (Section 2.2) |
| 85 | Burst playback frame counter (Section 2.4) |
| 86-167 | 82 byte burst Playback record (Section 2.4) |

### 2.1.3 Full Burst Frames (Frame Code 36-62 with Frame Type MSB =1)

These frames contain no real-time data, but two packets of Burst playback data. The MSB is set to distinguish these packets from Half Burst frames. The Frame Type indicates the type for the first burst packet. The type of the second packet is indicated in byte 85. This format is typically used for Commanded bursts.

| Byte | Contents |
|---|---|
| 3-84 | 82 byte burst playback record #1 (Section 2.4) |
| 85 | Record #2 Frame Code (Section 2.4) |
| 86-167 | 82 byte burst Playback record #2 (Section 2.4) |

### 2.1.4 Memory Dump Frames (Frame Type 63)

These frames include real-time MAG data and memory dump data. These packets may be selected by command, or they are produced automatically if no ER or Burst data is available. The 2 MSB of the Frame Code are set to 11.

| Byte | Contents |
|---|---|
| 3-84 | Real-time Mag data |
| 85-86 | Memory dump address (LS Byte first) |
| 86-167 | 81 bytes of memory data starting at Memory dump address. |

## 2.2 Mag Data Format

Both real-time Mag data (type 0-35) and Burst Mag data (type 56 – see section 2.4) use the same format. They include a MAG range/frame number byte plus 18 MAG samples (81 bytes). The format is:

| Byte # | Contents |
|---|---|
| 0 | MAG Status:<br>F.F.F.F.CAL.R.R.R (FFFF = Frame #,RRR=Range) |
| 1-9 | MAG sample 0 and 1 |
| 10-18 | MAG sample 2 and 3 |
| 19-27 | MAG sample 4 and 5 |
| 28-36 | MAG sample 6 and 7 |
| 37-45 | MAG sample 8 and 9 |
| 46-54 | MAG sample 10 and 11 |
| 55-63 | MAG sample 12 and 13 |
| 64-72 | MAG sample 14 and 15 |
| 73-81 | MAG sample 16 and 17 |

In this table, Byte # is relative to the start of the 82 byte MAG data block. CAL is a bit indicating the MAG is in calibration mode (1 = calibration mode, 0 = nominal mode). Calibration data is diagnostic, and should be ignored for science analysis. The Range code tells the gain of the instrument (see section 2.2.3).

A pair of MAG samples (2samples * 3 axis * 12bits) fills 9 bytes:

| Byte # | Bits | Contents |
|---|---|---|
| 0,1 | 0-11 | MAG sample 0, x axis (12 bits) |
| 1,2 | 12-23 | MAG sample 0, y axis (12 bits) |
| 3,4 | 24-35 | MAG sample 0, z axis (12 bits) |
| 4,5 | 36-47 | MAG sample 1, x axis (12 bits) |
| 6,7 | 48-59 | MAG sample 1, y axis (12 bits) |
| 7,8 | 60-71 | MAG sample 1, z axis (12 bits) |

In this table, Byte # is relative to the start of the 2 MAG sample block. Bit numbers start at zero for the LSB of the first byte of the MAG sample block.

The Frame Number included in the Mag status is redundant with that included in the spacecraft header for real-time data (it can be used as a consistency check). For Burst data (Frame Type 56), it tells how long since the most recent Major Frame marker block time this data was collected (Major Frame marker blocks are described in section 2.4). Since Burst data is collected at a rate of two frames per 2-second frame time, another bit of timing information is needed to tell which of the two samples is included. Bit 6 from the Frame Code byte serves this function for Frame Type 56. It is zero for the sample taken during the one second interval following the start of the frame, and one for the second sample.

### 2.2.1 MAG Sample Timing

The MAG is sampled 36 times per 2 second frame, synchronous with the telemetry clock. The first sample is taken at the time of the Frame pulse. Real-time data consists of averaged sample pairs. The first sample is the vector sum of the sample measured at the frame pulse time, and the sample taken 1/18 second later, divided by 2.

The Frame Time stamp is placed on the packet by the spacecraft 2 frame intervals (4 seconds) after the start of accumulation of the frame (first mag sample).

The spin-phase of the spacecraft at the time of the MAG sample can also be computed with the aid of data in the Digital Sub-Com (see section 2.5). For the $N^{th}$ raw MAG sample taken after the Major Frame pulse (with N=0 for the sample taken at the time of the Major Frame pulse), the spin phase (in degrees) is:

360. * (Phase/4096. + N/(18.*Period*.001024))

'Phase' and 'Period' are in the Digital Sub-Com.

The real-time data consists of averages of two consecutive Mag samples. The average of the two sample times for the $N^{th}$ real-time MAG sample is:

360. * (Phase/4096. + (N + 1/4)/(9.*Period*.001024))

### 2.2.2 MAG Data Calibration

In the deployed configuration, the nominal MAG orientation is has its Z-axis along the spacecraft spin axis (M3), its X-axis radially outwards from the spacecraft (M1), and its Y-axis pointing tangentially to the spacecraft in a right-handed coordinate system (M2). Once the booms are deployed, there may be a small rotational offset in this orientation which will be determined by the MAG team based on their data.

The MAG vector samples are telemetered as three 12-bit numbers coded excess-2048. The raw, signed measurement is computed as the telemetered value minus 2048. An offset in the measurement must be subtracted to account for instrument offsets and spacecraft field. This offset is different for each range, and may vary with time with spacecraft configuration. The MAG team will determine these offsets from their data. Once the offsets are subtracted, the measurement must be multiplied by a gain value which is a function of the Gain setting. The nominal gain factors (to convert to nT) are:

| Range | Gain |
|---|---|
| 0 | 1/512 |
| 1 | 1/128 |
| 2 | 1/32 |
| 3 | 1/8 |
| 4 | 1/2 |
| 5 | 2 |
| 6 | 8 |
| 7 | 32 |

These values are only nominal. The actual values are TBD.

## 2.3 Real-Time ER Frame Format

The 36 Real-time ER frame types together contain 16 spins of ER data. At the nominal spin rate, these are collected every 40 frames. When the next frame of ER data is not yet ready then the next Triggered Burst data or Memory Dump block is sent instead. ER frames will be read out sequentially, interrupted by occasional Burst or Memory Dump frames.

Each Real-time ER frame contains 83 bytes of ER data. These bytes contain from two to five 16-angle pitch angle samples. The remaining data is filled with the 3D (88 angle by 15 energy) data. The pitch angle data is sent out as close as possible to the end of the accumulation time to minimize latency through the system.

All ER counter data is log compressed to 8 bits of telemetry per sample (see section 2.6 below for a description of the compression scheme). Some accumulations are pre-scaled to avoid saturating the dynamic range of the compression scheme.

A 16-angle pitch angle sample is labeled by its energy bin number (0-14). Energy bin 0 is the highest energy. Energy bins 6 and 9 (in telemetry format 1) are transmitted every ½ spin. Energy bins 0-5 are sent every 8 spins, and energy bins 7, 8 and 10-14 every 4 spins.

