Mars 2020 (M2020)

Software Interface Specification

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Signatures

GDS Generating Elements:

Instrument Data System Lead
Stirling Algermissen

____
Subsystem Lead Date

Science Receiving Elements:

M2020 Deputy Project Scientist
Kenneth H. Williford

____
Deputy Project Scientist Date

GDS Receiving Elements:

M2020 GDS Manager
Jim Kurien

____
Manager Date

M2020 GDS System Engineer
Guy Pyrzak

____
Subsystem Engineer Date

Concurrence:

M2020 RIMFAX Principal Investigator
Svein-Erik Hamran

____
Principal Investigator Date

M2020 RIMFAX Deputy Principal Invest.
David Paige

____
Deputy Principal Investigator Date

M2020 RIMFAX Investigation Scientist
Daniel Nunes

____
Investigation Scientist Date

M2020 RIMFAX Instrument Engineer
Christina Diaz

____
Instrument Engineer Date

PDS Program Manager
Tim McClanahan

____
Manager Date

PDS Geosciences Node Manager
Ray Arvidson

____
Manager Date

Mars 2020

Software Interface Specification (SIS)

RIMFAX
Experiment Data Record (EDR)
Data Products

Version 2.0

Prepared by:
Daniel Nunes (JPL), Patrick Russell (UCLA), Rafael Alanis, Hyun Lee (JPL)

Custodians:
Rafael Alanis and Hyun Lee (JPL)

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ACRONYMS AND ABBREVIATIONS

ADC	Analog to Digital Converter
AM	Amplitude Modulated
AMMOS	Advanced Multi-Mission Operations System
AMPCS	AMMOS Mission data Processing and Control Subsystem
APID	Application Process Identifier
APPS	AMMOS-PDS Pipeline Service
APSS	Activity Planning and Sequencing Subsystem
ASCII	American Standard Code for Information Interchange
ATLO	Assembly, Test, Launch and Operations
CIDPH	Common Instrument Data Product Header
CODMAC	Committee on Data Management and Computation
CSV	Comma-separated-value
DAC	Digital to Analog Converter
DN	Digital Number
DP	Data Product (telemetry)
DPO	Data Product Object
DTE	Direct to Earth
DVT	Data Validity Time
EDL	Entry, Descent and Landing
EDR	Experiment Data Record
EHA	Engineering, Housekeeping & Accountability (EH&A)
EM	Engineering Model
EMC	Electromagnetic Compatibility
EMD	Earth Metadata file (".emd")
EMI	Electromagnetic Interference
EOP	Experiment Operations Plan
EPDU	End-of-Product PDU
ERT	Earth Received Time
FDD	Functional Design Document
FEI	File Exchange Interface
FFI	Forsvarets Forskningsinstitutt (Norwegian Defense Research Establishment)
FFT	Fast Fourier Transform
FGICD	Flight-Ground ICD
FM	Flight Model
FMCW	Frequency Modulated Continous Wave
FOV	Field of View
FPGA	Field Programmable Gate Array
FS	Flight System

FSW	Flight Software
GDS	Ground Data System
GEO	PDS Geosciences Node (Washington University, St. Louis, MO)
GPR	Ground Penetrating Radar
GSFC	Goddard Space Flight Center
Hazcam	Hazard Avoidance Camera
HGA	High Gain Antenna
HK	Housekeeping
ICD	Interface Control Document
ICER	Image compression algorithm (not an acronym)
ID	Identification
IDPH	Instrument Data Product Header
IDS	Instrument Data System
IF	Intermediate Frequency
IFFT	Inverse Fast Fourier Transform
ILUT	Inverse Lookup Table
ITAR	International Traffic in Arms Regulations
IVP	Inertial Vector Propagation
JPL	Jet Propulsion Laboratory
LID	Logical Identifier
LIDVID	Versioned Logical Identifier
LIS	Long Integration Sounding
LOCO	LOw-COmplexity, LOssless COmpression
LSB	Least Significant Byte
M2020	Mars 2020
MGSS	Multimission Ground Systems and Services
MIPL	Multimission Instrument Processing Laboratory
MMRTG	Multi-Mission Radio-isotope Thermoelectric Generator
MOS	Mission Operations System
MPCS	Mission data Processing and Control Subsystem
MPDU	Metadata Protocol Data Unit
MS	Mission System
MSB	Most Significant Byte
MSL	Mars Science Laboratory
NASA	National Aeronautics and Space Administration
NAIF	Navigation and Ancillary Information Facility
Navcam	Navigation Camera
NSC	Norwegian Space Centre
OCS	Operations Cloud Store

