RPI Telemetry Data Model

A detailed description of the logical and physical data models for telemetry data produced by the RPI instrument on the IMAGE satellite

Revision 2.8

November 5, 2008
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<td>ApID</td>
<td>Application ID (Telemetry Record Type)</td>
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<td>BIT</td>
<td>Built In Test.</td>
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<td>CDF</td>
<td>Common Data Format.</td>
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<td>CIDP</td>
<td>Central Instrument Data Processor</td>
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<td>CIT</td>
<td>Coherent Integration Time</td>
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<td>DBD</td>
<td>Double Byte Data</td>
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<td>HKD</td>
<td>House Keeping Data.</td>
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<tr>
<td>ICD</td>
<td>Interface Control Document.</td>
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<td>IDFS</td>
<td>Instrument Data File Set</td>
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<td>LTD</td>
<td>Linear Time-domain Data.</td>
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<tr>
<td>LSD</td>
<td>Linear Science Data</td>
</tr>
<tr>
<td>MET</td>
<td>Mission Elapsed Time</td>
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<td>PPS</td>
<td>Pulses Per Second</td>
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<td>PRD</td>
<td>Precision Range Data.</td>
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<tr>
<td>RMS</td>
<td>Root Mean Square</td>
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<tr>
<td>RPI</td>
<td>Radio Plasma Imager</td>
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<td>SBD</td>
<td>Single Byte Data.</td>
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<tr>
<td>S/C</td>
<td>Spacecraft</td>
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<td>SI</td>
<td>Science Instrument.</td>
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<td>SMD</td>
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<td>SPS</td>
<td>Staggered Pulse Sequence.</td>
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<td>SSD</td>
<td>Standard Science Data.</td>
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<td>SST</td>
<td>Schedule Start Time.</td>
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<td>TN</td>
<td>Thermal Noise.</td>
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<td>TPC</td>
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RPI Telemetry Data Model

1 General Considerations

1.1 Purpose

The purpose of this document is to describe RPI Telemetry Data Model that is used by the RPI instrument on the IMAGE satellite to produce full resolution science and housekeeping telemetry data. The Data Model consists of

- a logical data model describing all telemetry data elements, their relationship and organization, and
- a physical data model describing data packetization and physical presentation of the data elements in the telemetry packets.

1.2 Scope

The Data Model describes presentation of the following physical quantities:

- Antenna voltage samples acquired by the RPI in its Active Sounding and Passive Reception operational modes, together with their measurement attributes
- Auxiliary housekeeping data that include Built-In Test status, software messages, and memory content dump.

2 RPI Operating Modes and Data Products

2.1 Active and Passive operating modes

The RPI instrument is a low-power active/passive radar which operates in the radio frequency bands that contain the plasma resonance frequencies characteristic of the Earth's magnetosphere (3 kHz to 3 MHz). The RPI consists of a 10W radio transmitter that emits radio signals propagating through magnetospheric plasma medium, and a sensitive 3-channel receiver system mated to two 500 m dipole wire antennae and one 20 m lattice boom dipole antenna.

In its active operating mode, RPI can locate remote regions of various plasma densities by observing radar echoes. For the RPI transmitter signal to reflect from a remote plasma structure, return to the spacecraft location, and remain above the noise level, a number of conditions have to be met. RPI signals are reflected where the radio frequency is equal to the plasma frequency, and direction of the signal propagation is normal to the local plasma isodensity contour. By stepping through various frequencies for the transmitted signal, features of various plasma densities can be observed.

Resulting data product is RPI plasmagram, an image in which received signal strength (color scale) is a function of echo delay (range in vertical scale) and radio-sounder
frequency (horizontal scale) of the radar pulses (Figure 2.1-1). Radar echoes from important magnetospheric structures, such as the magnetopause and the plasmapause, appear as traces on plasmagrams. Plasmagram traces are intermixed with vertical signatures corresponding to the plasma resonances excited locally by the transmitted signal and various natural emissions propagating in space.

![RPI PLASGRAM](image)

**Figure 2.1-1**  RPI plasmagram measurement

Purpose of the RPI passive radio observation is to detect natural emissions present in the magnetosphere and plasmasphere of the Earth at frequencies between 3 kHz and 3 MHz. Similar to the plasmagram mode, RPI receivers are stepping through various frequencies to observe radio emissions.

Passive-mode observations admit visual presentation as dynamic spectrogram, in which received signal strength (color scale) is a function of frequency (range in vertical scale) and time (horizontal scale).

![RPI DYNAMIC SPECTROGRAM](image)

**Figure 2.1-2**  RPI dynamic spectrogram
RPI Science Telemetry Data Model

3 RPI Science Telemetry Logical Model

3.1 Rationale for Data Model Design

3.1.1 Data volume considerations

RPI is capable of producing data volumes much too high for the telemetry channel throughput. For example, with 5% logarithmic stepping through the nominal frequency band, 128 ranges, 16 repetitions per frequency and 2 polarizations, total data volume collected during a single RPI active sounding measurement is

\[(12 \text{ bit in-phase} +12 \text{ bit quadrature samples}) \times 3 \text{ antennas} \times 16 \text{ Doppler lines} \times 128 \text{ ranges} \times 2 \text{ polarizations} \times 142 \text{ frequencies} = 5,234,688 \text{ bytes}\]

With provision of up to 256 Doppler lines, 1024 ranges and smaller frequency steps these volumes may become even larger.

To overcome the problem of high data traffic, a number of measures is devised.

- **Onboard Rice Lossless compression** performed by CIDP.
- **Data thresholding**, which can substantially improve compression ratio.
- **Logarithmic (lossy) compression.** 33% data reduction can be achieved by storing 8 bit logarithmic scale amplitudes and 8 bit phases instead of 12 bit linear scale quadrature components.
- **Storing phase differences instead of absolute phases.** 16% reduction of spectral data per range bin comes from storing two phase differences relative to the third phase instead of three phases of all three antennas.
- **Collapsing of complete Doppler spectrum to one Doppler line** by selecting the spectrum peak. This is equivalent to considering only one echo per range.
- **Collapsing three antennae to one antenna** by r.m.s. averaging of amplitudes.

It is not necessary to apply all data reduction measures simultaneously. Only onboard compression of data by CIDP is performed always on all RPI data categories. Data thresholding ratio is specified as a measurement program parameter Z (see RPI Commanding document, Section 1.4.2, Table 1.4-1) which can be optimally adjusted by RPI flight software to control data volume. Logarithmic compression proved to be efficient for storage of spectral domain data (see Section 1.1.1 below), and in this case phase differences are always stored instead of absolute phases. Collapsing spectrum and antenna data are strong measures affecting amount of science information and should be used with caution.
3.1.2 Data loss and corruption

Data model design has to consider possibility of partial loss or corruption of individual data sections due to downlink errors and dropouts. Loss of a part of the RPI data record should not cause consequent problems in reading the rest of the data record.

3.2 Databin

Logical Data Model for RPI telemetry data uses concept of enumerated databins. A databin is a basic measurement data element holding antenna voltage samples acquired for a particular frequency and range. The databin concept allows single data representation that is universally applicable to RPI measurements conducted with various combinations of the operating parameters and onboard data reduction schemes. Enumeration of the databins pertaining to the same measurement makes it possible to restore databin attributes even if some of the databins in the original set were damaged or lost.

3.2.1 Databin Types

The databin consists of all measurement data associated with a single frequency/range/Doppler bin (i.e. log amplitude and phase bytes, or alternately real and imaginary amplitudes for 1 or 3 antennas, Doppler shift value). Figure 3.2-1 shows Linear Time Domain (LTD) databin contents. The antenna voltages are sampled twice with 90° phase delay to obtain two 12 bit quadratures per antenna, totaling 9 bytes per databin. The LTD format can be best used for time-domain data (SPS mode, relaxation sounding, chirp sounding).

A more compact Spectral Science Data (SSD) databin (see Figure 3.2-2) is best suited for storing individual lines of the Doppler spectrum.
SSD databin can be obtained from the LTD databin by:

- converting the quadratures to a “polar” representation (i.e., amplitude and phase),
- reducing them to 8 bits (logarithmic compression for the amplitude), and
- subtracting phase of antenna Z from the all phases.

Collapsing of complete Doppler spectrum to one line involves subsequent storage of its Doppler number in the output data bin. Corresponding format 3-Log Polar/8-reduced is shown in Figure 3.2-3.

Precision Group Range technique involves sounding on two closely spaced frequencies with reduction of both frequency data to one Doppler line and calculating phase differences.
with respect to selected phase on the second frequency. The PRD format (Figure 3.2-4) requires storing three amplitudes, five phase differences and one Doppler line.

![Figure 3.2-4. Precision Group Data (PRD) databin](image)

Figure 3.2-4 shows the databin contents for calibration data, which is very similar to SMD or SSD formats, but stores three amplitudes and three (absolute) phases.

![Figure 3.2-5 Calibration Data (CAL) databin](image)

Another two formats are envisioned to store one antenna data, with r.m.s. average amplitude calculated over three antennas. Double Byte Data (DBD) databin stores 1 byte log scale r.m.s. amplitude and 1 byte Doppler number (Figure 3.2-6). SBD (Single Byte Data) databin further reduces resolution of amplitude and Doppler to fit them in 1 byte.
Finally, a databin format is provided for the Thermal noise Time-domain Data (TTD), shown in Figure 3.2-7. In this measurement mode, the following operations are made for each frequency:

**Figure 3.2-7  Thermal-noise Time-domain Data (TTD) databin**

1. For each antenna, $4(2^N)+4$ raw quadrature samples are collected. $N$ is the standard RPI parameter used to specify number of transmitted pulses. No transmission is done
in the thermal noise mode, and all samples are taken consecutively with 3.2 ms sampling period.

2. $2^N$ averaged log amplitudes are computed using 8-point sliding window with 50% overlay.

3. For each set of 8 averaged amplitudes (36 raw quadrature samples), three cross-power terms are calculated (corresponding to the antenna pairs XY, XZ, and YZ).

One TTD databin accommodates:

- eight averaged amplitudes per antenna, totaling $8 \times 3 = 24$ logarithmic scale amplitudes, and
- one set of the amplitude and phase of the cross-power terms XY, XZ, and YZ.

Total size of one TTD databin is therefore $24 + 6 = 30$ bytes. Minimum 36 samples ($N=3$) per antenna have to be collected to produce a good data packet with a single TTD databin per frequency. Maximum value of $N$ is 8, with 32 TTD databins per frequency.

A detailed description of onboard thermal noise data processing is given in Appendix A.

### 3.2.2 Enumerating databins per frequency

The data model design suggests enumeration of all databin types (Figure 3.2-1 - Figure 3.2-7) collected at a particular frequency. Table 3.2-1 enlists the expected number of databins for available RPI measurement modes, signal waveforms, and databin formats.

#### Table 3.2-1 Number of databins per 1 frequency

<table>
<thead>
<tr>
<th>Mode</th>
<th>Waveform</th>
<th>Databin format</th>
<th>Number of databins per 1 frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sounding</td>
<td>SPS [X]=3</td>
<td>LTD</td>
<td># of ranges * # polarizations</td>
</tr>
<tr>
<td>[O]=S</td>
<td>Pulse modes [X]=1,4,5,8,9</td>
<td>LTD</td>
<td># of ranges * # polarizations</td>
</tr>
<tr>
<td></td>
<td>SSD</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SMD</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DBD</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SBD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sounding</td>
<td>Pulse modes [X]=1,4,5,8,9</td>
<td>LTD</td>
<td># of ranges * # polarizations</td>
</tr>
<tr>
<td>[O]=S</td>
<td>Chirp [X]=2</td>
<td>SSD</td>
<td># of ranges * # polarizations</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relaxation</td>
<td>Short pulse [X]=5</td>
<td>LTD</td>
<td># of ranges * # polarizations</td>
</tr>
<tr>
<td>[O]=R</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whistler</td>
<td>0.5 sec pulse [X]=6</td>
<td>LTD</td>
<td># of ranges * # polarizations</td>
</tr>
<tr>
<td>[O]=W</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calibration</td>
<td>Short Pulse [X]=5</td>
<td>CAL</td>
<td>1</td>
</tr>
<tr>
<td>[O]=C</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.2.3 Ordering databins per frequency

The order in which the databins are stored is always the same:

1. Doppler line #1 to \(2^N\) (program parameter \(N\) is # of repetitions)  \(\text{(fastest index)}\)
2. Range #
3. Polarization  \(\text{(slowest index)}\)

With this arrangement, any given databin number can be converted to the databin’s range bin #, polarization and, if used, Doppler line # or repetition #. The following equations for databin number apply:

\[
\widetilde{N}_{DB} = \widetilde{d} + \widetilde{r} \cdot D + \widetilde{p} \cdot D \cdot R\]  \hspace{1cm} (3.2-1)

where

- \(\widetilde{N}_{DB}\) = databin number
- \(D\) = total number of Doppler lines,
- \(R\) = total number of ranges (always assumed 1 for TTD databin)
- \(\widetilde{d}\) = databin Doppler line
- \(\widetilde{r}\) = databin range bin number
- \(\widetilde{p}\) = databin polarization

\(\sim\) means numbering from 0 to \(n-1\) instead of 1 to \(n\).

Restoring of databin parameters is done as follows:

\[
\widetilde{p} = \left\lfloor \frac{\widetilde{N}_{DB}}{D \cdot R} \right\rfloor\]  \hspace{1cm} (3.2-2)

\[
\widetilde{n}_{DB} = \widetilde{N}_{DB} \mod (D \cdot R)\]  \hspace{1cm} (3.2-3)

\[
\widetilde{r} = \left\lfloor \frac{\widetilde{n}_{DB}}{D} \right\rfloor\]  \hspace{1cm} (3.2-4)

\[
\widetilde{d} = \widetilde{n}_{DB} \mod D\]  \hspace{1cm} (3.2-5)

Let’s consider the following example:

RPI Sounding, Complimentary Code X=1, SSD databin, 16 Doppler lines, 64 ranges, 2 polarization. Total number of databins per frequency is \(16 \times 64 \times 2 = 2048\). The databin at Doppler line \(d = 4\) of 16, range \(r = 8\) of 64 and polarization \(p = 2\) of 2 has databin serial number, according to (3.2-1),

\[
N_{DB} = \widetilde{N}_{DB} + 1 = (4 - 1) + (8 - 1) \cdot 64 + (2 - 1) \cdot (8 \cdot 64) + 1 = 1140 \text{ (of 2048)}\]

Reverse calculations using (3.2-2 – 3.2-5) give:
3.3 Operating Modes, Waveforms and Databin Formats

Table 3.3-1 reviews the available choice of RPI scientific data formats, depending on selection of operating mode and waveform.