Energy bins 10-14 are ‘Cuts’ rather than Pitch Angle data (in Telemetry format 1). Cuts are taken from the fixed-sectored data (22.5 degree fixed resolution) when the magnetic field vector is in the FOV of the detector.  Cuts are sampled over 22.5 degrees of spin, not an averaged over multiple half-spins.  The magnetic field vector used to determine the sector number in the cut is the first of the two samples for the half-spin of the cut used by the pitch-angle sorting system.  The correspondence between energy bin number and energy level is a function of programmable parameters.  The nominal values are shown in section 2.3.4 below.

Pitch angle data (not Cuts) may be pre-scaled to avoid saturating the compression scheme dynamic range.  Pre-scaling may be done automatically based on the count rates measured in the previous 16-spin accumulation, or statically by command.  Pre-scaling is done separately in 8 energy bands.  In automatic pre-scaling mode, if any pitch-angle sample in a band is saturated (counts greater than 524,287), then all values in that band will be divided by a factor of 8 before compression on the following 16 spin accumulations.  The band will continue to be pre-scaled until all samples in the band are at least a factor of 2 below saturation without the pre-scale for a whole 16 spin accumulation.  The pre-scale can also be forced on or off for any band by command.  The pre-scale state is included in the ER header (see section 2.3.1).

The following table describes the contents of the ER real-time frames for each Frame Type.

**ER Real-Time Telemetry Frames Contents**
**Format 1**

| Frame Type | ER Data Contents | |
|---|---|---|
| 0 | E0S0, E1S0, E2S0, E3S0, E4S0, | Header bytes 0-2 |
| 1 | E5S0, E6S0, E7S0, E8S0, E9S0, | Header byte 3, 3D bytes 0-1 |
| 2 | E10S0,E11S0,E12S0,E13S0,E14S0, | 3D bytes 2-4 |
| 3 | E6S1, E9S1, E6S2, E9S2, | 3D bytes 5-23 |
| 4 | E6S3, E9S3, | 3D bytes 24-74 |
| 5 | E6S4, E9S4, | 3D bytes 75-125 |
| 6 | E6S5, E9S5, | 3D bytes 126-176 |
| 7 | E6S6, E9S6, | 3D bytes 177-227 |
| 8 | E6S7, E9S7, | 3D bytes 228-278 |
| 9 | E6S8, E7S1, E8S1, E9S8, E10S1, | 3D bytes 279-281 |
| 10 | E11S1,E12S1,E13S1,E14S1, | 3D bytes 282-300 |
| 11 | E6S9, E9S9, | 3D bytes 301-351 |
| 12 | E6S10,E9S10, | 3D bytes 352-402 |
| 13 | E6S11, E9S11, | 3D bytes 403-453 |
| 14 | E6S12,E9S12, | 3D bytes 454-504 |
| 15 | E6S13,E9S13, | 3D bytes 505-555 |
| 16 | E6S14, E9S14, | 3D bytes 556-606 |
| 17 | E6S15,E9S15, | 3D bytes 607-657 |
| 18 | E0S1, E1S1, E2S1, E3S1, E4S1, | 3D bytes 658-660 |
| 19 | E5S1, E6S16,E7S2, E8S2, E9S16, | 3D bytes 661-663 |
| 20 | E10S2,E11S2,E12S2,E13S2,E14S2, | 3D bytes 664-666 |
| 21 | E6S17,E9S17,E6S18,E9S18, | 3D bytes 667-685 |
| 22 | E6S19,E9S19, | 3D bytes 686-736 |
| 23 | E6S20,E9S20, | 3D bytes 737-787 |
| 24 | E6S21,E9S21, | 3D bytes 788-838 |
| 25 | E6S22,E9S22, | 3D bytes 839-889 |
| 26 | E6S23,E9S23, | 3D bytes 890-940 |
| 27 | E6S24,E7S3, E8S3, E9S24,E10S3, | 3D bytes 941-943 |
| 28 | E11S3,E12S3,E13S3,E14S3, | 3D bytes 944-962 |
| 29 | E6S25,E9S25, | 3D bytes 963-1013 |
| 30 | E6S26,E9S26, | 3D bytes 1014-1064 |
| 31 | E6S27, E9S27, | 3D bytes 1065-1115 |
| 32 | E6S28,E9S28, | 3D bytes 1116-1166 |
| 33 | E6S29,E9S29, | 3D bytes 1167-1217 |
| 34 | E6S30, E9S30, | 3D bytes 1218-1268 |
| 35 | E6S31,E9S31, | 3D bytes 1269-1319 |

The code E6S23 in the above table, for example, corresponds to the 24$^{th}$ sample of energy 6 of the pitch angle/cut data. Data is put into the frame starting with the item on the left, progressing through the last item on the right in the above table. Each pitch angle data sample includes 16 pitch angle bins installed in the frame in pitch-angle bin number order, while Cut data includes 16 fixed angle bins installed in the frame in fixed angle bin number order (see the figures in section 1.2). Header data is described in section 2.3.1, and 3D data in section 2.3.2.

2.3.0 Telemetery Format 2 and 3

The above format for ER real-time data is the format corresponding to the original default configuration of the ER. This format was modified early in the mission to change the energies of the high time resolution pitch angle samples, and to lower the energy at which Cuts are made. Data in the original format is indicated by the Version code in the DSC data being one. The Version number changed to two for this new format, called Telemetry Format 2. For the new format the high time resolution energy channels are 9 and 11 instead of 6 and 9, and the Cuts start with energy 12 instead of 10. The new format is described in the table below:

**ER Real-Time Telemetry Frames Contents**
**Format 2**

| Frame Type | ER Data Contents | |
|---|---|---|
| 0 | E0S0, E1S0, E2S0, E3S0, E4S0, | Header bytes 0-2 |
| 1 | E5S0, E6S0, E7S0, E8S0, E9S0, | Header byte 3, 3D bytes 0-1 |
| 2 | E10S0,E11S0,E12S0,E13S0,E14S0, | 3D bytes 2-4 |
| 3 | E9S1, E11S1,E9S2, E11S2, | 3D bytes 5-23 |
| 4 | E9S3, E11S3, | 3D bytes 24-74 |
| 5 | E9S4, E11S4, | 3D bytes 75-125 |
| 6 | E9S5, E11S5, | 3D bytes 126-176 |
| 7 | E9S6, E11S6, | 3D bytes 177-227 |
| 8 | E9S7, E11S7, | 3D bytes 228-278 |
| 9 | E6S8, E7S1, E8S1, E9S8, E10S1, | 3D bytes 279-281 |
| 10 | E11S1,E12S1,E13S1,E14S1, | 3D bytes 282-300 |
| 11 | E9S9, E11S9, | 3D bytes 301-351 |
| 12 | E9S10,E11S10, | 3D bytes 352-402 |
| 13 | E9S11, E11S11, | 3D bytes 403-453 |
| 14 | E9S12,E11S12, | 3D bytes 454-504 |
| 15 | E9S13,E11S13, | 3D bytes 505-555 |
| 16 | E9S14, E11S14, | 3D bytes 556-606 |
| 17 | E9S15,E11S15, | 3D bytes 607-657 |
| 18 | E0S1, E1S1, E2S1, E3S1, E4S1, | 3D bytes 658-660 |
| 19 | E5S1, E6S16,E7S2, E8S2, E9S16, | 3D bytes 661-663 |
| 20 | E10S2,E11S2,E12S2,E13S2,E14S2, | 3D bytes 664-666 |
| 21 | E9S17,E11S17, E9S18, E11S18, | 3D bytes 667-685 |
| 22 | E9S19,E11S19, | 3D bytes 686-736 |
| 23 | E9S20,E11S20, | 3D bytes 737-787 |
| 24 | E9S21,E11S21, | 3D bytes 788-838 |
| 25 | E9S22,E11S22, | 3D bytes 839-889 |
| 26 | E9S23,E11S23, | 3D bytes 890-940 |
| 27 | E6S24,E7S3, E8S3, E9S24,E10S3, | 3D bytes 941-943 |
| 28 | E11S3,E12S3,E13S3,E14S3, | 3D bytes 944-962 |
| 29 | E9S25,E11S25, | 3D bytes 963-1013 |
| 30 | E9S26,E11S26, | 3D bytes 1014-1064 |
| 31 | E9S27, E11S27, | 3D bytes 1065-1115 |
| 32 | E9S28,E11S28, | 3D bytes 1116-1166 |
| 33 | E9S29,E11S29, | 3D bytes 1167-1217 |
| 34 | E9S30, E11S30, | 3D bytes 1218-1268 |
| 35 | E9S31,E11S31, | 3D bytes 1269-1319 |