ODL	Object Description Language
PDS	Planetary Data System
PDS4	PDS Standard 4
PDU	Protocol Data Unit
PPDU	Product data Protocol Data Unit
PSDD	Planetary Science Data Dictionary
RA	Robotic Arm
RAF	RIMFAX Antenna Frame
RAMP	Rover Avionics Mounting Plate
RCE	Rover Compute Element
RDR	Reduced Data Record
RF	Radio Frequency
RIMFAX	Radar Imager for Mars subsurFAce eXperiment
RMECH	Rover Mechanical Reference Frame
RNAV	Rover Navigational Reference Frame
ROI	Region of Interest
RPAM	Rover Power and Analog Module
RSM	Remote Sensing Mast
RTG	Radio-isotope Thermoelectric Generator
RX	Receiver
SAPP	Surface Attitude, Positioning and Pointing
SCID	Spacecraft ID
SCLK	Spacecraft Clock
SCM	Spacecraft Configuration Manager
SCS	Sample Cache System
SDF	Science Data Frame
SFDU	Standard Format Data Unit
SIS	Software Interface Specification
SNR	Signal-to-Noise Ratio
SOH	State of Health
SOL	Mars Solar Day
SPICE	Spacecraft, Planet, Instrument, C-matrix, Events kernels
TBC	To Be Confirmed
TBD	To Be Determined
TDS	Telemetry Delivery System
TX	Transmitter
UART	Universal Asynchronous Receiver / Transmitter
UCLA	University of California, Los Angeles
UIO	University of Oslo
UTC	Coordinated Universal Time

VICAR	Video Image Communication and Retrieval
VID	Version Identifier
VSTB	Vehicle System Testbed
XML	eXtensible Markup Language

1. INTRODUCTION

1.1 Purpose and Scope

The purpose of this Data Product Software Interface Specification (SIS) is to provide consumers of Mars 2020 (M2020) instrument Experiment Data Record (EDR) data products with a detailed description of the products and how they are generated, including data sources and destinations. Content in this document supports EDR data products generated by the Instrument Data System (IDS) of the M2020 Mission Operations System (MOS) for the "Radar Imager for Mars subsurFAce eXperiment" (RIMFAX) science payload instrument.

The users for whom this SIS is intended include IDS, the Activity Planning and Sequencing Subsystem (APSS), the Rover Planner Subsystem (RPS), users and developers of Science Operations Analysis Software (SOAS), member scientists of the project's Science Operations Working Group (SOWG), users and archivists at Planetary Data System (PDS), where much of the EDR material will be archived and available to the public, and other scientists in the general planetary science community.

In this document, the EDR data product is the raw, uncalibrated, uncorrected data acquired by the RIMFAX ground penetrating radar instrument. EDR data has been uncompressed from the version of data products compressed onboard the rover for transmission to Earth.

1.2 Contents

This Data Product SIS describes at a high level how the ground-penetrating radar data is acquired onboard by the RIMFAX instrument and how it is processed, formatted, labeled, and uniquely identified as an EDR ground data product. The document discusses standards used in generating the product and software that may be used to access the product. The EDR structure, format, and organization is described in sufficient detail to enable a user to read the product. RIMFAX sounding data, related parameters in data and metadata files, and RIMFAX-specific parameters in the labels are described. The SIS also covers the two label formats for EDRs: ODL for Operations use and PDS4 for archival with the PDS.

1.3 Constraints and Applicable Documents

This SIS is meant to be consistent with the contract negotiated between the M2020 Project and the M2020 Principal Investigators (PI) for the instrument in which experiment data records and documentation are explicitly defined as deliverable products. Because this SIS governs the specification of data products used during mission operations, any proposed changes to this SIS must be impacted by all affected software subsystems observing this SIS in support of operations (e.g., APSS, RPS, IDS, SOAS).

Product label keywords/attributes may be changed and/or added to future revisions of this SIS. Therefore, it is recommended that software designed to process EDRs specified by this SIS should be robust to (new) unrecognized keywords/attributes.