<table>
<thead>
<tr>
<th>Operating Mode</th>
<th>Waveform</th>
<th>Databin Type</th>
<th>L0.5 Data Format</th>
<th>L1 Data Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active Sounding [O]=S</td>
<td>SPS</td>
<td>LTD</td>
<td>UDF</td>
<td>CDF Plasmagram</td>
</tr>
<tr>
<td></td>
<td>Chirp</td>
<td>DBD</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Complimentary code</td>
<td>LTD</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Long pulse</td>
<td>SMD</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Short pulse</td>
<td>SBD</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>PRD</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>SSD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passive Reception [O]=T</td>
<td>none</td>
<td>TTD</td>
<td>UDF</td>
<td>CDF Dynamic Spectrogram</td>
</tr>
<tr>
<td>Relaxation [O]=R</td>
<td>Short pulse</td>
<td>LTD</td>
<td>UDF</td>
<td>CDF Plasmagram</td>
</tr>
<tr>
<td>Whistler [O]=W</td>
<td>0.5 sec pulse</td>
<td>LTD</td>
<td>UDF</td>
<td>CDF Plasmagram</td>
</tr>
<tr>
<td></td>
<td>1.95 sec pulse</td>
<td>No output</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Calibration [O]=C</td>
<td>Short pulse</td>
<td>CAL</td>
<td>UDF</td>
<td>N/A</td>
</tr>
</tbody>
</table>
4 RPI Science Telemetry Physical Model

4.1 Partitioning data in instrument packets

Enumerated databins are partitioned in instrument packets for delivery to the ground station.

4.1.1 Assignment of ApID to packets

The instrument packets are assigned an ApID value to group data of similar content in packets of the same ApID. The ApID allocation is done by the databin format as indicated in Table 4.1-1.

<table>
<thead>
<tr>
<th>Databin</th>
<th>CAL</th>
<th>DBD</th>
<th>LTD</th>
<th>SMD</th>
<th>SBD</th>
<th>PRD</th>
<th>SSD</th>
<th>TTD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preface [D]</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>ApID</td>
<td>0x0C</td>
<td>0x20</td>
<td>0x30</td>
<td>0x40</td>
<td>0x50</td>
<td>0x60</td>
<td>0x70</td>
<td>0x10</td>
</tr>
</tbody>
</table>

In addition to 8 ApIDs assigned to the science packets, there are four types of the data packets used during development only. The "development" packets are listed and described in Section 8.

4.1.2 Packet Structure Design

Arrangement of data into packets imposes two constrains on the data format design:

1. Packs of the same ApID must have a fixed size.
2. Design should be robust to the loss of some packets during transfer.

A provision must be made to store, for each frequency, the following auxiliary information:

1. MET offset from nadir to calculate spin phase
2. Frequency offset obtained during search of the quietest frequency
3. Autogain selection
4. Antenna Impedance data

The size of data collected at a single frequency may vary substantially. In relaxation sounding mode with 8 ranges, 1 polarization, and single byte SBD content total amount of data per frequency is 8 bytes. In a regular sounding with N=5 (32 Doppler lines), 128 ranges, 2 polarizations and 5 byte SSD content the data per frequency amounts to 40,960 bytes. Thus, structuring of data into packets has to account for possible irregular insertion of auxiliary frequency information in the data.
4.1.3 Headers with auxiliary information

There are two types of headers designed to store complete per-frequency auxiliary information and ensure proper data handling in case of telemetry loss. A Data Header is stored once per packet with Frequency reading, MET nadir offset time and databin serial number related to the first databin in the data portion of the packet. The Data Header provides information necessary to proceed with data unpacking in case of missing previous telemetry packet. A Frequency Header precedes each numerated sequence of databins, containing autogain and frequency search settings, most probable amplitude, and antenna impedance characteristics. The Frequency Header provides necessary per-frequency information.

Detailed description of the headers can be found in Section 4.2.5.

4.1.4 Filling data section of packet

There is no difference in arrangement of the packet for different science data other than contents of the databins. The databins are stored in a packet one by one in accordance to the order described in section 3.2.3 (Next Doppler line# - next range – next polarization). The length of data section in packets is fixed at 3072 bytes (to meet the requirement to have fixed packet lengths for particular ApID). When the end of the defined 3072 byte data section is reached and no more databins can fit the packet, the unused part is zero filled. But, if the end of one frequency is reached before the end of the data block is reached, a frequency header is inserted (again, if there is no room for the frequency header at the end of the data block the block is zero filled). Each new data block contains enough information in the header to identify the first data bin contents, even if the preceding telemetry block is lost.

4.2 General Structure of RPI Data Packet

All Scientific Data Formats have identical general structure of the packet as indicated in Table 4.2-1. The structure always includes CCSDS Preamble, General Header, Preface, Data Header, Frequency Header, Data Section, and Checksum.

<table>
<thead>
<tr>
<th>Table 4.2-1 General Structure of RPI Science Data Packet</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RPI Data Block</strong></td>
</tr>
<tr>
<td>Sec_2.1</td>
</tr>
<tr>
<td>CCSDS Preamble (12 bytes)</td>
</tr>
</tbody>
</table>

4.2.1 CCSDS Preamble

The standard CCSDS preamble consists of 6 byte Primary Header and 6 byte Time Tag, as shown in Table 4.2-2 and Table 4.2-3.
Table 4.2-2  CCSDS Preamble, Primary Header

<table>
<thead>
<tr>
<th>Byte Count No.</th>
<th>Byte Offset No.</th>
<th>Byte Length</th>
<th>Description</th>
<th>Units</th>
<th>Type</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>0..1</td>
<td>0..1</td>
<td>2</td>
<td>16 bit ApID data: HHHHHiiiiAAAAAAA</td>
<td>N/A</td>
<td>Hex</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>H- header indicator</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>i – instrument ID</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A – ApID</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2..3</td>
<td>2..3</td>
<td>2</td>
<td>Sequence Counter</td>
<td>N/A</td>
<td>Unsigned short</td>
<td>N/A</td>
</tr>
<tr>
<td>4..5</td>
<td>4..5</td>
<td>2</td>
<td>Byte Count</td>
<td>N/A</td>
<td>Unsigned short</td>
<td>0-65535</td>
</tr>
</tbody>
</table>

Table 4.2-3  CCSDS Preamble, Time Tag

<table>
<thead>
<tr>
<th>Byte Count No.</th>
<th>Byte Offset No.</th>
<th>Byte Length</th>
<th>Description</th>
<th>Units</th>
<th>Type</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>6..9</td>
<td>6..9</td>
<td>4</td>
<td>MET Coarse Time</td>
<td>100 ms</td>
<td>Unsigned long</td>
<td>0 to 4294967296</td>
</tr>
<tr>
<td>10..11</td>
<td>10..11</td>
<td>2</td>
<td>MET Fine Time</td>
<td>195.3125 us</td>
<td>Short</td>
<td>0, 128-65408</td>
</tr>
</tbody>
</table>

4.2.2  RPI General Header

The general header format is standard for all science data packets. The only difference is in the value content of the ApID. The header identifies the data type, the preface length and the software version number.

Table 4.2-4  RPI General Header

<table>
<thead>
<tr>
<th>Byte Count No.</th>
<th>Byte Offset No.</th>
<th>Byte Length</th>
<th>Description</th>
<th>Units</th>
<th>Type</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>0</td>
<td>1</td>
<td>Application Identification ApID</td>
<td>N/A</td>
<td>int</td>
<td>exact</td>
</tr>
<tr>
<td>13</td>
<td>1</td>
<td>1</td>
<td>Preface length</td>
<td>N/A</td>
<td>int</td>
<td>100</td>
</tr>
<tr>
<td>14</td>
<td>2</td>
<td>1</td>
<td>Software Version Number</td>
<td>N/A</td>
<td>int</td>
<td>0-255</td>
</tr>
</tbody>
</table>

4.2.3  Preface

The “Preface” is standard to for all science data. The Preface (Table 4.2-5) contains the data headers that serve to tag the time/satellite characteristics for each measurement as well as list the required parameters to identify the RPI mode of operation. Unless otherwise specified all values are integers. Note: items in the “description” column that are followed by a bracketed abbreviation (e.g. [L]) correspond exactly to measurement parameters specified in the program parameters in the “Measurement Parameter Table” data (see RPI Commanding document, Section 1.4, Table 1.4-1).
### Table 4.2-5 Preface

<table>
<thead>
<tr>
<th>Byte Count No.</th>
<th>Byte Offset No.</th>
<th>Byte Len</th>
<th>Code</th>
<th>Description</th>
<th>Units</th>
<th>Type</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>15..18</td>
<td>0..3</td>
<td>4</td>
<td>4</td>
<td>Mission Elapsed Time of last nadir [MET] Stamp.</td>
<td>100 millisecond</td>
<td>Long</td>
<td>0 to 4294967296</td>
</tr>
<tr>
<td>19</td>
<td>4</td>
<td>1</td>
<td>N/A</td>
<td>Schedule #</td>
<td>N/A</td>
<td>Byte</td>
<td>1-32</td>
</tr>
<tr>
<td>20</td>
<td>5</td>
<td>1</td>
<td>N/A</td>
<td>Program #</td>
<td>N/A</td>
<td>Byte</td>
<td>1-64</td>
</tr>
<tr>
<td>21..22</td>
<td>6..7</td>
<td>2</td>
<td>01 (L)</td>
<td>Lower Frequency Limit</td>
<td>1kHz</td>
<td>Short</td>
<td>3kHz-3MHz</td>
</tr>
<tr>
<td>23..24</td>
<td>8..9</td>
<td>2</td>
<td>02 (C)</td>
<td>Coarse Frequency If &gt; 0 log steps If &lt; 0 linear steps</td>
<td>1%</td>
<td>Short</td>
<td>1-100%</td>
</tr>
<tr>
<td>25..26</td>
<td>10..11</td>
<td>2</td>
<td>03 (U)</td>
<td>Upper Frequency Limit</td>
<td>1kHz</td>
<td>Short</td>
<td>3kHz-3MHz</td>
</tr>
<tr>
<td>27..28</td>
<td>12..13</td>
<td>2</td>
<td>04 (F)</td>
<td>Fine Frequency Step</td>
<td>100 Hz</td>
<td>Short</td>
<td>100Hz-1MHz</td>
</tr>
<tr>
<td>29</td>
<td>14</td>
<td>1</td>
<td>05 (S)</td>
<td>No. of fine steps (no zero value) negative value disables multiplexing</td>
<td>Unit</td>
<td>Byte</td>
<td>+1 to +8</td>
</tr>
<tr>
<td>30..33</td>
<td>15..18</td>
<td>4</td>
<td>06 (X)</td>
<td>Tx Waveform * 0 = no waveform (passive msmt) 1 = Complimentary (51 msec) 2 = FM/CW “Chirp” (125 msec) 3 = Staggered Pulse (786 chips) 4 = Long Pulse (125 msec) 5 = Short Pulse (3.2 msec) 6 = 0.5 sec Pulse 7 = 1.95 sec Pulse 8 = 8 chip complimentary pulse (25 msec) 9 = 4 chip complimentary pulse (13 msec) -1 to –9 same but no phase switching up to four multiplexed waveforms are supported</td>
<td>Table</td>
<td>Four signed bytes</td>
<td>-9 to +9 (no zero value) Each byte contains information on a waveform used in the run</td>
</tr>
<tr>
<td>34..37</td>
<td>19..22</td>
<td>4</td>
<td>07 (A)</td>
<td>Tx Antenna options * 1 = Radio Silent (no Tx) 2 = X antenna only 3 = Y antenna only 4 = X+Y in linear polarization 5 = Right Circular Polarization RCP 6 = Left Circular Polarization, LCP 7 = RCP &amp; LCP alternate w.r.t. +Z 8 = X+Y switch linear Pol by 90° -1 to –7 same but bypass antenna coupler</td>
<td>Table</td>
<td>Four signed bytes</td>
<td>-8 to +8 (no zero value)</td>
</tr>
<tr>
<td>38..41</td>
<td>23..26</td>
<td>4</td>
<td>08 (N)</td>
<td>No. of Integrated Repetitions * Negative means power integration instead of coherent integration</td>
<td>$2^N$</td>
<td>Four signed bytes</td>
<td>-8 to +8</td>
</tr>
<tr>
<td>42..45</td>
<td>27..30</td>
<td>4</td>
<td>09 (R)</td>
<td>Pulse Repetition Rate*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>--------</td>
<td>-----</td>
<td>--------</td>
<td>------------------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>0.5 pps</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>1.0 pps</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>2.0 pps</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>4.0 pps</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10</td>
<td>10 pps</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>20</td>
<td>20 pps</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>50</td>
<td>50 pps</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table Four bytes 0, 1, 2, 4, 10, 20, 50

<table>
<thead>
<tr>
<th>46-49</th>
<th>31-34</th>
<th>4</th>
<th>10 (O)</th>
<th>Operating Mode*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>Standby</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>Calibration</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>Relaxation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>Sounding</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td>Thermal Noise</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>Whistler</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6</td>
<td>Test Pattern</td>
</tr>
</tbody>
</table>