Later in the mission (in May 1998) the ER software was changed again to automatically compute the offsets for the x and y components of the magnetometer (by averaging the values over 16 spins). The telemetry format was changed to bring down the computed magnetic field vectors used for pitch angle sorting to simplify ground processing. This software version is identified by a 3 in the version code in the DSC 'Ver' field.

**ER Real-Time Telemetry Frames Contents**
**Format 3**

| Frame Type | ER Data Contents | |
|---|---|---|
| 0 | E0S0, E1S0, E2S0, E3S0, E4S0, | Header bytes 0-2 |
| 1 | E5S0, E6S0, E7S0, E8S0, E9S0, | Header byte 3, 3D bytes 0-1 |
| 2 | E10S0,E11S0,E12S0,E13S0,E14S0, | 3D bytes 2-4 |
| 3 | E9S1, E11S1,E9S2, E11S2, | 3D bytes 5-23 |
| 4 | E9S3, E11S3, | 3D bytes 24-74 |
| 5 | E9S4, E11S4, | 3D bytes 75-125 |
| 6 | E9S5, E11S5, | 3D bytes 126-176 |
| 7 | E9S6, E11S6, | 3D bytes 177-227 |
| 8 | E9S7, E11S7, | 3D bytes 228-278 |
| 9 | E8S1, E9S8, E10S1, | 3D bytes 279-313 |
| 10 | E11S1,E12S1, | 3D bytes 314-364 |
| 11 | E9S9, E11S9, | 3D bytes 365-415 |
| 12 | E9S10,E11S10, | 3D bytes 416-466 |
| 13 | E9S11, E11S11, | 3D bytes 467-517 |
| 14 | E9S12,E11S12, | 3D bytes 518-568 |
| 15 | E9S13,E11S13, | 3D bytes 569-619 |
| 16 | E9S14, E11S14, | 3D bytes 620-670 |
| 17 | E9S15,E11S15, | 3D bytes 671-721 |
| 18 | E0S1, E1S1, E2S1, E3S1, E4S1, | 3D bytes 722-724 |
| 19 | E5S1, E6S16,E7S2, E8S2, E9S16, | 3D bytes 725-727 |
| 20 | E10S2,E11S2,E12S2,E13S2,E14S2, | 3D bytes 728-730 |
| 21 | E9S17,E11S17, E9S18, E11S18, | 3D bytes 731-749 |
| 22 | E9S19,E11S19, | 3D bytes 750-800 |
| 23 | E9S20,E11S20, | 3D bytes 801-851 |
| 24 | E9S21,E11S21, | 3D bytes 852-902 |
| 25 | E9S22,E11S22, | 3D bytes 903-953 |
| 26 | E9S23,E11S23, | 3D bytes 954-1004 |
| 27 | E8S3, E9S24,E10S3, | 3D bytes 1005-1039 |
| 28 | E11S3,E12S3, | 3D bytes 1040-1090 |
| 29 | E9S25,E11S25, | 3D bytes 1091-1141 |
| 30 | E9S26,E11S26, | 3D bytes 1142-1192 |
| 31 | E9S27, E11S27, | 3D bytes 1193-1243 |
| 32 | E9S28,E11S28, | 3D bytes 1244-1294 |
| 33 | E9S29,E11S29, | 3D bytes 1295-1319, MagThPh bytes 0-25 |
| 34 | E9S30, E11S30, | MagThPh bytes 26-76 |
| 35 | E9S31,E11S31, | MagThPh bytes 77-127 |

The magnetic field direction data is read out 4 times a spin (as fast the field is updated in the pitch angle sorter). Each readout consists of 2 bytes; first MagPh, then MagTh. Both are coded in units of 256/360 degrees. MagTh is the polar angle, coded 0 to 180 degrees (0 degrees is along the spin axis), and MagPh is the azimuthal angle coded 0-360 degrees (0 degrees along the ER X axis at the time of the sun pulse).

2.3.1 ER Header Format

The 5 LSB of the first byte of the ER header contain the number of half-spins since the start of the Major Frame that the 16-spin accumulation started (see section 2.3.5 on accumulation timing). The 3 MSB of the first byte of the ER header is a version number for the pitch angle boundaries map. This number is set by command (PABBVersion in Table 4 - see “Lunar prospector MAG/ER Commanding” document). The default value is zero, corresponding to equally spaced (11.25 degree) pitch angle bins. If the spacing of the bins is changed by command, this number should also be changed so that ground software can correctly interpret the data. This code may also be used to identify other important changes in the ER data format, such as a change in the ’cut’ energy limit, which may be changed by command but are not otherwise indicated in the telemetry.

The second header byte contains the ‘Pre-scale’ state for the real-time pitch angle accumulations. The longer pitch angle accumulations (all except energies 6 and 9 and cut data) may be pre-scaled to avoid saturation of the compression scheme. Pre-scaling involves dividing the count values by 8. Pitch angle data is divided into 8 energy bands: all counters in an energy band are either pre-scaled or not together. The 8 bits in the second ER header byte correspond to the pre-scale state of the 8 energy bands (0=not pre-scaled, 1=pre-scaled), (Bit 0 is the LSB):

| Bit Number | Energy Steps |
|---|---|
| 0 | 0,1 |
| 1 | 2,3 |
| 2 | 4,5 |
| 3 | 6, 7 |
| 4 | 8,9 |
| 5 | 10,11 |
| 6 | 12,13 |
| 7 | 14 |

Note that high time resolution and Cut data is not prescaled.