This Data Product SIS is responsive to the following M2020 documents:

1. Mars 2020 Flight-Ground Interface Control Document (FGICD), "Volume 1, Downlink, Rev A, Version 1.0", Biren Shah, JPL D-95521, October 3, 2017.

2. Mars 2020 Project: Archive Generation, Validation, and Transfer Plan. JPL D-95520.

Additionally, this SIS is consistent with Planetary Data System (PDS) documents [3 - 6] and dictionaries [8 – 11]. These documents and dictionaries are subject to periodic revision. The most recent versions of PDS documents may be found at https://pds.nasa.gov/datastandards/documents/. Current and older versions of all PDS dictionaries are available at https://pds.nasa.gov/datastandards/dictionaries/. The PDS products described in this SIS have been designed based on the versions current at the time, which are those listed here:

3. PDS Concepts Document, Version 1.14.0.0, May 19, 2020.

4. PDS Data Provider's Handbook - Guide to Archiving Planetary Data Using the PDS4 Standard, Version 1.14.0.0, May 19, 2020.

5. PDS Standards Reference, Version 1.14.0.0, JPL D-7669, Part 2, May 22, 2020.

6. PDS Common Data Dictionary, Version 1.14.0.0, March 23, 2020.

7. PDS Information Model Specification, Version 1.14.0.0, March 23, 2020.

8. PDS4 Mars 2020 Mission Data Dictionary, Version 1G00_1000, August 19, 2021. https://pds.nasa.gov/datastandards/dictionaries/index-missions.shtml#mars2020.

9. PDS4 Geometry Discipline Data Dictionary, Version 1G00_1920, June 9, 2021. https://pds.nasa.gov/datastandards/dictionaries/index-1.16.0.0.shtml#geom.

10. PDS4 Processing Information Discipline Data Dictionary, Version 1G00_1210, June 10, 2021. https://pds.nasa.gov/datastandards/dictionaries/index-1.16.0.0.shtml#proc.

11. PDS4 Surface Mission Information Discipline Data Dictionary, Version 1G00_1220, June 10. 2021. https://pds.nasa.gov/datastandards/dictionaries/index-1.16.0.0.shtml#msn_surface.

12. Radar Imager for Mars' Subsurface Experiment – RIMFAX, Svein-Erik Hamran, David A. Paige, Hans E. F. Amundsen, Tor Berger, Sverre Brovoll, Lynn Carter, Leif Damsgård, Henning Dypvik, Jo Eide, Sigurd Eide, Rebecca Ghent, Øystein Helleren, Jack Kohler, Mike Mellon, Daniel C. Nunes, Dirk Plettemeier, Kathryn Rowe, Patrick Russell & Mats Jørgen Øyan, Space Science Reviews 216, Article Number 128 (2020). https://doi.org/10.1007/s11214-020-00740-4

13. Mars 2020 Radar Imager for Mars' subsurFAce eXperiment (RIMFAX) PDS Archive Calibrated Data Record (CDR) Software Interface Specification (SIS), Prepared by: Patrick Russell and Mark Sullivan, Custodian: Mark Sullivan, Date: August 6, 2021.

14. Mars 2020 Software Interface Specification (SIS): RIMFAX PDS Archive Bundle, Prepared by: Susan Slavney, Custodian: Susan Slavney, Date: August 20, 2021.

15. Mars 2020 Rover Attitude, Positioning and Pointing (RAPP) Functional Design Description (FDD) document, JPL D-95865, ID 64632, Owner: Farah Alibay, Last Modified: 2020-05-27, Date: April 20, 2021.

1.3.1 Relationships with Other Interfaces

Changes to this EDR data product SIS document affect the products, software, and/or documents listed in Table 1.3.1.1.

Table 1.3.1.1 - Product and Software Interfaces to this SIS

Name	Type P = product S = software D = document	Owner
MIPL database schema	S	MIPL (JPL)
M20EDRGEN	S	MIPL (JPL)
M2020 RIMFAX EDRs • GPR Sounding • Housekeeping • Fault Condition *(not archived with PDS)*	P	MIPL (JPL)

2. THE RIMFAX INSTRUMENT

In this section, a brief overview of the RIMFAX instrument is provided to familiarize the reader with the instrument's primary functionality, operational implementation, and objectives that the EDR data products will serve.