Table Four bytes 0 to 5

<table>
<thead>
<tr>
<th>50</th>
<th>35</th>
<th>1</th>
<th>11 (W)</th>
<th>Power Limit constraint</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Watts</td>
<td>Byte 0-120</td>
</tr>
<tr>
<td></td>
<td>51</td>
<td>1</td>
<td>12 (E)</td>
<td>Start Range 960 km units</td>
</tr>
<tr>
<td></td>
<td>52</td>
<td>1</td>
<td>13 (H)</td>
<td>Range Resolution 10 km</td>
</tr>
<tr>
<td></td>
<td>53..54</td>
<td>2</td>
<td>14 (M)</td>
<td>No. of range bins 8, 16, 32, 64, 128, 256, 512, 1024</td>
</tr>
<tr>
<td></td>
<td>55</td>
<td>1</td>
<td>15 (G)</td>
<td>Base Gain negative = Fixed Gain positive = Automatic Gain</td>
</tr>
<tr>
<td></td>
<td>56</td>
<td>1</td>
<td>16 (I)</td>
<td>Frequency Search 0 = Disabled n = 5 freq spaced by n*244 Hz negative = Default calibration positive = Dynamic calibration</td>
</tr>
<tr>
<td></td>
<td>57..58</td>
<td>2</td>
<td>17 (P)</td>
<td>No. of ranges stored 1-1024</td>
</tr>
<tr>
<td></td>
<td>59</td>
<td>1</td>
<td>18 (B)</td>
<td>Bottom of range window 1 Mm</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>1</td>
<td>19 (T)</td>
<td>Top of range window 1 Mm</td>
</tr>
<tr>
<td></td>
<td>61..64</td>
<td>4</td>
<td>20 (D)</td>
<td>Databin Format* 0 = No Data 1 = Calibration – CAL 2 = Double Byte Data – DBD 3 = Linear Time Domain – LTD 4 = Spectral Maximum Data – SMD 5 = Single Byte Data – SBD 6 = Precision Range Data – PRD 7 = Spectral Science Data – SSD 8 = Thermal Time Domain – TTD</td>
</tr>
<tr>
<td></td>
<td>65..68</td>
<td>4</td>
<td>21 (Z)</td>
<td>Threshold cleaning, in % * 0 = no thresholding</td>
</tr>
<tr>
<td></td>
<td>69..71</td>
<td>3</td>
<td>22</td>
<td>Spare program parameter</td>
</tr>
<tr>
<td></td>
<td>72</td>
<td>1</td>
<td>57</td>
<td>High RF Noise setting, 0 = no, 1 = yes. Unit Byte 0 or 1</td>
</tr>
<tr>
<td>73..74</td>
<td>58..59</td>
<td>2</td>
<td>CIT length 10 ms Byte 0 to 650sec</td>
<td></td>
</tr>
<tr>
<td>75</td>
<td>60</td>
<td>1</td>
<td>Number of multiplexed programs unit Byte 1</td>
<td></td>
</tr>
<tr>
<td>76..77</td>
<td>61..62</td>
<td>2</td>
<td>Data Status Flags N/A Short N/A</td>
<td></td>
</tr>
<tr>
<td>78..81</td>
<td>63..66</td>
<td>4</td>
<td>Spin Axis Inertial X component 2s Co. Int -1 to +1</td>
<td></td>
</tr>
<tr>
<td>82..85</td>
<td>67..70</td>
<td>4</td>
<td>Spin Axis Inertial Y component 2s Co. Int -1 to +1</td>
<td></td>
</tr>
<tr>
<td>86..89</td>
<td>71..74</td>
<td>4</td>
<td>Spin Axis Inertial Z component 2s Co. Int -1 to +1</td>
<td></td>
</tr>
</tbody>
</table>
Table 4.2-6 Data Header

<table>
<thead>
<tr>
<th>Byte Count No.</th>
<th>Byte Offset No.</th>
<th>Byte Length</th>
<th>Description</th>
<th>Units</th>
<th>Type</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>118..119</td>
<td>0..1</td>
<td>2</td>
<td>Frequency step number</td>
<td>unit</td>
<td>Short</td>
<td>1-65535</td>
</tr>
<tr>
<td>120..121</td>
<td>2..3</td>
<td>2</td>
<td>Time offset from nadir MET</td>
<td>0.1sec</td>
<td>Short</td>
<td>0 to 6553 sec</td>
</tr>
<tr>
<td>122-125</td>
<td>4..7</td>
<td>4</td>
<td>Serial number of the first databin in the packet, ( \hat{N}_{DB} )</td>
<td>unit</td>
<td>Long</td>
<td>0-262143</td>
</tr>
<tr>
<td>126-129</td>
<td>8..11</td>
<td>4</td>
<td>Total number of databins per frequency</td>
<td>unit</td>
<td>Long</td>
<td>8-262144</td>
</tr>
<tr>
<td>130</td>
<td>12</td>
<td>1</td>
<td>Multiplexed program number</td>
<td>unit</td>
<td>Byte</td>
<td>0-3</td>
</tr>
</tbody>
</table>

4.2.4 Calculation of nominal frequencies

RPI selects the actual frequency for transmission by searching for the quietest frequency around the nominal frequency. To obtain the actual sounding frequency,

- the nominal frequency shall be calculated using the Frequency Step Number stored in the Data Header,
- the frequency search adjustment shall be applied using Frequency Search parameter from the Frequency Header.
The Frequency Step Number is converted to the corresponding nominal frequency in kHz using information stored in the Preface. For **linear frequency stepping**, the nominal frequency is:

\[
f_{\text{nom}} = [L] + (-[C]) \cdot \left\lfloor \frac{\tilde{N}}{[S]_a} \right\rfloor + [F] \cdot \left( \tilde{N} \mod [S]_a \right),
\]

(4.2-1)

where

- \([L]\) is Lower Frequency Limit from the Preface,
- \([C]\) is Coarse Frequency Step (reported negative in this case),
- \([S]_a\) is the **absolute value** of Number of Fine Steps,
- \([F]\) is Fine Frequency Step, and
- \(\tilde{N}\) is frequency step number from the Data Header.

\[\left\lfloor x \right\rfloor\] is the **floor** function (the largest integer smaller than the argument)
\[\mod\] is **modulo** function (the remainder of integer division).

Example (see Figure 4.2-1):

\([L] = 100, [C] = -2000\) (i.e., 200 kHz), \([S] = -4, [F] = 250\) (i.e., 25 kHz), \(\tilde{N} = 15\)

\[
f_{\text{nom}} = 100 + (200) \cdot \left\lfloor \frac{15}{4} \right\rfloor + 25 \cdot (15 \mod 4) = 100 + 600 + 25 \cdot 3 = 775.0 \ kHz
\]

**Figure 4.2-1**  Example of nominal frequency calculations: linear steps, 4 multiplexed frequencies

For **logarithmic frequency stepping**, the nominal frequency is:
\[ f_{\text{nom}} = [L] \left( 1 + \left[ \frac{C}{100} \right] \frac{\tilde{N}}{[S]_a} \right) + [F] \cdot \left( \tilde{N} \mod [S]_a \right), \]  

(4.2-2)

where

- \([L]\) is Lower Frequency Limit,
- \([C]\) is Coarse Frequency Step (in %),
- \([S]_a\) is the absolute value of Number of Fine Steps,
- \([F]\) is Fine Frequency Step, and
- \(\tilde{N}\) is frequency step number from the Data Header.

The \([S]\) Fine Steps are linearly spaced.

Example 1:

\[ [L]=100, \ [C]=10, \ [S]=8, \ [F]=3, \ \tilde{N}=23 \]

\[ f_{\text{nom}} = 100 \cdot \left( 1 + \frac{10}{100} \right)^{\frac{23}{8}} + 3 \cdot (23 \mod 8) = 100 \cdot 1.1^2 + 3 \cdot 7 = 121 + 21 = 142.0 \ kHz \]

Example 2:

\[ [L]=3, \ [C]=5, \ [S]=1, \ [F]=\text{don't care}, \ \tilde{N}=100 \]

\[ f_{\text{nom}} = 3 \cdot \left( 1 + \frac{5}{100} \right)^{100} + X \cdot (100 \mod 1) = 3 \cdot 1.05^{100} + 0 = 394.5 \ kHz \]

Note that if \([C]\) is a multiple of 3 (3, 6, 9, 12...), the frequency stepping is not "logarithmic", but "coupler band centers" (see explanations below).

For **coupler band centers frequency stepping**, i.e., when \([C]\) is a positive multiple of 3 (3, 6, 9, 12...) the nominal frequency is taken from a pre-defined table of frequencies. Each of the table frequencies is the center of a coupler band where the maximum efficiency of the tuned transmission is reached. Table of the coupler central frequencies is given in Appendix B.

To convert the frequency index to nominal frequency for the coupler band centers stepping mode, the following procedure shall be used:

1. Find the table frequency closest to the Lower Frequency Limit, \([L]\). (The closest table frequency may appear to be lower or higher than \([L]\).) The found frequency, \(f_{i0}\), will be the first sounding frequency in the measurement, and its index, \(\tilde{N}\), is therefore 0. The index of \(f_{i0}\) in the frequency table will be \(i_{i0}\).

2. Frequency stepping is then done by incrementing the table index, \(i_{i0}\) from \(i_{i0}\) until the Upper Frequency Limit, \([U]\), is exceeded. The increment to \(i\) can be greater than 1 if
faster frequency scanning is required. For \([C]\) equal to 3, 6, 9… the increment to the table index is 1, 2, 3…, correspondingly.

Example 1:

\([L]=100, [C]=6, [S]=1, [F]=\text{don’t care}, \tilde{N}=2\)

Closest table frequency to 100 kHz is 100.500 kHz, index #65. As \([C]\) equal to 6, the table will be scanned with index increment of 2, i.e., #65 (100.5 kHz), #67 (105.0 kHz), #69 (111.5 kHz), etc. The frequency with \(\tilde{N}=2\) is therefore 111.5 kHz.

For **fixed frequency measurements** (i.e., when \([L]\) is equal to \([U]\)), the nominal frequency is:

\[
f_{\text{nom}} = [L] + [F] \cdot (\tilde{N} \mod |S|_a),
\]

where

\([L]\) is Lower Frequency Limit,
\([S]_a\) is the absolute value of Number of Fine Steps,
\([F]\) is Fine Frequency Step, and
\(\tilde{N}\) is frequency step number from the Data Header.

i.e., if no frequency multiplexing is requested (i.e., \([S]\) is 1), all frequencies are equal to \([L]\).

### 4.2.4.2 Calculation of total number of frequencies

The total number of frequencies sampled in a single RPI measurement run can be obtained using the following calculations.

For **linear frequency stepping**, the total number of frequencies is:

\[
N_{\text{total}} = \left(\frac{[U] - [L]}{[C]} + 1\right) \cdot |S|_a
\]

where

\([L]\) is Lower Frequency Limit,
\([U]\) is Upper Frequency Limit,
\([C]\) is Coarse Frequency Step, and
\([S]_a\) is the absolute value of Number of Fine Steps.

For **logarithmic frequency stepping**, the total number of frequencies is:

\[
N_{\text{total}} = \left[\frac{\log \left(\frac{U}{L}\right)}{\log \left(1 + \frac{|C|}{100}\right)} + 1.999\right] \cdot |S|_a
\]
For **coupler band centers frequency stepping**, the total number of frequencies is

\[ N_{\text{total}} = N_{\text{table}} \cdot [S]_a \]  (4.2-6)

where \( N_{\text{table}} \) is number of the coarse frequency steps, which in this case have to be calculated using Table B-1 (Appendix B) containing coupler band center frequencies:

\[ N_{\text{table}} = \frac{(i_{\text{upper}} - i_{\text{lower}})}{[C]/3} + 1 \]  (4.2-7)

where

\[ [C] \] is Coarse Frequency Step,

\( i_{\text{upper}} \) and \( i_{\text{lower}} \) are indeces of the Upper Frequency Limit, \([U]\) and Lower Frequency Limit, \([L]\), correspondingly, in the coupler frequency table, found by searching the table frequency closest to the nominal frequency.

For *fixed frequency measurements*, the total number of different frequencies is \([S]_a\), and transmission is repeated \([C]\) times, hence

\[ N_{\text{total}} = [C] \cdot [S]_a \]  (4.2-8)

### 4.2.5 Frequency Header

The format of Frequency Header is shown in Table 4.2-7.

**Table 4.2-7 Frequency Header**

<table>
<thead>
<tr>
<th>Byte Count No.</th>
<th>Byte Offset No.</th>
<th>Byte Length</th>
<th>Description</th>
<th>Units</th>
<th>Type</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>131</td>
<td>0</td>
<td>1</td>
<td>Gain offset from base gain (4 MSB) Frequency Search (4 LSB)</td>
<td>double steps n*244Hz</td>
<td>Nibble</td>
<td>0-3 (0,2,4,6 gain steps) 0 to 4</td>
</tr>
<tr>
<td>132</td>
<td>1</td>
<td>1</td>
<td>Most probable amplitude</td>
<td>TBD</td>
<td>Byte</td>
<td>TBD</td>
</tr>
<tr>
<td>133</td>
<td>2</td>
<td>1</td>
<td>Current on X antenna [Ix]</td>
<td>10mamp</td>
<td>Byte</td>
<td>0-2.55 amp</td>
</tr>
<tr>
<td>134</td>
<td>3</td>
<td>1</td>
<td>Voltage on +X dipole antenna [V_{x1}]</td>
<td>10 volt</td>
<td>Byte</td>
<td>0-2550 Volt</td>
</tr>
<tr>
<td>135</td>
<td>4</td>
<td>1</td>
<td>Voltage on -X dipole antenna [V_{x2}]</td>
<td>10 volt</td>
<td>Byte</td>
<td>0-2550 Volt</td>
</tr>
<tr>
<td>136</td>
<td>5</td>
<td>1</td>
<td>Current on Y antenna [Iy]</td>
<td>10mamp</td>
<td>Byte</td>
<td>0-2.55 amp</td>
</tr>
<tr>
<td>137</td>
<td>6</td>
<td>1</td>
<td>Voltage on +Y dipole antenna [V_{y1}]</td>
<td>10 volt</td>
<td>Byte</td>
<td>0-2550 Volt</td>
</tr>
<tr>
<td>138</td>
<td>7</td>
<td>1</td>
<td>Voltage on -Y dipole antenna [V_{y2}]</td>
<td>10 volt</td>
<td>Byte</td>
<td>0-2550 Volt</td>
</tr>
<tr>
<td>139-140</td>
<td>8-9</td>
<td>2</td>
<td>First Range Bin</td>
<td>Units</td>
<td>Short</td>
<td>0-511</td>
</tr>
</tbody>
</table>

Storing Frequency Header in each data packet is excessive if more that one packet is required to hold one frequency data, but this measure provides necessary robustness of data format to possible telemetry data losses.

### 4.2.6 Data Section

Data Section contains an array of databins arranged in the sequential order, possibly with frequency headers. The length of the Data Section is fixed at 3072 bytes.
The Data section can hold more than one frequency data and therefore store Frequency Headers (see Section 4.2.5 for format description) which separate individual frequency data. One Frequency Header is placed in front of every databin sequence, unless the Data Section begins with the first databin of the frequency and therefore the Frequency Header preceding the Data Section (see Section 4.2.5) can be used.

The actual frequency setting is not stored in the Frequency Header. To calculate actual frequency of \( n \)th frequency data in the packet, the frequency step number has to be obtained first by adding the frequency step number from the Data Header (see Section 4.2.4) to \( n \). Then, formulas (4.2-1) or (4.2-2) shall be used to obtain the nominal frequency. Finally, the actual frequency is obtained by applying frequency search correction to the nominal frequency:

\[
 f_{act}(n) = f_{nom}(n) + (FS - 2) \cdot [I] \cdot 244 \text{ Hz}
\]

where \( FS \) is frequency search adjustment value from the Frequency Header, and \([I]\) is Frequency Search parameter from the Preface.

**4.2.7 Checksum**

This section contains 1 byte checksum calculated from byte 7 to end of packet by successively applying Exclusive-Or operation on the bytes of the packet.