The third byte of the ER header contains the compressed, ‘Total Counts’. Total Counts is the sum of all counts for all angles and energies (including the ‘retrace’ energy step not included in other telemetry) over the first half-spin of the ER accumulation. It is the sum of all events processed by the ER Pulse Position Analyzer, excluding those masked by the Anode masks, and any lost by FIFO over-run between the PPA and event processor (the event processor handles an event every microsecond, and the FIFO is 4 events deep). The total counts are divided by 16 before being compressed to avoid saturation of the compression scheme.

The fourth byte contains the ‘Rate Counter’ accumulated for first half spin of the ER accumulation (corresponding to the same time interval as the Total counts in byte 3).

The Rate counter should be the same as the total counter except for events eliminated by one of the following: Pulse height above the upper level discriminator, Pulse occurred during PPA dead time (about 300ns per analyzed event), Pulse lost in event processor FIFO, or pulse rejected by anode masks. The Rate counter is prescaled by 2 in the hardware, and by another factor of 8 in software before being compressed.

The relative counts in Total and Rate, assuming the anode masks are all off and the event rate is not too high, should tell how many events are too large for the PPA, indicating that the MCP setting may be too high.

### 2.3.2 ER 3D Format

The 3D data consists of 88 angles (Ω) by 15 energies. The 1320 bytes (88*15) of 3D data are scattered over the 36 ER frames as indicated in the table in Section 2.3. The data is ordered as 15 groups of 88 angles, read out in ascending energy step number order. The phase space map below identifies the 88 phase space samples and their readout order. Bins covering more than one spin phase bin include the sum of the counts in all the covered bins. The figure in section 1.2 describes the anode bin numbering (fixed angle bins). The spin phase bin number corresponds to the time since the start of the half-spin that the data was collected, in units of 22.5°; Spin Phase bin 0, for example, is accumulated from 0 to 22.5° from the start of the half-spin.

<table>
<tr><th rowspan="2">Anode Bin #</th><th colspan="8">Spin Phase Bin # (22.5 ° per Bin)</th></tr>
<tr><th>0</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th></tr>
<tr><td>0</td><td colspan="4">0</td><td colspan="4">1</td></tr>
<tr><td>1</td><td colspan="2">2</td><td colspan="2">3</td><td colspan="2">4</td><td colspan="2">5</td></tr>
<tr><td>2</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td></tr>
<tr><td>3</td><td>14</td><td>15</td><td>16</td><td>17</td><td>18</td><td>19</td><td>20</td><td>21</td></tr>
<tr><td>4</td><td>22</td><td>23</td><td>24</td><td>25</td><td>26</td><td>27</td><td>28</td><td>29</td></tr>
<tr><td>5</td><td>30</td><td>31</td><td>32</td><td>33</td><td>34</td><td>35</td><td>36</td><td>37</td></tr>
<tr><td>6</td><td colspan="2">38</td><td colspan="2">39</td><td colspan="2">40</td><td colspan="2">41</td></tr>
<tr><td>7</td><td colspan="4">42</td><td colspan="4">43</td></tr>
<tr><td>8</td><td colspan="4">44</td><td colspan="4">45</td></tr>
<tr><td>9</td><td colspan="2">46</td><td colspan="2">47</td><td colspan="2">48</td><td colspan="2">49</td></tr>
<tr><td>10</td><td>50</td><td>51</td><td>52</td><td>53</td><td>54</td><td>55</td><td>56</td><td>57</td></tr>
<tr><td>11</td><td>58</td><td>59</td><td>60</td><td>61</td><td>62</td><td>63</td><td>64</td><td>65</td></tr>
<tr><td>12</td><td>66</td><td>67</td><td>68</td><td>69</td><td>70</td><td>71</td><td>72</td><td>73</td></tr>
<tr><td>13</td><td>74</td><td>75</td><td>76</td><td>77</td><td>78</td><td>79</td><td>80</td><td>81</td></tr>
<tr><td>14</td><td colspan="2">82</td><td colspan="2">83</td><td colspan="2">84</td><td colspan="2">85</td></tr>
<tr><td>15</td><td colspan="4">86</td><td colspan="4">87</td></tr>
</table>

### 2.3.3 Real-Time ER 'Bits'

For real-time ER frames, the 2 MSB of the frame type code for the 36 frames are collected together into 72 bits (9 bytes) per 16-spin accumulation. The first 8 bits contain the 8 MSB of the ER test pulser command setting (parameter TestP in Table 1, see 'Lunar Prospector MAG/ER Commanding' document). The remaining 64 bits contain the MAG sample information discussed in section 1.2 above. To determine which MAG sample is used for each 1/4 spin, first compute the MAG sample closest to the start of each 1/4 spin based on the spin phase timing in the Digital Sub-Com (see section 2.2.1). To resolve any ambiguity when the MAG sample time is close to the start of a 1/4 spin, the bit for that 1/4 spin indicates if the MAG sample was odd or even (with the first MAG sample in a frame being even).

### 2.3.4 ER Energy Bins

The ER sweep waveform is programmable, parameterized by two values; the top value and the sweep rate. The sweep starts out at the top value at the beginning of the sweep, and steps at a rate of 128 steps per sweep (8 steps per energy accumulation) to provide a fairly smooth sampling of energy. Energy step N+1 is computed from energy step N by:

$$E[N+1] = E[N] - F*E[N]/512$$

F is a parameter that controls the sweep rate, and can be set to any value between 0 and 47. Note that F=0 gives a constant value. The top energy step is set with a 16 bit number (the sweep is controlled by a 16 bit DAC), with the maximum value (65535) corresponding to the maximum sweep supply voltage (4835V), which corresponds to about 27KeV (assuming an analyzer constant of 5.65). The values of F and the sweep maximum are contained in the Digital Sub-Com (see section 2.5).

Note that the first 1/16th sweep is held fixed at the maximum value while the supply charges up. The data from this period is discarded.

With the default settings of sweep maximum set to 48000 (20KeV), and sweep rate F=34 (Telemetry Format 1), the energy bins are as follows:

**Telemetry Format 1**

| Step | Energy (K=5.65) | Default Accumulation |
|---|---|---|
| 14 | 6 - 10 eV | Cut every 4 spins plus 3D every 16 spins |
| 13 | 10 - 17 eV | Cut every 4 spins plus 3D every 16 spins |
| 12 | 17 - 29 eV | Cut every 4 spins plus 3D every 16 spins |
| 11 | 29 - 51 eV | Cut every 4 spins plus 3D every 16 spins |
| 10 | 51 - 88 eV | Cut every 4 spins plus 3D every 16 spins |
| 9 | 88 - 152 eV | PAD every 1/2 spin plus 3D every 16 spins |
| 8 | 152 - 263 eV | PAD every 4 spins plus 3D every 16 spins |
| 7 | 263 - 466 eV | PAD every 4 spins plus 3D every 16 spins |
| 6 | 466 - 791 eV | PAD every 1/2 spin plus 3D every 16 spins |
| 5 | 791 - 1,371 eV | PAD every 8 spins plus 3D every 16 spins |
| 4 | 1.37 - 2.38 keV | PAD every 8 spins plus 3D every 16 spins |
| 3 | 2.38 - 4.12 keV | PAD every 8 spins plus 3D every 16 spins |
| 2 | 4.12 - 7.14 keV | PAD every 8 spins plus 3D every 16 spins |
| 1 | 7.14 - 12.4 keV | PAD every 8 spins plus 3D every 16 spins |
| 0 | 12.4-20.0 keV | PAD every 8 spins plus 3D every 16 spins |