The RIMFAX instrument and science investigation are more fully described in the publication "Radar Imager for Mars' Subsurface Experiment – RIMFAX", Svein-Erik Hamran, David A. Paige, Hans E. F. Amundsen, Tor Berger, Sverre Brovoll, Lynn Carter, Leif Damsgård, Henning Dypvik, Jo Eide, Sigurd Eide, Rebecca Ghent, Øystein Helleren, Jack Kohler, Mike Mellon, Daniel C. Nunes, Dirk Plettemeier, Kathryn Rowe, Patrick Russell & Mats Jørgen Øyan, Space Science Reviews 216, Article Number 128 (2020) https://doi.org/10.1007/s11214-020-00740-4

2.1 Instrument Goals and Science

The principal goal of the RIMFAX investigation is to probe the shallow subsurface beneath the rover, providing information on its structure and composition. The data provided by RIMFAX will aid the Mars2020 rover in its mission to explore Mars habitability, most notably in providing context and suggesting locations of interest for sampling and possible sample return.

Scientific objectives anticipated to be attained through direct or derived use of RIMFAX data products are listed in Table 2.1.1.

Table 2.1.1 – RIMFAX Use Cases

General Use Case	Specific Objective
A. Determine subsurface structure to discover evidence of geological processes that shaped Mars' sedimentary environment	Detect subsurface layering at >10m depth with <30cm vertical resolution
	Detect subsurface layering at <10m depth with <30cm vertical resolution
	Correlate subsurface reflections with rover surface observations
B. Search for evidence of past habitable environments	Search for buried climate-diagnostic landforms
	Search for relict subsurface ice
	Search for subsurface liquid water / brine
C. Search for lateral variations in subsurface composition	Search for lateral variations in dielectric constant indicating compositional variation

2.2 Instrument Hardware

Received GPR signals are digitized and sent to the Rover Compute Elements (RCE-A or RCE-B), where they can be additionally processed, stored, and then sent back to Earth for further processing. Figure 2.2.1 is a block diagram illustrating the RIMFAX instrument, comprising an antenna, an antenna cable, a calibration cable, and electronics that interface with the RCEs. Figure 2.2.2 shows schematic representations of the RIMFAX electronics box and antenna. Figure 2.2.3 illustrates the mount position of the RIMFAX instrument on the rover.