**Table 4.2-8 Checksum**

<table>
<thead>
<tr>
<th>Byte Count No.</th>
<th>Byte Offset No.</th>
<th>Byte Length</th>
<th>Description</th>
<th>Units</th>
<th>Type</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>N-1</td>
<td>0</td>
<td>1</td>
<td>Checksum</td>
<td>N/A</td>
<td>Byte</td>
<td>0-255</td>
</tr>
</tbody>
</table>
5 Calibration and conversion of measured data to physical units

5.1 Onboard data processing

Figure 5.1-1 shows a complete diagram of RPI onboard data processing, further detailed in subsequent sections of Chapter 3. For illustration purpose, the diagram indicates an assumed signal of 100 nVp/m in the x, y, and z directions undergoing SSD processing with a gain \([G] = 15\) and operation at a frequency of 65 kHz. To simplify the example, the phase differences of the receivers are not reflected in the processing. The signal phase is assumed 0° so that the in-phase component \(I\) is equal to the signal amplitude, and the quadrature component \(Q\) is zero.

5.1.1 Analog signal processing

Figure 5.1-2 shows the diagram of analog signal processing circuitry of RPI.
As Figure 5.1-2 indicates, there are two equal channels, X and Y, each connected to a 500 m dipole antenna. Channel Z is provided with a shorter, 20 m antenna, and therefore has to compensate for the smaller input signal\(^1\) by yielding a higher voltage gain. The broadband preamplifiers in the Z channel have 4 dB more gain than the X/Y preamplifiers, and the Z receiver has ~10 dB more gain. This results in a ~14 dB higher gain in Z channel, unless the high gain setting is selected in the Z preamp. In the latter case, the Z channel has ~26 dB more gain.

All receivers have selectable gain that can be set fixed or chosen optimally in the autogain mode. X and Y gain setting are always set identical, the Z gain is typically greater because of the shorter Z antenna. There are 18 different combinations of two gains (Z and X/Y) that are encoded in a single value of the nominal gain, \([G]\), as shown in Table 5.1-1. The actual gain readings (in dB above the minimum receiver gain) are provided in Table

\(^1\) For frequencies below 300 kHz, the difference in the signal voltages induced in the X/Y antennas are \(\sim 20 \log(500/20) = 28\) dB higher than in the Z antenna.
5.1-2 for the X, Y, and Z channels. The minimum receiver gain is frequency dependent for all receiver channels, and can be derived from the calibration results as discussed below.

*Table 5.1-1 Nominal receiver voltage gains (X, Y, and Z) for various settings of G, in dB relative to the minimum gain at G=1.*

<table>
<thead>
<tr>
<th>G</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
</tr>
</thead>
<tbody>
<tr>
<td>dB steps</td>
<td>0</td>
<td>+6</td>
<td>+12</td>
<td>+18</td>
<td>+24</td>
<td>+30</td>
<td>+30</td>
<td>+30</td>
<td>+36</td>
<td>+42</td>
<td>+48</td>
<td>+54</td>
<td>+48</td>
<td>+54</td>
<td>+42</td>
<td>+48</td>
<td>+54</td>
<td></td>
</tr>
<tr>
<td>Z preamp</td>
<td>low</td>
<td>low</td>
<td>low</td>
<td>low</td>
<td>low</td>
<td>hi</td>
<td>hi</td>
<td>hi</td>
<td>hi</td>
<td>hi</td>
<td>hi</td>
<td>low</td>
<td>low</td>
<td>low</td>
<td>low</td>
<td>low</td>
<td>low</td>
<td>low</td>
</tr>
</tbody>
</table>

*Table 5.1-2 Measured receiver voltage gains for various settings of G, in dB relative to the minimum gain at G=1.*

| G   | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|-----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| X   | 0  | 4.6| 10.9| 18 | 24.3| 30.7| 24.3| 30.7| 37.1| 42.7| 49.1| 55.5| 24.3| 30.7| 37.1| 42.7| 49.1| 55.5|
| Y   | 0  | 3.8| 10.9| 20.6| 24.4| 32.1| 24.4| 32.1| 37.1| 47.3| 55. | 60  | 24.4| 32.1| 37.1| 47.3| 55. | 60  |
| Z   | 0  | 5.2| 9.3 | 20.3| 23.5| 29.2| 35.5| 40.6| 46.7| 56.8| 61.9| 68  | 23.5| 28.6| 34.7| 44.8| 49.9| 56  |

Figure 5.1-3 shows the actual voltage gains in dB of the X, Y, and Z receivers for the gain setting of 15:

\[
g(f) = 20 \log_{10} \frac{V_{out}(f)}{V_{in}(f)}
\]  

(5.1-1)

where \( V_{out}(f) \) is receiver output voltage before the digitizer, and \( V_{in}(f) \) is input voltage at the antenna terminals. Using the actual gains for G=15 and the table of measured gains relative to the minimum gain (Table 3.1-2), it is possible to calculate the gains for all frequencies and base gain settings.
5.1.2 Correcting gain and phase differences of X, Y, and Z receiver channels

RPI measures the 3 orthogonal components of electric field vectors and derives angle-of-arrival of the echoes reflected from magnetospheric plasma. The signals from each antenna go through individual receiver channels that introduce frequency-dependent amplification and phase shifts. Differences between the channel characteristics would introduce errors to angle-of-arrival calculations, unless corrected. Therefore, calibration of the phase and gain characteristics of the receiver channels assumes vital importance to the angle-of-arrival data validity.

To ensure proper compensation of differences between the receiving channels, RPI introduces phase and amplitude corrections, for each sounding frequency, to the quadrature components measured by the X and Y receivers. Channel Z acts as the amplitude and phase reference and therefore is passed through unchanged. The purpose of introducing the corrections is to obtain identical response of all channels to the input signal. Figure 5.1-4 illustrates the correction process, assuming identical field strengths along the x, y, and z directions.

The correction applied to the X and Y channels makes the outputs identical. The actual correction factors are calculated based on measurements of the voltage gain and phase shifts of the receiver channels.
5.1.3 Default and Dynamic calibration

Two calibration modes are implemented

1. "DEFAULT". A CAL Table is stored in the flight software with results of the X, Y, Z channel calibrations obtained in the laboratory (see description of the phase calibration procedure in Appendix C). The key disadvantage of the "default" correction algorithm is its inability to reflect the actual variability of the RPI hardware characteristics with temperature, time, mechanical impacts, etc. during the mission. Also, the CAL Table contains data collected for a particular, predefined set of frequencies, and therefore when the actual sounding frequency does not match any of the frequencies in the default CAL Table, the algorithm has to select the closest available frequency instead.

2. "DYNAMIC": RPI has calibration circuitry that allows the attenuated transmitter signal to go through the receiver channels. The measured receiver response can be directly used to compensate for the inequalities. The dynamic calibration senses the actual receiver characteristics for each sounding frequency immediately before the transmission starts. However, the calibration signals for the X/Y channels are affected by the impedance characteristics of the antennas and therefore the calibration voltages applied at the receiver inputs vary with frequency. A loopback laboratory calibration was conducted to measure the amplitude and phase of the calibration source signal. Further description of the loopback calibration is given in Appendix C.

Either "default" or "dynamic" calibration can be selected in the RPI measurement programs. When dynamic calibration is chosen, it must be combined with the frequency search procedure as both of them are performed during the period of time allocated for the frequency search. Calibration data, regardless of their origin, are reported into the telemetry.
channel in a data packet with ApID = 0x0C. The unified data format (see Section 2) is used to hold calibration data; however, there are no frequency headers in the Data Section of the CAL packets (see section 2.6).

5.1.4 Phase and Amplitude calibration

Gain and phase characteristics of the analog circuitry were studied in laboratory conditions, as described in detail in Appendix C.

5.1.5 Scaling of X and Y channels

For low Z preamp gain, the Z axis channel has ~14 dB more gain than X and Y, but the output signals from the X and Y channels will typically be larger due to the different antenna lengths. An appropriate scaling is required to optimally packet all data for telemetry and avoid data storage related saturation of the X and Y readings. The scaling factor of 1/8 is introduced for the X and Y channel data, which has to be removed during ground data processing to return to the case of matched X, Y, Z channels.

5.1.6 Despinning of X and Y channels

After the differences in X and Y channels are removed by calibration, it becomes possible to compensate for the spinning of the X and Y antennas (nominally at 1/2 rpm). The despinning procedure calculates the projection of the E-field vector in the $x', y', z'$ system, where

- the $x'$ axis points to the center of the Earth,
- the $z'$ axis, equal to the $z$ axis, points in the direction of the orbital angular momentum, and
- the $y'$ axis is perpendicular to the $x'$ axis in the orbital plane.

The IMAGE spin vector points opposite to the $z$ axis, and therefore the voltages in the primed coordinate system are

$$
V_{x'} = V_x \cos 2\pi S t' + V_y \sin 2\pi S t' \\
V_{y'} = -V_x \sin 2\pi S t' + V_y \cos 2\pi S t' \\
V_{z'} = V_z
$$

Here $V_x$, $V_y$, $V_z$ are the corrected voltages in the antenna coordinate system, $S$ is the spin rate ($S = 1/120$ sec), and $t'$ is the time measured from the last alignment of the $x$ axis with the $x'$ axis.

5.1.7 Digital signal processing

Certain RPI waveforms require specialized onboard signal processing. The processing includes pulse compression for the complementary phase code sequences, and spectral analysis for equidistant pulse sequences. For the purpose of calibration and conversion of amplitudes to physical units, it is important that the "digital" gain of the signal processing is known.
5.1.8 Linear-to-log signal compression

In order to reduce the telemetry data volume, some of the output data are converted to amplitude/phase representation and logarithmically compressed. The amplitude $A_{\text{lin}}$ and phase $\phi$ can be obtained from the in-phase and quadrature samples $I$ and $Q$ using equation (5.1-3):

$$
A_{\text{lin}} = \sqrt{I^2 + Q^2}
$$

$$
\phi = \arctg \left( \frac{Q}{I} \right)
$$

(5.1-3)

The phase $\phi$ is then stored in an 8-bit integer, in linear 360º/255 steps. The amplitude $A_{\text{lin}}$ is converted to the logarithmic scale and stored in another 8-bit integer:

$$
A_{\log} = 20 \log_{10}(A_{\text{lin}}) \cdot C_1 + C_2
$$

(5.1-4)

The constants $C_1$ and $C_2$ are selected to accommodate the dynamic range of $A_{\text{lin}}$ in the 256 levels of $A_{\log}$. The choice of $C_1$ and $C_2$ is influenced by the need to minimize real-time computations. By rewriting (3.1-4) as

$$
A_{\log} = \left[ 10 \log_{10}(I^2 + Q^2) \right] \cdot C_1 + C_2
$$

(5.1-5)

the root function does not have to be calculated. Also, $\log_2$ function can be used instead of a slower implementation of $\log_{10}$:

$$
A_{\log} = 10 \frac{\log_2(I^2 + Q^2)}{\log_2 10} \cdot C_1 + C_2 = 3.0103 \cdot \log_2(I^2 + Q^2) \cdot C_1 + C_2
$$

(5.1-6)

$C_1$ shall be then selected to allow enough dynamic range. The 12-bit digitizer produces 12 bit numerical voltage values (11 bits and sign) for $I$ and $Q$. Assuming that both $I$ and $Q$ are saturated, the maximum $A_{\text{lin}}$ is $(2^{11}-1) \cdot \sqrt{2}$. For 4, 8, and 16 chip phase code waveforms, the pulse compression processing (Section 3.1.7) increases the maximum amplitude 4, 8, and 16 times, correspondingly, resulting in $(2^{13}-1) \cdot \sqrt{2}$, $(2^{14}-1) \cdot \sqrt{2}$, and $(2^{15}-1) \cdot \sqrt{2}$ values of the maximum $A_{\text{lin}}$. Therefore, the maximum amplitude to be ever converted to log scale is $32767 \cdot \sqrt{2} = 46340 = 93.32$ dB. Making

$$
C_1 = \frac{8}{3.0103}
$$

(5.1-7)

allows for $255 \cdot 3.0103/8 \approx 96$ dB dynamic range of $A_{\log}$ and a convenient formula for $A_{\log}$ calculation:

$$
A_{\log} = 8 \log_2(I^2 + Q^2) + C_2
$$

(5.1-8)

To simplify the ground processing, $C_2$ is selected to always reference the maximum possible value of $A_{\text{lin}}$, for each waveform, to the maximum level of $A_{\log}$ (i.e., 255):
\[ C_2 = C_3 - C_4 \]
\[ C_3 = 72.547 \quad (5.1-9) \]
\[ C_4 = \begin{cases} 
64, & \text{for 16 – chip code} \\
48, & \text{for 8 – chip code} \\
32, & \text{for 4 – chip code} \\
0, & \text{for all other waveforms} 
\end{cases} \]

Shifting of the reference level by introducing the waveform-dependent \( C_4 \) constant normalizes the DSP gain from the pulse compression (Section 5.1.7) and thus simplifies the log-to-linear decompression algorithm discussed below in the Section 5.2.2.1.

5.2 Converting RPI readings to physical units

Table 5.2-1 shows the choice of physical units for the RPI science data.

<table>
<thead>
<tr>
<th>Measured parameter</th>
<th>Standard units</th>
<th>Stored in the data as</th>
<th>Calibration/Conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Frequency</td>
<td>KHz</td>
<td>Frequency Step Number</td>
<td>Section 2.4.1</td>
</tr>
<tr>
<td>Range</td>
<td>Km</td>
<td>Range Bin Number</td>
<td>Section 3.2.1</td>
</tr>
<tr>
<td>Field Strength</td>
<td>nVp/m(^*)</td>
<td>12 bit quadrature component</td>
<td>Section 3.2.2</td>
</tr>
<tr>
<td>Field Strength</td>
<td>nVp/m(^*)</td>
<td>8 bit log amplitude, except TTD databin</td>
<td>Section 3.2.2</td>
</tr>
<tr>
<td>Voltage</td>
<td>dBV/root-Hz</td>
<td>8 bit log amplitude (TTD databin)</td>
<td>Section 3.2.3</td>
</tr>
<tr>
<td>Antenna voltage</td>
<td>Vrms</td>
<td>8 bit values in Frequency Header</td>
<td>Section 3.2.6</td>
</tr>
<tr>
<td>Antenna current</td>
<td>MA</td>
<td>8 bit values in Frequency Header</td>
<td>Section 3.2.6</td>
</tr>
<tr>
<td>Phase</td>
<td>Degrees</td>
<td>8 bit linear phase</td>
<td>Section 3.2.4</td>
</tr>
<tr>
<td>Doppler Frequency</td>
<td>Hz</td>
<td>Doppler Bin Number</td>
<td>Section 3.2.5</td>
</tr>
</tbody>
</table>

5.2.1 Converting range bin number to km

The range bin number, \( \tilde{r} \), for a particular databin is obtained using Equation 3.2-4, Section 3.2.3. Then the range in km is

\[
R = [E] \cdot 960 + (\tilde{r} + r_{st}) \cdot 10[H] \quad (5.2-1)
\]

where

- \([E]\) is Start Range in 960 km units (from Preface)
- \(\tilde{r}\) is range bin number
- \(r_{st}\) is First Range Bin (from Frequency Header, Table 4.2-7)
- \([H]\) is Range Resolution in 10 km (from Preface), i.e., 24 or 48

* RPI received voltages are defined as peak-to-ground, not rms. Vp corresponds to the amplitude of the phasors (the arrows shown in Figure 3.1-3).
5.2.2 Converting amplitude to field strength in [nVp/m]

Figure 5.2-5 details the ground processing steps to convert measured amplitudes from the raw telemetry representation to the field strengths in [nVp/m]. Onboard calibration tables used by the flight software v31 and below have to be replaced by an updated calibration data now available. Before the calibration corrections to the quadrature samples can be removed, un-despinning of the data has to be done. After the new corrections are introduced, despinning has to be reapplied.