For Telemetry Format 2, with F=27 and Sweep Max = 48000:

**Telemetry Format 2**

| Step | Energy (K=5.65) | Default Accumulation |
|---|---|---|
| 14 | 32 - 49 eV | Cut every 4 spins plus 3D every 16 spins |
| 13 | 49 - 75 eV | Cut every 4 spins plus 3D every 16 spins |
| 12 | 75 - 116 eV | Cut every 4 spins plus 3D every 16 spins |
| 11 | 116 - 180 eV | PAD every 1/2 spin plus 3D every 16 spins |
| 10 | 180 - 277 eV | PAD every 4 spins plus 3D every 16 spins |
| 9 | 277 - 427 eV | PAD every 1/2 spin plus 3D every 16 spins |
| 8 | 427 - 659 eV | PAD every 4 spins plus 3D every 16 spins |
| 7 | 659 – 1,016 eV | PAD every 4 spins plus 3D every 16 spins |
| 6 | 1.02 – 1.57 keV | PAD every 4 spins plus 3D every 16 spins |
| 5 | 1.57 – 2.42 keV | PAD every 8 spins plus 3D every 16 spins |
| 4 | 2.42 – 3.73 keV | PAD every 8 spins plus 3D every 16 spins |
| 3 | 3.73 – 5.75 keV | PAD every 8 spins plus 3D every 16 spins |
| 2 | 5.75 – 8.87 keV | PAD every 8 spins plus 3D every 16 spins |
| 1 | 8.87 – 13.7 keV | PAD every 8 spins plus 3D every 16 spins |
| 0 | 13.7-20.0 keV | PAD every 8 spins plus 3D every 16 spins |

**Telemetry Format 3**

| Step | Energy (K=5.65) | Default Accumulation |
|---|---|---|
| 14 | 32 - 49 eV | Cut every 8 spins plus 3D every 16 spins |
| 13 | 49 - 75 eV | Cut every 8 spins plus 3D every 16 spins |
| 12 | 75 - 116 eV | Cut every 4 spins plus 3D every 16 spins |
| 11 | 116 - 180 eV | PAD every 1/2 spin plus 3D every 16 spins |
| 10 | 180 - 277 eV | PAD every 4 spins plus 3D every 16 spins |

| | | |
|---|---|---|
| 9 | 277 - 427 eV | PAD every 1/2 spin plus 3D every 16 spins |
| 8 | 427 - 659 eV | PAD every 4 spins plus 3D every 16 spins |
| 7 | 659 – 1,016 eV | PAD every 8 spins plus 3D every 16 spins |
| 6 | 1.02 – 1.57 keV | PAD every 8 spins plus 3D every 16 spins |
| 5 | 1.57 – 2.42 keV | PAD every 8 spins plus 3D every 16 spins |
| 4 | 2.42 – 3.73 keV | PAD every 8 spins plus 3D every 16 spins |
| 3 | 3.73 – 5.75 keV | PAD every 8 spins plus 3D every 16 spins |
| 2 | 5.75 – 8.87 keV | PAD every 8 spins plus 3D every 16 spins |
| 1 | 8.87 – 13.7 keV | PAD every 8 spins plus 3D every 16 spins |
| 0 | 13.7-20.0 keV | PAD every 8 spins plus 3D every 16 spins |

### 2.3.5 ER Real-Time Data Timing

The base time for the real-time ER data is taken from the most recent Major Frame time. The Digital Sub-Com contains the spin phase at the time of the Major Frame pulse, and the spin period. With these values, the time of the start of a reference spin can be computed, the spin that started just before the Major Frame pulse. The ER header contains the last bit of information needed, the number of half-spins between the Major Frame pulse and the start of the 16-spin ER accumulation. The 16-spin ER accumulation time, $T_{Acc}$, can be computed as:

$$T_{Acc} = T_{MF} + 2.4\text{ms} – T_{Phase} + T_{NHS}$$

Where:

$T_{MF}$ Is the time of the Major Frame pulse (see section 1.5). The 2.4ms is a fixed delay in the Frame pulse timing in the instrument.

$T_{Phase}$ Is the time interval between the Major Frame pulse and the start of the preceding half-spin. This can be computed from the data in the Digital Sub-com as:

$$T_{Phase} = \text{(Phase modulo 2048)*Period*0.00025 (sec)}$$

‘Phase’ and ‘Period’ are the values in the Digital Sub Com.

$T_{NHS}$ Is the time interval from the half-spin preceding the Master Frame pulse to the start of the ER 16-spin accumulation. This is equal to the half-spin period times the number of half-spins (NHS) indicated in the ER header, plus 1 (section 2.3.1).

$$T_{NHS} = \text{((NHS+1) modulo 32) *Period*.000512 (sec)}$$

‘Period’ is the value in the Digital Sub Com.

It is possible that the ER 16-spin accumulation started before the Major Frame that contains the first frame of the data for that accumulation. This is indicated by the computed $T_{Acc}$ being greater than the frame time of the first frame of data of the 16-spin ER accumulation. In that case, the $T_{MF}$ and $T_{Phase}$ in the above computations should be taken from the previous Major Frame.

$T_{Acc}$ is the end-time of the first accumulation of each type. 3D data is sampled during the half spin just preceding $T_{Acc}$ (i.e. $T_{Acc}$ – ½ spin to $T_{Acc}$). The $N^{th}$ sample of pitch angle data is accumulated from $T_{Acc}$ + (N-1)*A to $T_{Acc}$ + N*A (A is the accumulation time, ½ spin, 4 spins, or 8 spins, and N=0 for the first sample). Cut data is sampled from the last ½ spin of the 4-spin accumulation interval: for the Nth cut sample, the accumulation time is: $T_{Acc}$ + N*A – ½ spin to $T_{Acc}$ + N*A (A is the accumulation time, 4 spins, and N=0 for the first sample).

### 2.3.6 ER Calibration

The ER full instrument geometric factor, G, is approximately 0.07 E (KeV) cm2 ster KeV. This sensitivity is divided amongst 256 effective look directions (anodes), each with nominally 1/256 of the geometric factor. In fact there is significant variation in the geometric factor from anode to anode due to differential non-linearity in the Analog-to-Digital converter that does the binning, and due to variations in the gain of the micro-channel plate detector. A table of anode efficiency factors, F, is TBS.

The basic integration time is given by the spin period divided by 256. The 3D data and cuts are accumulated for this interval (except the 3D polar bins which are summed over 2 or 4 accumulations – see section 2.3.2). Pitch Angle accumulations are multiples of this basic integration time – see below.