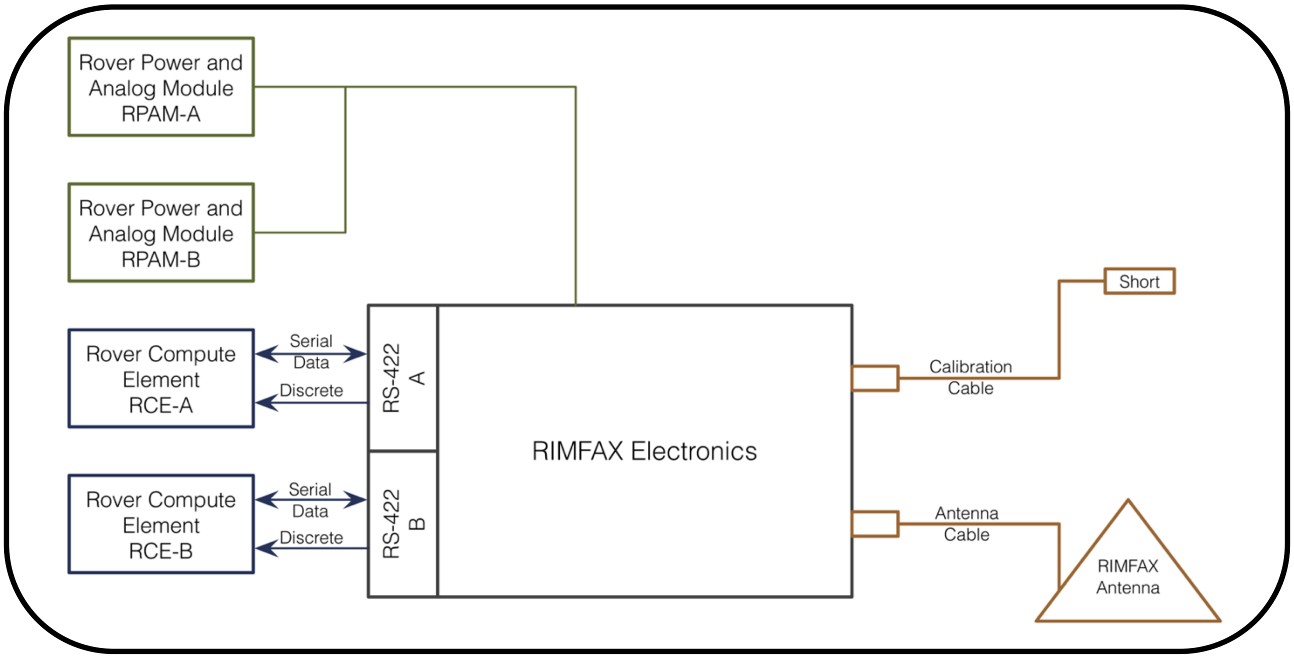

Figure 2.2.1 – RIMFAX Hardware Interfaces with RCEs

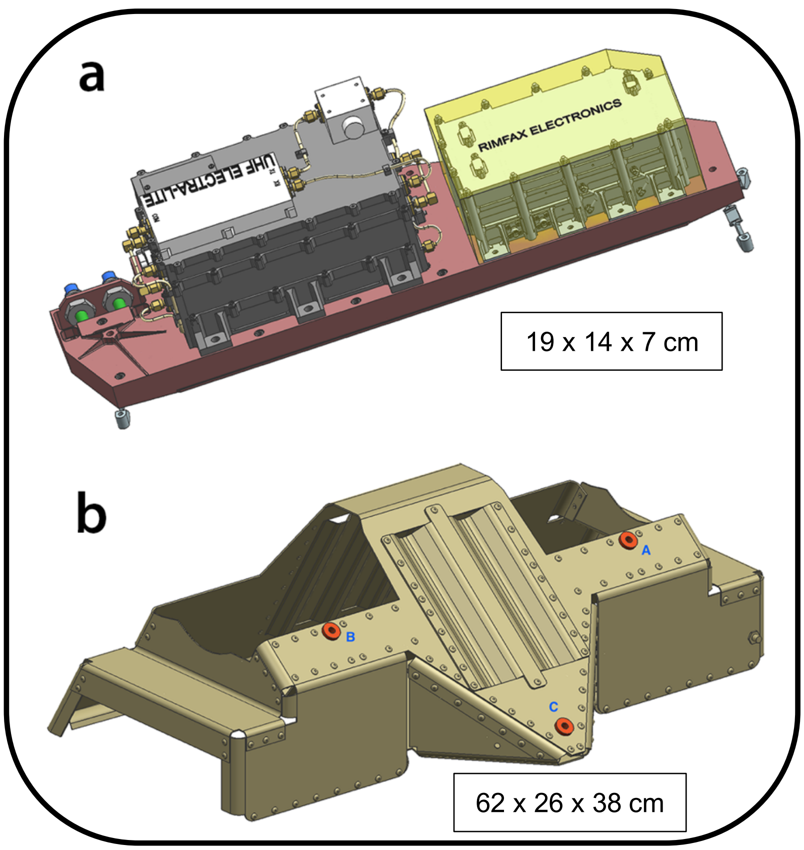

Figure 2.2.2 – RIMFAX Hardware: (a) Electronics Enclosure (w/ Electra), (b) RIMFAX Antenna