5.2.2.1 Log-to-linear decompression

RPI science data with databin formats SSD, SMD, PRD, SBD and DBD (see Section 3.2) report 8 bit logarithmically compressed amplitudes. The amplitudes have to be converted back to linear scale before they enter the rest of the conversion process:

\[
A_{\text{lin}} = 10^\frac{A_{\text{log}} - C_3}{20C_1}
\]

where \(A_{\text{log}}\) is the stored amplitude, and \(C_1\) and \(C_3\) are the compression algorithm constants:

\[
C_1 = \frac{8}{3.0103}
\]

\[
C_3 = 72.547
\]

Figure 5.2-5 Conversion of amplitudes to physical units.

5.2.2.2 Polar to Rectangular Conversion

For spectral domain data, the in-phase and quadrature components are restored from the amplitude and phase:
\[ I = A_{\text{lin}} \cos \varphi \]
\[ Q = A_{\text{lin}} \sin \varphi \]

where \( \varphi \) is the phase in radians obtained from the 8-bit stored value as discussed below in Section 5.2.4.

**5.2.2.3 Un-despinning**

The de-spinning procedure (Section 5.1.6) has to be undone before the v28 corrections can be removed. The rotation is done in the opposite direction to de-spinning (5.1-2):

\[ V_x = V_{x'} \cos 2\pi S t' - V_y \sin 2\pi S t' \]
\[ V_y = V_{x'} \sin 2\pi S t' + V_y \cos 2\pi S t' \]

\( V_x \) and \( V_y \) are the voltages in the antenna coordinate system, \( S \) is the spin rate (1/120 sec), and \( t' \) is the time measured from the last alignment of the \( x \) axis with the \( x' \) axis. For all time domain data, \( t' \) is the time offset from the nadir, \( \Delta T_{\text{nadir}}(f) \), stored in Data Header of each telemetry packet. If more than one frequency data fits one packet, \( \Delta T_{\text{nadir}}(f) \) for the second, third, … frequency of the packet has to be interpolated (or extrapolated, for the last packet). For the spectral domain data, 0.5 CIT has to be added to \( t' \) (see Section 5.2.5 for CIT calculation). Spin rate magnitude \( S \) is stored in the Preface.

**5.2.2.4 Un-scaling**

All X and Y channel data had been scaled down by a factor of 8 for the purpose of optimal binary data storage (see Section 5.1.5). This factor has to be removed here by multiplying the amplitudes by 8.

**5.2.2.5 Removing correction factors**

Only amplitude corrections for the flight software v31 and below have to be removed, so the un-calibration procedure is simply:

\[ O_{x,y} = \frac{Q_{x,c,y}}{A_{x,c,y}} \]
\[ I_{x,y} = \frac{I_{x,c,y}}{A_{x,c,y}} \]

where \( A_{x,c} \) and \( A_{y,c} \) are the amplitude corrections introduced by the flight software. The onboard correction factors are reported in the calibration packet as 8-bit log-scale amplitudes and 8-bit phases for the channels X, Y, and Z. \( A_{x,c} \) and \( A_{y,c} \) can be restored from CAL packet data using the following formula:

\[ A_{x,c,y} = \frac{2 \cdot 8}{1000\sqrt{2}} \cdot \frac{\text{CAL}_{x,y} - 72.547}{53.151} = 0.0113137 \cdot 10^{\text{CAL}_{x,y} - 72.547} \]

where \( \text{CAL}_x \) and \( \text{CAL}_y \) are the calibration amplitudes of X and Y channels.
5.2.2.6 Re-calibrating

Re-calibration involves amplitude scaling only, and therefore can be expressed simply as

\[ Q'_{x,y} = Q_{x,y} \cdot A'_{x,y} \]
\[ I'_{x,y} = I_{x,y} \cdot A'_{x,y} \]  (5.2-8)

The table with the new amplitude correction factors \( A'_{x,y} \) and \( A'_{y,x} \) can be found in Appendix C, Table C1-1.

5.2.2.7 Despinning

The de-spinning procedure (Section 5.1.6) has to be done after the new corrections are applied, using the equations (5.1-2) and the offset time \( t' \) from Section 5.2.2.3.

5.2.2.8 Applying coefficients from the Physical Units Table

The Physical Units Table Each table has coefficients \( C_{x,y,z}(f, [G]) \) in [nV/unit] for all settings of base gain \([G]\) and selected set of frequencies. The table is derived from the \( Z \) channel calibration results obtained during the amplitude calibration at \([G] = 15 \) (see description of the calibration in Appendix C and the coefficient values in Table C3-1). The coefficients for other settings of \([G]\) are obtained using the relative gain data shown in Table 5.1-1:

\[ C_{x,y,z}(f,[G]) = C_{x,y,z}(f,15) \cdot 10^{\frac{C_{x,y,z}(f,15) - C_{x,y,z}(f,[G])}{20}} \]  (5.2-9)

5.2.2.9 Calculations of field strength

The received field strength, \( E_R \), is proportional to the antenna voltage, \( V \):

\[ \vec{E}_R = \frac{1}{L'} \vec{V} \]  (5.2-10)

where the proportionality factor \( L' \) is the effective antenna length, \( L' \approx 0.5L_a \), \( L_a \) is the tip-to-tip dipole length. The effective antenna lengths are

\[ L'_x = L'_y = 250m \]
\[ L'_z = 10m \]  (5.2-11)

5.2.3 Converting thermal noise amplitudes to \([ \text{dBVrms/\sqrt{Hz}} ]\)

The processing steps to convert thermal noise amplitudes from the raw telemetry representation to \([ \text{dBVrms/\sqrt{Hz}} ]\) are shown in Figure 5.2-6.
Logarithmic compression of TTD amplitudes is done differently from the spectral domain data (see Appendix A). To convert TTD amplitudes to the linear scale, the following formula is used:

$$ A_{lin} = 10^{\frac{1}{\ln(10)}(A_{log}+9.031)-9.031} $$

(3.2-12)

Un-scaling, un-calibrating, re-calibrating and conversion to nVp is done the same way it is done for other databins. Then nVp are converted to Vrms, and then the thermal noise energy collected over the receiver bandwidth of 300 Hz is normalized to 1 Hz, which corresponds to $1/\sqrt{300}$ factor in voltage. Finally, the value is put in dB scale.

### 5.2.4 Converting phase data to physical units

All phase values given in the RPI data can be converted from 8 bit integer number to $1^\circ$ units by multiplying them with 360/255.

### 5.2.5 Converting Doppler bin number to Hz

The coherent integration time is

$$ T = \frac{2^{[N_a]}}{[R']} \cdot [S]' \cdot [R]' $$

(3.2-13)

- $[N_a]$ is absolute value of Number of Repetitions
- $[S]'$ is the Number of Fine Steps, $[S]$, only if it is a positive value, 1 otherwise
- $[R]'$ is Pulse Repetition Rate in pps units; when $[R]$ from Preface is 0, $[R]'$ is 0.5

The Doppler frequency increments are
\[ \Delta d = \frac{1}{T}, \text{ [Hz]} \]  

(3.2-14)

The Doppler frequencies corresponding to the Doppler bin numbers are listed in Table 5.2-2.

**Table 5.2-2 Doppler shift frequency**

<table>
<thead>
<tr>
<th>[N]</th>
<th>Doppler bin numbers</th>
<th>Doppler frequencies, Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>N/A</td>
</tr>
<tr>
<td>1</td>
<td>1-2</td>
<td>-1/2(\Delta d), +1/2(\Delta d)</td>
</tr>
<tr>
<td>2</td>
<td>1-4</td>
<td>-1/2(\Delta d), -1/2(\Delta d), +1/2(\Delta d), +3/2(\Delta d)</td>
</tr>
<tr>
<td>3</td>
<td>1-8</td>
<td>-1/2(\Delta d), -1/2(\Delta d), ...,-1/2(\Delta d), +1/2(\Delta d), ...,+3/2(\Delta d), +5/2(\Delta d)</td>
</tr>
<tr>
<td>4</td>
<td>1-16</td>
<td>-1/2(\Delta d), -13/2(\Delta d), ...,-1/2(\Delta d), +1/2(\Delta d), ...,+13/2(\Delta d), +15/2(\Delta d)</td>
</tr>
<tr>
<td>5</td>
<td>1-32</td>
<td>-1/2(\Delta d), -27/2(\Delta d), ...,-1/2(\Delta d), +1/2(\Delta d), ...,+27/2(\Delta d), +31/2(\Delta d)</td>
</tr>
<tr>
<td>6</td>
<td>1-64</td>
<td>-63/2(\Delta d), -63/2(\Delta d), ...,-1/2(\Delta d), +1/2(\Delta d), ...,+63/2(\Delta d), +63/2(\Delta d)</td>
</tr>
<tr>
<td>7</td>
<td>1-128</td>
<td>-127/2(\Delta d), -127/2(\Delta d), ...,-1/2(\Delta d), +1/2(\Delta d), ...,+127/2(\Delta d), +127/2(\Delta d)</td>
</tr>
</tbody>
</table>

### 5.2.6 Converting antenna impedance data to physical units

Frequency Header contains six 8-bit values from the antenna impedance measurement:

**Table 5.2-3 Antenna impedance data in physical units**

<table>
<thead>
<tr>
<th>Measured characteristic</th>
<th>Physical Units</th>
<th>Conversion Polynomial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current on X antenna ([I_x]) mA</td>
<td>0.017196<em>x^2+23.697063</em>x+18.055805</td>
<td></td>
</tr>
<tr>
<td>Voltage on +X dipole antenna ([V_{x1}]) V(r.m.s)</td>
<td>0.001041<em>x^3-0.079089</em>x^2+6.833423*x+77.628601</td>
<td></td>
</tr>
<tr>
<td>Voltage on -X dipole antenna ([V_{x2}]) V(r.m.s)</td>
<td>0.000340<em>x^3-0.072471</em>x^2+10.139749*x+27.581501</td>
<td></td>
</tr>
<tr>
<td>Current on Y antenna ([I_y]) mA</td>
<td>0.021766<em>x^3+21.881399</em>x+15.814330</td>
<td></td>
</tr>
<tr>
<td>Voltage on +Y dipole antenna ([V_{y1}]) V(r.m.s)</td>
<td>0.041969<em>x^2+3.503154</em>x+96.108014</td>
<td></td>
</tr>
<tr>
<td>Voltage on -Y dipole antenna ([V_{y2}]) V(r.m.s)</td>
<td>0.039404<em>x^2+3.459442</em>x+96.996135</td>
<td></td>
</tr>
</tbody>
</table>
RPI Level 0 House Keeping Data Formats

The following sections introduce and describe the formats for housekeeping (HK) data produced by the RPI instrument, which include R_HK Housekeeping packet with Build-In Test results, R_SRD Segment Report packet containing the contents of RPI SRAM segments, R_MSG Software Message packet containing software generated message, and R_ECH Command Echo packet with a copy of the latest ground command.

6 HOUSE KEEPING DATA

There are four RPI housekeeping (HK) data packets reporting various information pertaining to instrument operations. All HK packets include the standard CCSDS data header, followed by HK Header, Data Block whose content depends on the type of HK information, and a checksum as shown in Table 5.2-1.

<table>
<thead>
<tr>
<th>Table 5.2-1 Universal RPI Housekeeping packet format</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sec 4.2.1</td>
</tr>
<tr>
<td>CCSDS Preamble</td>
</tr>
</tbody>
</table>

6.1 Housekeeping Header

Housekeeping Header format is identical to all four HK packets (R_HK, R_SRD, R_MSG, and R_ECH). It contains five items, as shown in Table 6.1-1.

<table>
<thead>
<tr>
<th>Table 6.1-1 HK Header</th>
</tr>
</thead>
<tbody>
<tr>
<td>Byte Count Offset</td>
</tr>
<tr>
<td>7</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>9..12</td>
</tr>
<tr>
<td>13..16</td>
</tr>
<tr>
<td>17..18</td>
</tr>
</tbody>
</table>

Packet ApID is preserved for data identification purpose outside the standard data archive environment. Software version is reported for backward compatibility in case of design changes. CIDP and RPI time stamps are given for the clock comparison purpose. Orbital position phase is given to verify calculation algorithm.
6.2 (R_HK) House Keeping data sets. ApID = 0x02

The RPI house keeping represents the RPI health and safety data packet. The R_HK packet is generated by RPI to report on system (hardware and software) status. The packet is sent periodically (nominally every 10 minutes) or by request from the ground. The structure of the data block is given in subsequent sections. Each section describes part of the data block that is given by the overview in Table 6.2-1.

### Table 6.2-1 RPI House Keeping data format

<table>
<thead>
<tr>
<th>Sec 4.2.1</th>
<th>Sec 6.1</th>
<th>Sec 6.2.1</th>
<th>Sec 6.2.2</th>
<th>Sec 6.2.3</th>
<th>Sec 6.2.4</th>
<th>Sec 6.2.5</th>
<th>Sec 6.2.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>HK</td>
<td>Misc.</td>
<td>Digital</td>
<td>Analog</td>
<td>Power</td>
<td>Checksum</td>
<td></td>
</tr>
<tr>
<td>Packet</td>
<td>Header</td>
<td>status info</td>
<td>Sensors</td>
<td>Sensors</td>
<td>Limits</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preamble</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### 6.2.1 Miscellaneous status information

This section contains various status information items listed in Table 6.2-2.