The fixed-anode distribution geometric factors can be computed from G and F by summing over the 16 anodes in each fixed bin. Computing the pitch-angle data geometric factors is more complex. Pitch angle binning is computed for each event when it occurs. The magnetic field vector used to compute pitch angles is sampled 4 times a spin, and then rotated into the detector coordinates, updated 256 times a spin. To determine the effective geometric factor of a pitch angle bin, first sum the geometric factors of each of the 256 anode bins that are mapped into this pitch angle bin by the rotated magnetic field vector in a given $1/256^{th}$ of a spin. Then sum these factors over the time that the bin is accumulated. The energy sweep must be taken into account; data is accumulated into a given pitch angle/energy bin only $1/16^{th}$ of an energy sweep, and energy sweeps repeat 32 times a spin. To perform these calculations accurately, the arithmetic must match that of the on-board process in terms of accuracy, rounding, etc. A detailed description of this arithmetic is included in Appendix TBS.

## 2.4 Burst Frame Format

Burst packets consist of 82 bytes of data plus a type code. Either one or two burst packets can be transmitted per frame. When there are two burst packets per frame (Full Burst Packets – see section 2.1.3), the Frame Type of the second burst packet is contained in byte 85 of the frame. Mag burst data (Frame Type 56) is the same format as for real-time MAG data, described in section 2.2 above. One burst Mag packet is generated each second. ER data, consisting of a 1/2 spin snapshot of both 3D and pitch angle data, plus ancillary data, is collected nominally each 1/2 spin, and fills 20 packets (Frame Types 36-55). Type 57 is a Major Frame marker packet, generated at the start of each Major Frame during burst collection. This packet includes timing information and ancillary data (see section 2.4.2). A Major Frame marker is jammed in at the start of a burst (before the preamble). It is a copy of the last Major Frame marker packet before the start of the burst. It is identified by bit 6 of the Frame Code being set to 1 (to indicate that a new burst read-out is starting). In special cases the first packet of a burst might be a fill packet (Frame Type 62) instead of a Major Frame marker. If so, it will still have bit 6 set in the type code to indicate the start of a burst. As just indicated, Frame Type 62 packets are fill. They are rarely if ever generated, and contain no useful data. Frame Types 58-61 are undefined.

### 2.4.1 Burst ER Format

The 20 Burst ER packets contain:

**ER Burst Packet Contents**

| Packet Type | Contents |
|---|---|
| 36 | ER Header (4 bytes), 3D data bytes 0-77 |
| 37 | 3D data bytes 78-159 |
| 38 | 3D data bytes 160-241 |
| 39 | 3D data bytes 242-323 |
| 40 | 3D data bytes 324-405 |
| 41 | 3D data bytes 406-487 |
| 42 | 3D data bytes 488-569 |
| 43 | 3D data bytes 570-651 |
| 44 | 3D data bytes 652-733 |
| 45 | 3D data bytes 734-815 |
| 46 | 3D data bytes 816-897 |
| 47 | 3D data bytes 898-979 |
| 48 | 3D data bytes 980-1061 |
| 49 | 3D data bytes 1062-1143 |
| 50 | 3D data bytes 1044-1225 |
| 51 | 3D data bytes 1226-1307 |
| 52 | 3D data bytes 1308-1319, PA data bytes 0-69 |
| 53 | PA data bytes 70-151 |
| 54 | PA data bytes 152-233 |
| 55 | PA data bytes 234-239, MagAngles (4 bytes), ER Table (72 bytes) |

The ER Header is in the same format described in section 2.3.1 above (note that the burst pitch angle data is not pre-scaled, and the pre-scale bits are not useful). The

1320 bytes of 3D data are in the same format as described in section 2.3.2 above. The 240 bytes of Pitch Angle (PA) data consist of 16 pitch angle samples for each of 15 energies, in ascending energy step number order. The data is Pitch Angle for all 15 energies - no ‘cuts’. The accumulation time for both 3D and pitch angle data is 1/2 spin.

The MagAngles includes 2 samples of the computed magnetic field angles as sent to the ER on the two 1/4 spin intervals during this 1/2 spin accumulation. This is in place of the Mag sample number bits used in real-time data, and avoids having to find the MAG sample corresponding to the 1/4 spin interval, and computing the angles from the 3 components. MagPhi is the spin phase of the MAG vector (in de-spun coordinates, with zero at the sun pulse time). MagTh is the elevation angle, with zero along the spin vector. Both are coded in degrees*256/360.

**MagAngles**

| Byte | Contents |
|---|---|
| 0 | MagTh #0 |
| 1 | MagPhi #0 |
| 2 | MagTh #1 |
| 3 | MagPhi #1 |

The ER Table contains the current ER control parameters, as described in the ‘Lunar Prospector MAG/ER Commanding’ document, under Table 1.

### 2.4.2 Burst Major Frame Marker Packet

This packet is generated at the start of each Major Frame (32 seconds) during burst collection. It contains timing information needed to determine when the burst data was collected, as well as some instrument status information. All the information is current as of the collect time, except the second entry (Major Frame count at transmit time). The Byte number is relative to the start of the Burst packet.

| Byte | Contents |
|---|---|
| 0,1 | The Major Frame count at the time this frame was collected (16 bits, LS Byte first) |
| 2,3 | The Major Frame count at the time this frame is transmitted (16 bits, LS Byte first) |
| 4 | The Burst number (increments by one for each transmitted burst) |
| 5-11 | Burst status information (see below) |
| 12-23 | Spin Phase-Locked Loop control table (see Commanding document) |
| 24-33 | Magnetometer control table (see Commanding document) |
| 34-49 | Burst control table (see Commanding document) |
| 50-81 | Digital Subcom data (all 32 bytes - see section 2.5) |

The Burst Status information contains (Byte number relative to start of Burst Status):

| Byte | Contents |
| --- | --- |
| 0 | Best Available Flag (1 if there is a ‘best’ burst ready to transmit, else 0) |
| 1 | Burst Read State (0 if nothing to read, 1 if reading preamble, 2 if reading ending) |
| 2 | Burst Record State (0=recording preamble, 1=over-writing preamble while waiting for a new ‘best’ burst, 2=recording ending) |
| 3 | Best Trigger: trigger criteria of current ‘best’ burst |
| 4 | Read Trigger: trigger criteria of burst being read out |
| 5-6 | Filtered criteria: baseline trigger criteria level (*256) |

### 2.4.3 Burst Timing

Burst data may reside in the burst memory for quite a while. Data in the Major Frame marker packets can be used to determine when the data was collected. The difference between the Major Frame count at the time the packet is transmitted and the Major Frame count at the time it was collected (modulo $2^{16}$ = NF) is the number of frames that the Major frame marker packet was in the burst memory. The Major Frame marker packet was collected at the time of Major Frame in which it is transmitted, minus 32 seconds times NF (call this $T_{MFM}$).

The first MAG burst packet following a Major Frame marker packet was collected starting at $T_{MFM}$, with subsequent MAG burst packets collected on 1-second intervals. The Frame Counter and a bit in the Frame code can be used to compute the offset from $T_{MFM}$ that a MAG burst packet was collected – see section 2.2.

The ER burst accumulation timing is computed similarly to the real-time ER data (see section 2.3.5), using $T_{MFM}$ instead of $T_{MF}$, and taking ‘Phase’ and ‘Period’ from the Major Frame Marker packet rather than the current Digital Sub-Com. The 3D and Pitch Angle data accumulation intervals are from $T_{Acc}$ – ½ spin to $T_{Acc}$.