### Table 6.2-2 Miscellaneous status information

<table>
<thead>
<tr>
<th>Byte Count Offset</th>
<th>Byte Offset No</th>
<th>Byte Length</th>
<th>Description</th>
<th>Units</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>19..22</td>
<td>0</td>
<td>4</td>
<td>Last SST in the SST Queue</td>
<td>0.1 sec</td>
<td>0 to 4294967296</td>
</tr>
<tr>
<td>23</td>
<td>4</td>
<td>1</td>
<td>Memory checksum failure</td>
<td>N/A</td>
<td>0..1, 1 -failed</td>
</tr>
<tr>
<td>24</td>
<td>5</td>
<td>1</td>
<td>Program status (format variable)</td>
<td>N/A</td>
<td>0-255</td>
</tr>
<tr>
<td>25</td>
<td>6</td>
<td>1</td>
<td>Communication Status (from serial port UART)</td>
<td>N/A</td>
<td>0-255</td>
</tr>
</tbody>
</table>

#### 6.2.2 Digital Sensor Readings

This section contains digital sensor readings in accordance with the state of digital I/O lines on the BIT card.

### Table 6.2-3 Digital sensor readings

<table>
<thead>
<tr>
<th>Byte Count Offset</th>
<th>Byte Offset No</th>
<th>Byte Length</th>
<th>Description</th>
<th>Units</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>26</td>
<td>0</td>
<td>1</td>
<td>Digital sensor readings</td>
<td>N/A</td>
<td>0-255</td>
</tr>
</tbody>
</table>

Each bit of the status byte signifies if reading is valid or not valid. The actual bit readings need to be compared against the expected "Go" value to correctly interpret the result. This comparison is done onboard to fill the NoGo Table where 1 always indicates "NoGo" (and 0 indicates "Go").

The Digital Sensors names and "Go" condition are listed in Table 6.2-4. The following categories of signals are monitored:

- 16MHz RPI master 16 MHz oscillator signal
• Vc  Antenna coupler voltages +12 and +24V
• V  DC -5, -15 and +15V

Table 6.2-4  Digital Sensor Readings

<table>
<thead>
<tr>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal name</td>
<td>-</td>
<td>16 MHz</td>
<td>+24 Vc</td>
<td>-</td>
<td>+12Vc</td>
<td>-5V</td>
<td>-15 V</td>
</tr>
<tr>
<td>GO condition</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Go conditions for digital sensors are specified in the onboard ARMENU control structure, question 351 (see RPI Commanding document, Section 2).

6.2.3 Analog Sensor Readings

This section contains the measurements from the analog input channels on the BIT card. The values are 16 bit integers with 12 bits containing raw value from the ADC.

Table 6.2-5  Analog sensor readings

<table>
<thead>
<tr>
<th>Byte Count Offset</th>
<th>Byte Offset No</th>
<th>Byte Length</th>
<th>Description</th>
<th>Type</th>
<th>Units</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>27,28</td>
<td>0,1</td>
<td>2</td>
<td>Channel.00 Xmtr Xb</td>
<td>B</td>
<td>5/4096 V</td>
<td>0-2.5 V</td>
</tr>
<tr>
<td>29,30</td>
<td>2,3</td>
<td>2</td>
<td>Channel.01 Xmtr Yb</td>
<td>B</td>
<td>5/4096 V</td>
<td>0-2.5 V</td>
</tr>
<tr>
<td>31,32</td>
<td>4,5</td>
<td>2</td>
<td>Channel.02 1st Lob</td>
<td>B</td>
<td>5/4096 V</td>
<td>0-2.5 V</td>
</tr>
<tr>
<td>33,34</td>
<td>6,7</td>
<td>2</td>
<td>Channel.03 SysTemp</td>
<td>S</td>
<td>5/4096 V</td>
<td>0-2.5 V</td>
</tr>
<tr>
<td>35,36</td>
<td>8,9</td>
<td>2</td>
<td>Channel.04 500 kb</td>
<td>B</td>
<td>5/4096 V</td>
<td>0-2.5 V</td>
</tr>
<tr>
<td>37,38</td>
<td>10,11</td>
<td>2</td>
<td>Channel.05 3.84 Mb</td>
<td>S</td>
<td>5/4096 V</td>
<td>0-2.5 V</td>
</tr>
<tr>
<td>39,40</td>
<td>12,13</td>
<td>2</td>
<td>Channel.06 95 kb</td>
<td>S</td>
<td>5/4096 V</td>
<td>0-2.5 V</td>
</tr>
<tr>
<td>41,42</td>
<td>14,15</td>
<td>2</td>
<td>Channel.07 X+Tmp</td>
<td>B</td>
<td>5/4096 V</td>
<td>0-2.5 V</td>
</tr>
<tr>
<td>43,44</td>
<td>16,17</td>
<td>2</td>
<td>Channel.08 X-Tmp</td>
<td>B</td>
<td>5/4096 V</td>
<td>0-2.5 V</td>
</tr>
<tr>
<td>45,46</td>
<td>18,19</td>
<td>2</td>
<td>Channel.09 Y+Tmp</td>
<td>S</td>
<td>5/4096 V</td>
<td>0-2.5 V</td>
</tr>
<tr>
<td>47,48</td>
<td>20,21</td>
<td>2</td>
<td>Channel.10 Y-Tmp</td>
<td>S</td>
<td>5/4096 V</td>
<td>0-2.5 V</td>
</tr>
<tr>
<td>49,50</td>
<td>22,23</td>
<td>2</td>
<td>Channel.11 Ztmp</td>
<td>S</td>
<td>5/4096 V</td>
<td>0-2.5 V</td>
</tr>
<tr>
<td>51,52</td>
<td>24,25</td>
<td>2</td>
<td>Channel.12 RFX+</td>
<td>B</td>
<td>5/4096 V</td>
<td>0-2.5 V</td>
</tr>
<tr>
<td>53,54</td>
<td>26,27</td>
<td>2</td>
<td>Channel.13 RFX-</td>
<td>B</td>
<td>5/4096 V</td>
<td>0-2.5 V</td>
</tr>
<tr>
<td>55,56</td>
<td>28,29</td>
<td>2</td>
<td>Channel.14 RFY+</td>
<td>B</td>
<td>5/4096 V</td>
<td>0-2.5 V</td>
</tr>
<tr>
<td>57,58</td>
<td>30,31</td>
<td>2</td>
<td>Channel.15 RFY-</td>
<td>B</td>
<td>5/4096 V</td>
<td>0-2.5 V</td>
</tr>
<tr>
<td>59,60</td>
<td>32,33</td>
<td>2</td>
<td>Channel.16 RFSpmpZ</td>
<td>B</td>
<td>5/4096 V</td>
<td>0-2.5 V</td>
</tr>
<tr>
<td>61,62</td>
<td>34,35</td>
<td>2</td>
<td>Channel.17 RFSpmpX</td>
<td>B</td>
<td>5/4096 V</td>
<td>0-2.5 V</td>
</tr>
<tr>
<td>63,64</td>
<td>36,37</td>
<td>2</td>
<td>Channel.18 IFSpmpZ</td>
<td>B</td>
<td>5/4096 V</td>
<td>0-2.5 V</td>
</tr>
<tr>
<td>65,66</td>
<td>38,39</td>
<td>2</td>
<td>Channel.19 IFSpmpY</td>
<td>B</td>
<td>5/4096 V</td>
<td>0-2.5 V</td>
</tr>
<tr>
<td>67,68</td>
<td>40,41</td>
<td>2</td>
<td>Channel.20 2500 b</td>
<td>S</td>
<td>5/4096 V</td>
<td>0-2.5 V</td>
</tr>
<tr>
<td>69,70</td>
<td>42,43</td>
<td>2</td>
<td>Channel.21 400 kb</td>
<td>S</td>
<td>5/4096 V</td>
<td>0-2.5 V</td>
</tr>
<tr>
<td>71,72</td>
<td>44,45</td>
<td>2</td>
<td>Channel.22 XvarI</td>
<td>B</td>
<td>5/4096 V</td>
<td>0-2.5 V</td>
</tr>
<tr>
<td>73,74</td>
<td>46,47</td>
<td>2</td>
<td>Channel.23 YvarI</td>
<td>B</td>
<td>5/4096 V</td>
<td>0-2.5 V</td>
</tr>
<tr>
<td>75,76</td>
<td>48,49</td>
<td>2</td>
<td>Channel.24 YvarV</td>
<td>B</td>
<td>5/4096 V</td>
<td>0-2.5 V</td>
</tr>
</tbody>
</table>

Type B = Burst measurement of a pulse signal must be done during sounding only.
Type S = Single measurement of a continuous signal may be done anytime.
6.2.4 NoGo Table

This section contains 5 bytes indicating Go/NoGo condition of all sensor readings. Each bit of the NoGo Table bytes is set to 1 (NoGo) if:

- analog sensor reading is outside the onboard red tolerance limits or digital sensor reading is not GO and
- the sensor is specified as capable of generating NoGo condition.

Onboard red limits are specified in questions 330-343 of the ARMENU control structure (see RPI Commanding document, section 2.1), GO conditions of digital sensors are given in question 351 of the ARMENU structure, and sensors capable of generating NoGo condition are listed in questions 361-365.

Table 6.2-6  NoGo Table

<table>
<thead>
<tr>
<th>Byte</th>
<th>Byte</th>
<th>Byte</th>
<th>Description</th>
<th>Units</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Count</td>
<td>Offset</td>
<td>No</td>
<td>Offset</td>
<td>Byte</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Byte</td>
<td>Offset</td>
<td>Offset</td>
<td></td>
</tr>
<tr>
<td>77</td>
<td>0</td>
<td>1</td>
<td>Digital Sensor</td>
<td>N/A</td>
<td>0-255</td>
</tr>
<tr>
<td>78</td>
<td>1</td>
<td>1</td>
<td>Analog Status : Ch00-Ch07</td>
<td>N/A</td>
<td>0-255</td>
</tr>
<tr>
<td>79</td>
<td>2</td>
<td>1</td>
<td>Analog Status : Ch08-Ch15</td>
<td>N/A</td>
<td>0-255</td>
</tr>
<tr>
<td>80</td>
<td>3</td>
<td>1</td>
<td>Analog Status : Ch16-Ch23</td>
<td>N/A</td>
<td>0-255</td>
</tr>
<tr>
<td>81</td>
<td>4</td>
<td>1</td>
<td>Analog Ch24 and Reserved Bits</td>
<td>N/A</td>
<td>0-255</td>
</tr>
</tbody>
</table>

The Digital and Analog sensor flags and their associated reading parameters are listed in Table 6.2-7.

Table 6.2-7  Digital and Analog sensor flag parameters

<table>
<thead>
<tr>
<th>Line Count</th>
<th>Category</th>
<th>D7</th>
<th>D6</th>
<th>D5</th>
<th>D4</th>
<th>D3</th>
<th>D2</th>
<th>D1</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Byte 1 digital</td>
<td></td>
<td>16 MHz</td>
<td>+24 Vc</td>
<td>-</td>
<td>+12Vc</td>
<td>-5V</td>
<td>-15 V</td>
<td>+15 V</td>
</tr>
<tr>
<td>4</td>
<td>Ch00-Ch07 analog</td>
<td>XMTR 1</td>
<td>XMTR 2</td>
<td>1st LO</td>
<td>SysTemp</td>
<td>C140K Hz</td>
<td>3.84M Hz</td>
<td>95kHz</td>
<td>X+tmp</td>
</tr>
<tr>
<td>5</td>
<td>Ch08-Ch15 analog</td>
<td>X-tmp</td>
<td>Y+tmp</td>
<td>Y-tmp</td>
<td>Ztmp</td>
<td>RFX+</td>
<td>RFX-</td>
<td>RFY-</td>
<td>RFY+</td>
</tr>
<tr>
<td>6</td>
<td>Ch16-Ch23 analog</td>
<td>RFSmpZ</td>
<td>RFSmpX</td>
<td>IFsmpZ</td>
<td>IFsmpX</td>
<td>2500 Hz</td>
<td>400 kHz</td>
<td>Xvarl</td>
<td>Yvarl</td>
</tr>
<tr>
<td>7</td>
<td>Reserved</td>
<td>XyvarV</td>
<td>Reserved</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6.2.5 RPI Power Limits

If necessary, PRI can be instructed to use power limit different from the limit specified in the measurement programs (see program parameter 11(W) in the Preface, Section 4.2.3). There is a pass-through command R_SYS_PLIM_SET that specifies Peak and Average power limits. Before running a program, RPI evaluates all available limits, and selects the minimum.
The following section of HK packet reports current settings of peak and average power limits as instructed from the ground.

**Table 6.2-8  Peak and Average Power Limits**

<table>
<thead>
<tr>
<th>Byte Count Offset</th>
<th>Byte Offset No</th>
<th>Byte Length</th>
<th>Description</th>
<th>Units</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>82</td>
<td>0</td>
<td>1</td>
<td>Peak Power Limit</td>
<td>Watts</td>
<td>0-255</td>
</tr>
<tr>
<td>83</td>
<td>1</td>
<td>1</td>
<td>Average Power Limit</td>
<td>Watts</td>
<td>0-255</td>
</tr>
</tbody>
</table>

6.3  **(R_SRD) Segment Report data set. ApID=0x04**

This report segment is generated by RPI in response to the ground request R_MEM_DATA_SEND, which instructs RPI to downlink a specific segment of memory from the RPI CPU. The segment can be a section of the flight software or one of the control data structures (Programs, Schedules, SST Tables, ARMENU). The structure of the Segment Report packet is given in Table 6.3-1.

**Table 6.3-1  RPI Segment Report data format**

<table>
<thead>
<tr>
<th>RPI-SRD Block</th>
<th>Sec_4.2.1</th>
<th>Sec_6.1</th>
<th>Sec_6.3.1</th>
<th>Sec_4.2.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Packet</td>
<td>HK</td>
<td>Segment data</td>
<td>Checksum</td>
<td></td>
</tr>
<tr>
<td>Preamble</td>
<td>HK</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6.3.1  **Segment Data**

The segment data are stored in accordance to the format described in Table 6.3-2.

**Table 6.3-2  Segment Data**

<table>
<thead>
<tr>
<th>Byte Count Offset</th>
<th>Byte Offset No</th>
<th>Byte Length</th>
<th>Description</th>
<th>Units</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>19..20</td>
<td>0..1</td>
<td>2</td>
<td>SCLen Segment length</td>
<td>N/A</td>
<td>0-65536</td>
</tr>
<tr>
<td>21..24</td>
<td>2..5</td>
<td>4</td>
<td>Segment Address</td>
<td>32 bit words</td>
<td>0-0x00FFFFFFFF</td>
</tr>
<tr>
<td>25..SCLen*4+25</td>
<td>3..SCLen*4+3</td>
<td>SCLen*4</td>
<td>Segment Contents</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

6.4  **(R_MSG) Software Message. ApID=0x06**

When a software fault is detected, a R_MSG software message packet is generated. The message contains a message code (associated with a table for identification of the problem type), and two message parameters. The structure of the Software Message packet is given in Table 6.4-1.