## 2.5 Digital Subcom Format

The digital subcom is sampled at the start of each Master frame (32 seconds), and transmitted in the second and third byte of each frame, for a total of 2*16=32 bytes of data. The Frame number used to decomutate the data can be extracted from either the spacecraft telemetry or from the real-time Mag data if present. The frame number in the spacecraft telemetry is one larger (modulo 16) than the frame number indicated below due to pipe-line delays.

**Digital Sub-Com Definition**

| Frame # | Byte #1 MSB | | | | | | | LSB | Byte #2 MSB | | | | | | | LSB |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| 0 | Cmd 0 | | | | | | | | Cmd 1 | | | | | | | |
| 1 | Cmd 2 | | | | | | | | Cmd Cnt | | | | | | | |
| 2 | Error | | | | | | | | RCnt | | | | ECnt | | | |
| 3 | Ver | | | | D | E | S | B | IMon 0 | | | | | | | |
| 4 | SW 0 | | | | IMon 1 | | | | SW 1 | | | | | | | |
| 5 | PC Temp | | | | | | | | Mag +12V | | | | | | | |
| 6 | Mag Temp | | | | | | | | Mag –12V | | | | | | | |
| 7 | Mag +5V | | | | | | | | ER MCPI | | | | | | | |
| 8 | ER MCPV | | | | | | | | ER SWPI | | | | | | | |
| 9 | ER –5V | | | | | | | | ER +5V | | | | | | | |
| 10 | ER +12V | | | | | | | | ER +28V | | | | | | | |
| 11 | Phase 0 | | | | | | | | P | C | A | M | Phase 1 | | | |
| 12 | Period 0 | | | | | | | | L | | Period 1 | | | | | |
| 13 | SW Max 0 | | | | | | | | SW Max 1 | | | | | | | |
| 14 | ER | R | SW Rate | | | | | | MCP Set | | | | | | | |
| 15 | Best | | | | | | | | BE | Q | W | | BRF | | | |

| Name | Description |
|---|---|
| Cmd 0 | 8 LSB of the most recently received MAG/ER command |
| Cmd 1 | 8 middle bits of the most recently received command |
| Cmd 2 | 8 MSB of the most recently received command |
| Cmd Cnt | number of commands (modulo 256) since instrument reset |
| Error | an 8 bit code indicating the most recent error type |
| ECnt | number of errors (modulo 16) that have occurred since instrument reset |
| RCnt | number of processor resets (modulo 16) since instrument power-up |
| Ver | software version number (0 for PROM code) |
| D | Mag 1m boom deploy status |
| E | EEPROM Write Enable (1=Enabled) |
| S | Mag electronics side currently operating |
| B | Boot mode for next reset (1=PROM, 0 = EEPROM) |
| IMon 0 | Instrument current monitor 8 LSB (IMON has a 2048 offset) |
| IMon 1 | Instrument current monitor, 4 MSB |
| SW 0 | * ER Sweep HV supply voltage monitor, 4 LSB (SW has a 2048 offset) |
| SW 1 | * ER Sweep HV supply voltage monitor, 8 MSB |
| PC Temp | Power Converter temperature (128 offset) |
| Mag +12V | Mag/ER DPU +12V supply voltage monitor (absolute value) |
| Mag Temp | Magnetometer temperature (128 offset) |
| Mag -12V | Mag/ER DPU -12V supply voltage monitor (absolute value) |
| Mag +5V | Mag/ER DPU +5V supply voltage monitor (absolute value) |
| ER MCPI | * ER MCP High Voltage supply current monitor (absolute value) |
| ER MCPV | * ER MCP High Voltage supply voltage monitor (absolute value) |

| | |
|---|---|
| ER SWPI | * ER Sweep High Voltage supply, current monitor (absolute value) |
| ER -5V | * ER -5V supply voltage monitor (absolute value) |
| ER +5V | * ER +5V supply voltage monitor (absolute value) |
| ER +12V | * ER +12V supply voltage monitor (absolute value) |
| ER +28V | * ER +28V supply voltage monitor (absolute value) |
| Phase 0 | * 8 LSB of the Spin Phase at the time of the Master Frame pulse (plus a small TBD time offset (approx. 2-3msec). The phase is a value from 0 to 4095, in units of spin period/4096, indicating the time interval between the last Sun pulse from the spacecraft and the Master Frame pulse of the start of this DSC block |
| Phase 1 | * 4 MSB of the Spin Phase at the time of the Master Frame pulse |
| P | * ER HV Enable Plug state; 1 = in/enabled, 0 = out/disabled |
| C | * ER internal cover status; 1 = Closed, 0 = Open |
| A | * ER Sweep HV Enable; 1 = enable, 0 = disable |
| M | * ER MCP HV Enable (1=enable, 0=disable) |
| Period 0 | * 8 LSB of current spacecraft Spin Period setting, units are 1.024 ms |
| Period 1 | * 6 MSB of current spacecraft Spin Period setting |
| L | Spin Period Phase Locked Loop status:<br>➢ 00 = Unlocked (no sun pulse)<br>➢ 10 = Locked<br>➢ 11 = ReSynced (the PLL has achieved Lock in the last Major Frame interval) |
| SW Max 0 | * 8 LSB of ER Sweep HV Maximum level |
| SW Max 1 | * 8 MSB of ER Sweep HV Maximum level |
| ER | ER Power status: 1 = On, 0 = Off |
| R | Mag Autoranging mode: 1 = autorange, 0 = manual |
| SW Rate | * ER Sweep HV supply sweep rate code |
| MCP Set | * ER MCP High Voltage Setting |
| Best | Current Best burst trigger evaluation (excluding the burst being read out) |
| BE | Burst readout enable: 1=enabled |
| Q | Burst Readout state: 0 = preamble, 1 = ending |
| W | Burst Record state:<br>➢ 00 = preamble<br>➢ 01='Wait' (over-writing preamble waiting for a better burst that 'best'<br>➢ 10=ending. |
| BRF | Burst Read Fraction: Indicates how far through the burst the readout is (in 16ths of the burst size) |

Items marked with a * are only valid when the ER is on (ER is 1)

The analog housekeeping is converted by a 12 bit bipolar ADC, which converts with a 2048 code offset, so that zero volts is converted as 2048, positive voltages are greater that 2048, and negative voltages are less than 2048. The IMon and SW values are transmitted with the full 12 bits just as sampled by the ADC. For the other analog samples, only 8 bits is transmitted. The temperatures (PC Temp and Mag Temp) are bipolar values, so the 8 MSB are sent. This gives a value which has a 128 step offset. The other values are either always positive or always negative, so the absolute value is taken of the ADC value minus 2048, and then the 8 MSB of the remaining 11 bit value is sent.

Analog Monitor values can be converted using the following nominal coefficients. The conversion process involves first subtracting the B value, then multiplying by the A value.