**Table 6.4-1  RPI Segment Report data format**

<table>
<thead>
<tr>
<th>RPI-MSG Block</th>
<th>Sec_4.2.1</th>
<th>Sec_6.1</th>
<th>Sec_6.4.1</th>
<th>Sec_4.2.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Packet</td>
<td>HK</td>
<td>Software message</td>
<td>Checksum</td>
<td></td>
</tr>
</tbody>
</table>

Printed: 12/12/08
6.4.1 Software Message

Table 6.4-2 Software message

<table>
<thead>
<tr>
<th>Byte Count Offset</th>
<th>Byte Offset</th>
<th>Byte Length</th>
<th>Description</th>
<th>Units</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>0</td>
<td>1</td>
<td>Message Code</td>
<td>Table 7.1-2</td>
<td>0-255</td>
</tr>
<tr>
<td>20..23</td>
<td>1..4</td>
<td>4</td>
<td>Message Parameter #1</td>
<td>Table 7.1-2</td>
<td>Message dependent</td>
</tr>
<tr>
<td>24..27</td>
<td>5..8</td>
<td>4</td>
<td>Message Parameter #2</td>
<td>Table 7.1-2</td>
<td>Message dependent</td>
</tr>
</tbody>
</table>

Message codes and the associated parameters are listed in Table 6.4-3.

Table 6.4-3 Message Codes and Parameters

<table>
<thead>
<tr>
<th>Message Code</th>
<th>Message Code Description</th>
<th>Message Parameters Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>202 0xCA</td>
<td>CIT start timeout</td>
<td>#1 -- Timeout, sec</td>
</tr>
<tr>
<td>203 0xCB</td>
<td>Pulse start timeout</td>
<td>#1 -- Timeout, sec</td>
</tr>
<tr>
<td>204 0xCC</td>
<td>Prerun condition timeout</td>
<td>#1 -- Timeout, sec</td>
</tr>
<tr>
<td>205 0xCD</td>
<td>Blank command parameter</td>
<td>#1 -- Command stem</td>
</tr>
<tr>
<td>207 0xCF</td>
<td>No timing port signal</td>
<td></td>
</tr>
<tr>
<td>208 0xD0</td>
<td>No 1. PPS signal</td>
<td></td>
</tr>
<tr>
<td>209 0xD1</td>
<td>No Clock Pulse signal</td>
<td></td>
</tr>
<tr>
<td>210 0xD2</td>
<td>Digitizer timeout</td>
<td>#1 -- Timeout, sec</td>
</tr>
<tr>
<td>211 0xD3</td>
<td>EEPROM load error</td>
<td></td>
</tr>
<tr>
<td>212 0xD4</td>
<td>EEPROM save error</td>
<td>#1 -- Address, 32 bit</td>
</tr>
<tr>
<td>213 0xD5</td>
<td>Data upload checksum error</td>
<td>#1 -- Checksum, 8 bit</td>
</tr>
<tr>
<td>214 0xD6</td>
<td>Bad command stem</td>
<td>#1 -- Command stem</td>
</tr>
<tr>
<td>215 0xD7</td>
<td>System is not in HiPower to execute command</td>
<td></td>
</tr>
<tr>
<td>216 0xD8</td>
<td>Communications: Unknown Error</td>
<td></td>
</tr>
<tr>
<td>217 0xD9</td>
<td>Communications: Framing Error</td>
<td></td>
</tr>
<tr>
<td>218 0xDA</td>
<td>Communications: Sync. Byte Error</td>
<td></td>
</tr>
<tr>
<td>219 0xDB</td>
<td>Communications: Bad Command Message Checksum</td>
<td></td>
</tr>
<tr>
<td>220 0xDC</td>
<td>Communications: Bad Command Message Header</td>
<td></td>
</tr>
<tr>
<td>221 0xDD</td>
<td>Communications: Bad Command Stem</td>
<td></td>
</tr>
<tr>
<td>222 0xDE</td>
<td>Communications: Bad Upload Checksum</td>
<td></td>
</tr>
<tr>
<td>223 0xDF</td>
<td>Communications: Bad Upload Address</td>
<td></td>
</tr>
<tr>
<td>224 0xE0</td>
<td>Communications: Command Queue Overflow</td>
<td></td>
</tr>
<tr>
<td>225 0xE1</td>
<td>SST Queue Overflow</td>
<td></td>
</tr>
<tr>
<td>226 0xE2</td>
<td>SST Queue Error: MET Already Active</td>
<td></td>
</tr>
<tr>
<td>227 0xE3</td>
<td>SST Queue Error: MET already passed</td>
<td></td>
</tr>
<tr>
<td>228 0xE4</td>
<td>Bad CIDP Data Block Number in Data Load Request</td>
<td></td>
</tr>
<tr>
<td>229 0xE5</td>
<td>Lost Sync. Pulse (Delphi)</td>
<td></td>
</tr>
</tbody>
</table>
6.5 (R_ECH) Command Echo. ApID=0x08

Every command sent to RPI has a corresponding RPI_ECHO packet sent back as an acknowledgement. The structure of the Software Message packet is given in Table 6.5-1.

Table 6.5-1  RPI Command Echo format

<table>
<thead>
<tr>
<th>R_ECH Block</th>
<th>Sec_4.2.1</th>
<th>Sec_6.1</th>
<th>Sec_6.5.1</th>
<th>Sec_4.2.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Packet</td>
<td>HK</td>
<td>Header</td>
<td>Command Replica</td>
<td>Checksum</td>
</tr>
</tbody>
</table>

6.5.1 Command Replica

Table 6.5-2  Command Replica

<table>
<thead>
<tr>
<th>Byte Count Offset</th>
<th>Byte Offset No</th>
<th>Byte Length</th>
<th>Description</th>
<th>Units</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>0</td>
<td>1</td>
<td>Command stem</td>
<td>N/A</td>
<td>0-255</td>
</tr>
<tr>
<td>20..23</td>
<td>1</td>
<td>4</td>
<td>Command action Parameter 1</td>
<td>N/A</td>
<td>Command specific</td>
</tr>
<tr>
<td>24..27</td>
<td>5</td>
<td>4</td>
<td>Command action Parameter 2</td>
<td>N/A</td>
<td>Command specific</td>
</tr>
</tbody>
</table>
RPI Development Packet Formats

The following sections introduce and describe the formats for development data packets produced by the RPI instrument in response to debugging commands.

7 Development Packet Formats

RPI responds to certain development commands by outputting Development Packet(s) to the RS-422 port (to be received by CIDP, GSEOS, ASIST, etc.). All development packets are formatted as standard Science Data Packets, however, they are unlikely to be used during the mission time.

7.1 ApID=0x1F Frequency Set Response Packet

The frequency set command R_DEB_FREQ_SET is acknowledged by a message giving the programmed frequency, the coupler mode character, the relay settings for all four couplers, the synthesizer control byte settings, and the preselector control byte setting (see Table 7.1-1).

<table>
<thead>
<tr>
<th>Byte No.</th>
<th>Name</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>0..2</td>
<td>Sync pattern</td>
<td>FEFA30h</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Header</td>
<td>0xDC</td>
<td>Data packet</td>
</tr>
<tr>
<td>4</td>
<td>ApID</td>
<td>0x1F</td>
<td>(constant)</td>
</tr>
<tr>
<td>5..6</td>
<td>Byte Count</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>7-10</td>
<td>Frequency</td>
<td>f&lt;31:24&gt; f&lt;23:16&gt; f&lt;15:8&gt; f&lt;7:0&gt;</td>
<td>Sounding frequency in Hz.</td>
</tr>
<tr>
<td>11</td>
<td>Coupler mode</td>
<td>‘N’ - normal ‘D’ - direct ‘C’ - calibrate ‘S’ - calibrate-direct</td>
<td>This character indicates whether a special coupler mode has been selected.</td>
</tr>
<tr>
<td>12..13</td>
<td>Xplus relays</td>
<td>&lt;15:8&gt; &lt;7:0&gt;</td>
<td>This 16-bit value indicates the states of the 16 relays in this antenna coupler. Bit zero equals 1 if relay K1 is on; bit 1 is 1 for relay K2, etc.</td>
</tr>
<tr>
<td>14..15</td>
<td>Xminus relays</td>
<td>&lt;15:8&gt; &lt;7:0&gt;</td>
<td>This 16-bit value indicates the states of the 16 relays in this antenna coupler. Bit zero equals 1 if relay K1 is on; bit 1 is 1 for relay K2, etc.</td>
</tr>
<tr>
<td>16..17</td>
<td>Yplus relays</td>
<td>&lt;15:8&gt; &lt;7:0&gt;</td>
<td>This 16-bit value indicates the states of the 16 relays in this antenna coupler. Bit zero equals 1 if relay K1 is on; bit 1 is 1 for relay K2, etc.</td>
</tr>
<tr>
<td>18..19</td>
<td>Yminus relays</td>
<td>&lt;15:8&gt; &lt;7:0&gt;</td>
<td>This 16-bit value indicates the states of the 16 relays in this antenna coupler. Bit zero equals 1 if relay K1 is on; bit 1 is 1 for relay K2, etc.</td>
</tr>
</tbody>
</table>
7.2 ApID=0x2F Memory Read/Write Response Packet

The memory read/write command reply gives the starting and ending addresses of the memory block followed by the contents of the block. The format for the memory read/write command reply message is given in Table 7.2-1.

Table 7.2-1 Memory Read/Write Response packet, ApID=0x2F

<table>
<thead>
<tr>
<th>Byte No.</th>
<th>Name</th>
<th>Byte Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>0..2</td>
<td>Sync pattern</td>
<td>FEFA30h</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Header</td>
<td>0xDC</td>
<td>Data packet</td>
</tr>
<tr>
<td>4</td>
<td>ApID</td>
<td>0x2F</td>
<td></td>
</tr>
<tr>
<td>5..6</td>
<td>Byte Count</td>
<td>Data Byte 0</td>
<td>‘R’ or ‘W’</td>
</tr>
<tr>
<td>7</td>
<td>Starting Address</td>
<td>&lt;31:24&gt;</td>
<td>Starting address of memory block to be read/written</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt;23:16&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt;15:8&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt;7:0&gt;</td>
<td></td>
</tr>
<tr>
<td>12..15</td>
<td>Ending Address</td>
<td>&lt;31:24&gt;</td>
<td>Ending address of memory block to be read/written</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt;23:16&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt;15:8&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt;7:0&gt;</td>
<td></td>
</tr>
<tr>
<td>16..19</td>
<td>Data 1</td>
<td>&lt;31:24&gt;</td>
<td>32 bit word</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt;23:16&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt;15:8&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt;7:0&gt;</td>
<td></td>
</tr>
<tr>
<td>15+4*n</td>
<td>Checksum</td>
<td>xor sum bytes 7-19</td>
<td></td>
</tr>
</tbody>
</table>

7.3 ApID=0x3F VME Read/Write Response Packet

The VME Read/Write response packet returns the VME address and contents for the affected VME port. The format for the VME read/write command reply message is given in Table 7.3-1.

Table 7.3-1 VME Read/Write Response packet, ApID=0x3F

<table>
<thead>
<tr>
<th>Byte No.</th>
<th>Name</th>
<th>Byte Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>0..2</td>
<td>Sync pattern</td>
<td>FEFA30h</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Header</td>
<td>0xDC</td>
<td>Data packet</td>
</tr>
<tr>
<td>4</td>
<td>ApID</td>
<td>0x3F</td>
<td></td>
</tr>
</tbody>
</table>
5..6 byte count 6

7..10 address

VME address of affected VME port.

11 value

Contents of affected VME port after VME Port command is executed.

12 checksum

xor sum bytes 7-11

### 7.4 ApID=0x4F Digitizer Samples Packet

The R_DEB_DGTZ_GET command continuously takes digitizer samples, sending back digitizer sample blocks as indicated below. Packets are transmitted continuously until RPI receives a new command. The format for the Digitizer Samples packet is shown in Table 7.4-1.

<table>
<thead>
<tr>
<th>Byte No.</th>
<th>Name</th>
<th>Byte Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>0..2</td>
<td>Sync pattern</td>
<td>FEFA30h</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Header</td>
<td>0xDC</td>
<td>Data packet</td>
</tr>
<tr>
<td>4</td>
<td>ApID</td>
<td>0x4F</td>
<td></td>
</tr>
<tr>
<td>5..6</td>
<td>Byte Count</td>
<td>4N+1</td>
<td>N = number of complex samples</td>
</tr>
<tr>
<td>7..8</td>
<td>Real 1</td>
<td>&lt;15:8&gt; &lt;7:0&gt;</td>
<td>First real sample</td>
</tr>
<tr>
<td>9..10</td>
<td>Imaginary 1</td>
<td>&lt;15:8&gt; &lt;7:0&gt;</td>
<td>First imaginary sample</td>
</tr>
<tr>
<td>11..12</td>
<td>Real 2</td>
<td>&lt;15:8&gt; &lt;7:0&gt;</td>
<td>Second real sample</td>
</tr>
<tr>
<td>13..14</td>
<td>Imaginary 2</td>
<td>&lt;15:8&gt; &lt;7:0&gt;</td>
<td>Second imaginary sample</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>...</td>
<td>Real N</td>
<td>&lt;15:8&gt; &lt;7:0&gt;</td>
<td>Nth real sample</td>
</tr>
<tr>
<td>...</td>
<td>Imaginary N</td>
<td>&lt;15:8&gt; &lt;7:0&gt;</td>
<td>Nth imaginary sample</td>
</tr>
<tr>
<td>4N+6</td>
<td>Checksum</td>
<td></td>
<td>xor sum</td>
</tr>
</tbody>
</table>

**Table 7.4-1 Digitizer Sample packet, ApID=0x4F**
Appendix A. Thermal Noise Data Processing

Since lots of effort has been put into making standard reusable tools for operational software and data analysis software we would like to find a way to structure the TTD output telemetry packets to use the standard RPI packet format (see Section 2). In order to force TTD data into this format, a TTD databin has to be introduced. In the thermal noise mode, RPI produces averaged amplitudes (for each antenna), as well as cross-power and cross-phase terms for each 8 average amplitudes (see Section 1.1 for more details). To avoid paying too dearly in storage efficiency, we have defined the standard TTD databin with 8x3 average amplitudes, 3 cross-power terms, and 3 cross-phase terms, thus making N=3 the minimum value allowed. This requires that we have at least 36 time domains samples per frequency step\(^2\).

The elements of the TTD databin are 8-bit Logarithmic amplitudes, 8-bit cross-power log amplitudes, and the corresponding cross-power phase arguments also in an 8-bit format (0-359 deg in 1.4deg steps). The algorithm for computing one databin elements uses 36 samples collected on each of three antennas (\(S_{x1}\) to \(S_{x36}\), \(S_{y1}\) to \(S_{y36}\), and \(S_{z1}\) to \(S_{z36}\)).

A1. Calculating Log Amplitudes

The goal is to compute 8-point average amplitudes in the logarithmic scale. For the sake of computational efficiency, calculations operate with the power terms. The signal power terms for antenna X, \(p_{xi}\), can be obtained from the complex samples \(S_i\):

\[
p_{xi} = I_{xi}^2 + Q_{xi}^2, \quad i = 1..8
\]

(A-1)

where \(I_{xi}\) is the real (in-phase) component of the sample \(S_i\), and \(Q_{xi}\) is the imaginary (quadrature) component of \(S_i\). Note that the power term is always positive, so we can add the terms without concern that anti-phased signals may cancel each other:

\[
P_x = \sum_{i=1}^{8} p_{xi}
\]

(A-2)

Averaging and converting to log scale gives the first average amplitude \(A_x\):

\[
A_x[1] = 10\log_{10}\left(\frac{P_x}{8}\right) = 10\log_{10} P_x - 10\log_{10} 8 = 10\log_{10} P_x - 9.031
\]

(A-3)

Now move the starting point up 4 samples, and create a new 8-point average which overlaps half the data used in the previous average. Continue up until samples 29 to 36 are used in making the eighth average, the final amplitude to store in the TTD databin.

\(^2\) For standard sounder modes, all of samples are collected after a single pulse. The TTD mode is a Receive Only mode, so there is no transmitted pulse, but there is still a logic pulse that triggers the digitizer to make a one-dimensional sample array of 32 to 1024 samples at each frequency step.
Repeat for $A_y[1-8]$ and $A_z[1-8]$. Store all $A_{x,y,z}[1]$ to $A_{x,y,z}[8]$ (24 values) in the databin.

A2. Calculating Cross Power Terms (XY, XZ and YZ)

Three complex cross-power terms, $W_{xy}$, $W_{yz}$, and $W_{xz}$, can be calculated from the samples obtained simultaneously from antenna X, Y, and Z:

\[ W_{xy} = (I_x + jQ_x) \times (I_y - jQ_y) \]  
\[ W_{xz} = (I_x + jQ_x) \times (I_z - jQ_z) \]
\[ W_{yz} = (I_y + jQ_y) \times (I_z - jQ_z) \]

Conjugating the Y sample in (A-4) gives the cross-power vector, $W_{xy}$, a phase equal to the phase difference between the X axis and Y axis sample. Since the signals have the receiver calibration corrections as well as the spin-phase rotation correction already performed, the X, Y, and Z signal components are already lined up with the RPI coordinate system, and the combined amplitude of the cross-products is representative of the real E-field strengths.

36 samples are used from each of the antennas to obtain 36 sets of power terms W and then calculate the averages:

\[ \text{Re}\left[<W_{xy}>\right] = \frac{1}{36} \sum_{i=1}^{36} \text{Re}[W_{xy}] \]
\[ \text{Im}\left[<W_{xy}>\right] = \frac{1}{36} \sum_{i=1}^{36} \text{Im}[W_{xy}] \]

These averages are not necessarily positive numbers, and in order to express the magnitude of the cross-power, $CP_{XY}$, we have to use $\sqrt{\text{Re}^2 + \text{Im}^2}$:

\[ CP_{XY} = \sqrt{\text{Re}\left[<W_{xy}>\right]^2 + \text{Im}\left[<W_{xy}>\right]^2} \]

And in dB,

\[ CP_{XY,\text{dB}} = 10 \log_{10} \left( \text{Re}\left[<W_{xy}>\right]^2 + \text{Im}\left[<W_{xy}>\right]^2 \right) \]

A3. Calculating Cross Phases (XY, XZ and YZ)

Cross phase term, $CPh_{XY}$, is calculated as

\[ CPh_{XY} = \arctan \left( \frac{\text{Im}\left[<W_{xy}>\right]}{\text{Re}\left[<W_{xy}>\right]} \right), \quad \text{[range -180deg to +179deg]} \]

and stored in [360/255] degree units as 8 bit integer. The terms $CPh_{XZ}$ and $CPh_{YZ}$ are calculated similarly.
## Appendix B. Coupler Band Center Frequency Table

<table>
<thead>
<tr>
<th>Index</th>
<th>Frequency, kHz</th>
<th>Index</th>
<th>Frequency, kHz</th>
<th>Index</th>
<th>Frequency, kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3.000</td>
<td>46</td>
<td>45.600</td>
<td>92</td>
<td>193.500</td>
</tr>
<tr>
<td>1</td>
<td>9.500</td>
<td>47</td>
<td>47.150</td>
<td>93</td>
<td>195.000</td>
</tr>
<tr>
<td>2</td>
<td>9.900</td>
<td>48</td>
<td>48.700</td>
<td>94</td>
<td>195.750</td>
</tr>
<tr>
<td>3</td>
<td>10.200</td>
<td>49</td>
<td>51.600</td>
<td>95</td>
<td>198.000</td>
</tr>
<tr>
<td>4</td>
<td>10.450</td>
<td>50</td>
<td>54.500</td>
<td>96</td>
<td>200.000</td>
</tr>
<tr>
<td>5</td>
<td>10.800</td>
<td>51</td>
<td>56.025</td>
<td>97</td>
<td>205.000</td>
</tr>
<tr>
<td>6</td>
<td>11.150</td>
<td>52</td>
<td>57.550</td>
<td>98</td>
<td>220.000</td>
</tr>
<tr>
<td>7</td>
<td>11.600</td>
<td>53</td>
<td>59.425</td>
<td>99</td>
<td>233.000</td>
</tr>
<tr>
<td>8</td>
<td>11.950</td>
<td>54</td>
<td>61.300</td>
<td>100</td>
<td>259.000</td>
</tr>
<tr>
<td>9</td>
<td>12.500</td>
<td>55</td>
<td>63.325</td>
<td>101</td>
<td>308.000</td>
</tr>
<tr>
<td>10</td>
<td>13.100</td>
<td>56</td>
<td>65.350</td>
<td>102</td>
<td>320.000</td>
</tr>
<tr>
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<td>13.500</td>
<td>57</td>
<td>68.300</td>
<td>103</td>
<td>380.000</td>
</tr>
<tr>
<td>12</td>
<td>13.750</td>
<td>58</td>
<td>72.700</td>
<td>104</td>
<td>440.000</td>
</tr>
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<td>14.300</td>
<td>59</td>
<td>74.550</td>
<td>105</td>
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<td>14.750</td>
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<td>76.400</td>
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<td>535.000</td>
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<tr>
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<td>15.350</td>
<td>61</td>
<td>78.850</td>
<td>107</td>
<td>575.000</td>
</tr>
<tr>
<td>16</td>
<td>15.800</td>
<td>62</td>
<td>81.200</td>
<td>108</td>
<td>605.000</td>
</tr>
<tr>
<td>17</td>
<td>16.500</td>
<td>63</td>
<td>84.900</td>
<td>109</td>
<td>630.000</td>
</tr>
<tr>
<td>18</td>
<td>17.350</td>
<td>64</td>
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<td>17.900</td>
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<td>111</td>
<td>685.000</td>
</tr>
<tr>
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<td>18.300</td>
<td>66</td>
<td>97.400</td>
<td>112</td>
<td>760.000</td>
</tr>
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<td>18.950</td>
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<td>100.500</td>
<td>113</td>
<td>870.000</td>
</tr>
<tr>
<td>22</td>
<td>19.600</td>
<td>68</td>
<td>102.500</td>
<td>114</td>
<td>904.000</td>
</tr>
<tr>
<td>23</td>
<td>20.400</td>
<td>69</td>
<td>105.000</td>
<td>115</td>
<td>973.000</td>
</tr>
<tr>
<td>24</td>
<td>21.000</td>
<td>70</td>
<td>108.000</td>
<td>116</td>
<td>1190.000</td>
</tr>
<tr>
<td>25</td>
<td>21.950</td>
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<td>111.500</td>
<td>117</td>
<td>1220.000</td>
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<tr>
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<td>72</td>
<td>114.000</td>
<td>118</td>
<td>1280.000</td>
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<td>27</td>
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<td>119</td>
<td>1320.000</td>
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<td>24.150</td>
<td>74</td>
<td>134.500</td>
<td>120</td>
<td>1510.000</td>
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<td>25.050</td>
<td>75</td>
<td>137.500</td>
<td>121</td>
<td>1600.000</td>
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<tr>
<td>30</td>
<td>25.900</td>
<td>76</td>
<td>139.750</td>
<td>122</td>
<td>2000.000</td>
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<tr>
<td>31</td>
<td>26.900</td>
<td>77</td>
<td>143.500</td>
<td>123</td>
<td>3000.000</td>
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<tr>
<td>32</td>
<td>27.700</td>
<td>78</td>
<td>146.000</td>
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<td></td>
</tr>
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<td>28.900</td>
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<td>151.500</td>
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<td>81</td>
<td>154.500</td>
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</tr>
<tr>
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<td>32.300</td>
<td>82</td>
<td>172.000</td>
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<td>83</td>
<td>174.000</td>
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<td>38</td>
<td>34.500</td>
<td>84</td>
<td>175.500</td>
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<td></td>
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<td>35.900</td>
<td>85</td>
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</tr>
<tr>
<td>40</td>
<td>37.000</td>
<td>86</td>
<td>180.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>41</td>
<td>38.700</td>
<td>87</td>
<td>182.500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>40.400</td>
<td>88</td>
<td>185.000</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>41.600</td>
<td>89</td>
<td>186.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>44</td>
<td>42.550</td>
<td>90</td>
<td>190.500</td>
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<td></td>
</tr>
<tr>
<td>45</td>
<td>44.075</td>
<td>91</td>
<td>192.000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix C. Calibration Procedures

C1. Phase calibration procedure

Phase calibration was done at SwRI labs by feeding a known generator signal into three receivers set at G=15, as shown on Figure C1-1.

![Phase calibration setup with HP synthesizer](image)

Figure C1-1 Phase calibration setup with HP synthesizer

The output of each receiver was sampled twice, to capture $I$ and $Q$ quadrature components spaced 90° apart. The ratio of Z channel output to X and Y channels comprises the default calibration table.
C2. Onboard calibration procedure

Onboard calibration procedure is done by feeding identical calibration signals to the receivers on each frequency before the actual transmission is made, as shown in Figure C2-1. The calibration signal is applied directly to the couplers at the base of the X and Y antennas; however, the Z channel is calibrated without the wide-band pre-amplifiers whose gain is assumed equal to 12 dB (LoGain setting) and phase contributions are assumed constant for the mission period. The amplitude of the calibration signals is always the same and is selected optimally to obtain good receiver responses with any setting of their gain.

The receiver response to the calibration signals is used onboard to introduce corrections to the X and Y channel data that equalize their phase and gain characteristics with the Z channel. It is important to make +12 dB corrections to the X and Y data on the ground if HiGain setting was used for the Z preamplifier. With this correction introduced, RPI data can be directly used to derive the angles of arrival. An additional effort is required to convert the observed amplitudes to the physical units, $[\text{nV/m}]$, as discussed in Section 3.2.1.

![Diagram of calibration signals application to X(Y) and Z receiver channels](image)

Figure C2-1  Application of calibration signals to X(Y) and Z receiver channels

C3. Amplitude calibration procedure

Amplitude calibration was done at SwRI labs by feeding a known generator signal into receiver as shown on Figure C3-1.
Figure C3-1  Amplitude calibration setup with HP synthesizer

C3.1. Input voltage calculation

The generator input was originally expressed in [dBm into a 50 ohm load]. The following considerations are used to express the input voltage in [Vp]:

- dBm units are referenced to 1 mW of power on 50 ohm load
- Voltage corresponding to 1 mW on 50 ohm is:
  \[ V_{ref, rms} = \sqrt{1 \text{mW} \cdot 50 \text{ohm}} = 0.05 \text{ [V]} \]
  \[ V_{ref, p} = \sqrt{2} V_{ref, rms} = \sqrt{2} \cdot 0.05 \text{ [V]} = 0.1 \text{ [V]} \]
- For \( D \) dBm the generator output voltage is
  \[ V_{g-out, p} = V_{ref, p} \cdot 10^{(D/20)} = 0.1 \cdot 10^{(D/20)} \text{ [V]} \]

To account for the fact that the calibration setup (Figure C1-1) is different from the operational RPI setup where both dipole elements feed the receiver, 6 dB are subtracted from the test source power. Another 6 dB are subtracted to account for the losses in the 3 way splitter. Thus, the input voltage for this test is

\[ V_{in, p} = 0.1 \cdot 10^{(D-12)/20} \text{ [V]} \]

To obtain the value of receiver sensitivity in volts per digitizer unit, \( S_{du, p}(f) \), from the amplitude calibration data, the following formula is used:

\[ S_{du, p}(f) = \frac{V_{in, p}}{D_{out}(f)} \text{ [V/unit]}, \]

where \( D_{out}(f) \) are the amplitudes [in digitizer units] and \( V_{in, p} \) is the peak voltage in [V].

C3.2. Amplitude calibration coefficients

Ratio of Z channel amplitudes to X and Y channel amplitudes gives the correction coefficients \( A'_{xc} \) and \( A'_{yc} \) for the re-calibration procedure described in Section 3.2.2.6. The coefficients are given in the Table C3-1.
C3.3. Physical Units table

Figure C3-1 shows graph of the Z channel zero-to-peak voltage per digitizer unit, in [nV/unit], which is used for conversion of the amplitudes to physical units in Section 3.2.2.8.

![Z channel voltage per digitizer unit, [nV].](image)

The gains of the X and Y channels are matched to the gain of the Z receiver during onboard calibration (see Section 3.1.2) so that, for the purpose of conversion to physical units, X and Y digitizer unit values are not used. The zero-to-peak voltage [in nV] per digitizer units for Z channel are given in Table C3-1. Section 3.2.2.3 explains how to use these coefficients to derive the Physical Units table for all channels and all settings of the base gain.
Table C3-1  X/Y Amplitude Corrections and Physical Units table.

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