**DSC Housekeeping Nominal Calibration Coefficients**

| Value | Bits | A | B | Units |
|---|---|---|---|---|
| Imon | 12 | 0.0724 | 2006.6 | mA |
| SW | 12 | 2.475 | 2047.1 | V |
| PCTemp | 8 | Polynomial | | C * |
| Mag +12V | 8 | 0.0640 | 0 | V |
| Mag Temp | 8 | Polynomial | | C * |
| Mag -12V | 8 | -0.0640 | 0 | V |
| Mag +5V | 8 | 0.032 | 0 | V |
| ERMCPI | 8 | 0.0988 | 0 | mA |
| ERMCPV | 8 | 15.02 | -0.5 | V |
| ERSWPI | 8 | 0.060 | 0 | mA |
| ER -5V | 8 | -0.0258 | 0 | V |
| ER +5V | 8 | 0.0252 | 0 | V |
| ER +12V | 8 | 0.0627 | 0 | V |
| ER +28V | 8 | 0.137 | 0 | V |

*- Temperatures are converted with a polynominals:
V = Value-128 (Value is the value in the Digital Sub-Com, 0-255)
Temp = $a + b*V + c*V^2 + d*V^3$

| Value | a | b | c | d |
|---|---|---|---|---|
| PC Temp | 32.33 | 0.413 | 1.84E-3 | 1.00E-5 |
| MAG Temp | 9.46 | 0.332 | 5.98E-5 | 4.40E-6 |

## 2.6 ER Counter Data Compression Scheme

The ER accumulations are log-compressed to 8 bits. The compression scheme is a 4 bit exponent with 4 bit mantissa (hidden bit) unsigned format with a dynamic range of 1 to 500,000. Un-transmitted bits of the mantissa are truncated, not rounded, so the decompressed values shown in the table below are the minimum value the counter must have had for that code. The counter value above or equal to this value, but below the value for the next highest code. Note that pre-scaled data is also not rounded but truncated.

## ER Counter Compression Scheme

Code (Hex)

| | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 0A | 0B | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 00 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | |
| 10 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | |
| 20 | 32 | 34 | 36 | 38 | 40 | 42 | 44 | 46 | 48 | 50 | 52 | 54 | |
| 30 | 64 | 68 | 72 | 76 | 80 | 84 | 88 | 92 | 96 | 100 | 104 | 108 | |
| 40 | 128 | 136 | 144 | 152 | 160 | 168 | 176 | 184 | 192 | 200 | 208 | 216 | |
| 50 | 256 | 272 | 288 | 304 | 320 | 336 | 352 | 368 | 384 | 400 | 416 | 432 | |
| 60 | 512 | 544 | 576 | 608 | 640 | 672 | 704 | 736 | 768 | 800 | 832 | 864 | |
| 70 | 1024 | 1088 | 1152 | 1216 | 1280 | 1344 | 1408 | 1472 | 1536 | 1600 | 1664 | 1728 | |
| 80 | 2048 | 2176 | 2304 | 2432 | 2560 | 2688 | 2816 | 2944 | 3072 | 3200 | 3328 | 3456 | |
| 90 | 4096 | 4352 | 4608 | 4864 | 5120 | 5376 | 5632 | 5888 | 6144 | 6400 | 6656 | 6912 | |
| A0 | 8192 | 8704 | 9216 | 9728 | 10240 | 10752 | 11264 | 11776 | 12288 | 12800 | 13312 | 13824 | 1 |
| B0 | 16384 | 17408 | 18432 | 19456 | 20480 | 21504 | 22528 | 23552 | 24576 | 25600 | 26624 | 27648 | 2 |
| C0 | 32768 | 34816 | 36864 | 38912 | 40960 | 43008 | 45056 | 47104 | 49152 | 51200 | 53248 | 55296 | 5 |
| D0 | 65536 | 69632 | 73728 | 77824 | 81920 | 86016 | 90112 | 94208 | 98304 | 102400 | 106496 | 110592 | 11 |
| E0 | 131072 | 139264 | 147456 | 155648 | 163840 | 172032 | 180224 | 188416 | 196608 | 204800 | 212992 | 221184 | 22 |
| F0 | 262144 | 278528 | 294912 | 311296 | 327680 | 344064 | 360448 | 376832 | 393216 | 409600 | 425984 | 442368 | 45 |

## 3. Analog Housekeeping

The MAG/ER instrument provides the spacecraft with a single analog line onto-which the instrument multiplexes one of 16 analog housekeeping values. The values are changed at the start of each frame, and the cycle is synchronized to the Major Frame pulse. The multiplexing circuit is powered by the instrument heater bus, so that the measurement is only valid when the instrument heater circuit is on. Half of the values are related to the heater circuit operation, and are valid even if the rest of the instrument is off. The other half are monitors of the ER instrument, and are only valid when the instrument power bus is on and the ER is on. The ER monitors are redundant with values in the Digital Sub-Com (see section 2.5). They are included as monitors of the ER high voltage when the spacecraft is in low telemetry rate mode (300bps), when the science data is not transmitted.

The following table describes the analog housekeeping values, sub-commutation, and calibration. The calibration uses a third order polynomial to convert the counts value in the housekeeping (0-255) to the engineering value in the indicated units:

$$\text{Value} = C0 + C1{*}\text{Counts} + C2{*}\text{Counts}^2 + C3{*}\text{Counts}^3$$

**Analog Housekeeping Calibration Table**

| Frame # | Value | C0 | C1 | C2 | C3 | Units |
|---|---|---|---|---|---|---|
| 0 | ER +28V Monitor | 0.0 | 1.395E-1 | 0.0 | 0.0 | Volts |
| 1 | MAG Heater Power | 0.0 | 2.700E-3 | 2.04E-5 | 4.00E-8 | Watts |
| 2 | ER MCP HV Current | 0.0 | 1.010E-1 | 0.0 | 0.0 | mA |
| 3 | MAG Temperature | -4.08E1 | 8.340E-1 | -4.876E-3 | 1.384E-5 | °C |
| 4 | ER MCP HV Voltage | 8.20E0 | 1.533E1 | 0.0 | 0.0 | Volts |
| 5 | ER Heater Power | 0.0 | 7.20E-3 | -2.00E-5 | 8.00E-8 | Watts |
| 6 | ER Sweep HV Current | 0.0 | 6.138E-2 | 0.0 | 0.0 | mA |
| 7 | ER Temperature | -4.08E1 | 8.340E-1 | -4.876E-3 | 1.384E-5 | °C |
| 8 | ER Sweep HV Voltage | 2.20E0 | 2.022E1 | 0.0 | 0.0 | Volts |
| 9 | Heater +12V Monitor | 0.0 | 6.40E-2 | 0.0 | 0.0 | Volts |
| 10 | ER –5V Monitor | 0.0 | -2.631E-2 | 0.0 | 0.0 | Volts |
| 11 | Heater +5V Monitor | 0.0 | 3.268E-2 | 0.0 | 0.0 | Volts |
| 12 | ER +5V Monitor | 0.0 | 2.570E-2 | 0.0 | 0.0 | Volts |
| 13 | DPU Heater Power | 5.20E-1 | 7.20E-3 | -2.00E-5 | 8.00E-8 | Watts |
| 14 | ER +12V Monitor | 0.0 | 6.401E-2 | 0.0 | 0.0 | Volts |
| 15 | DPU Temperature | -4.08E1 | 8.340E-1 | -4.876E-3 | 1.384E-5 | °C |