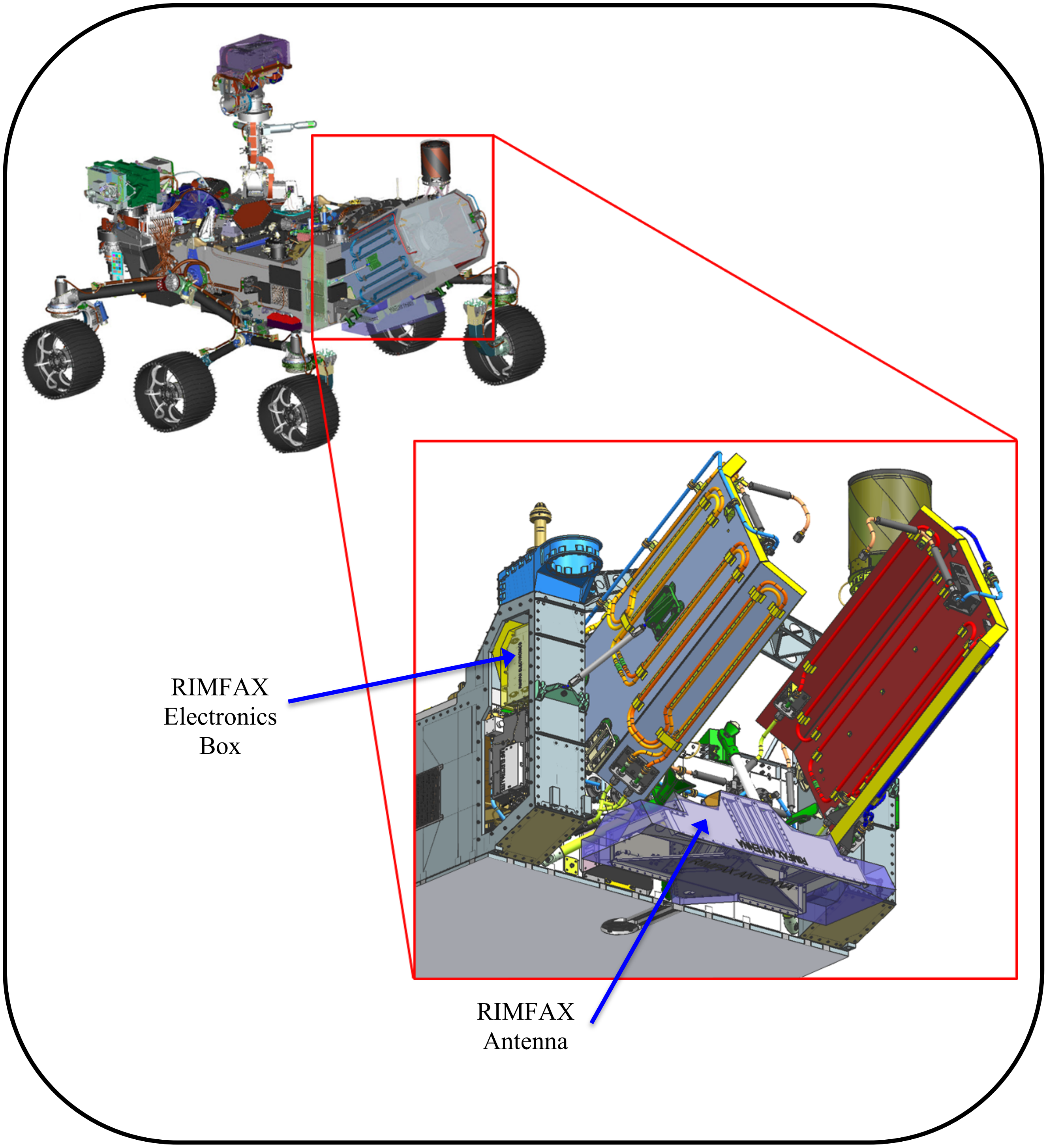

Figure 2.2.3 – Rover Mounting Locations for RIMFAX Electronics Box and Antenna

2.3 Instrument Functionality

RIMFAX is a ground penetrating radar (GPR) that uses a single antenna to transmit (Tx) and receive (Rx) electromagnetic waves over a range of frequencies into/from the subsurface. The instrument can be operated in either "Active" (Tx and Rx) or "Passive" (Rx-only) modes.

Transmitted waves propagate downward and outward until they are reflected back by the surface and interfaces in shallow (≤ 10s of m) subsurface geologic structures and materials. Reflection and refraction occur across interfaces representing discontinuities in dielectric permittivity (the storage of electrical energy in an electric field). Variation in permittivity is largely controlled by density in dry geologic materials.

Each Active or Passive measurement taken across the frequency range is known as a "sounding". A raw RIMFAX sounding is a record of the reflected power returned at each frequency increment over the bandwidth. Though not covered in this EDR SIS, processed RIMFAX soundings become more analogous to results from most terrestrial-use GPRs once they have been transformed into the time domain, i.e., into a time series of reflected and received power. This processing, along with the resulting PDS-archived RIMFAX Calibrated data products is described in the RIMFAX CDR SIS [13] and the RIMFAX instrument paper [12].

As the rover (and RIMFAX) moves along its traverse path, successive soundings are taken at fixed increments of distance along the surface. The resulting dataset records the dielectric structure of the surface/subsurface as a function of location along the rover's traverse path. Measurements are also made while the rover (and RIMFAX) is stationary with respect to the surface, in which case successive co-located soundings can build a time series. Such a dataset may capture how the dielectric properties of the surface/subsurface at that individual location may change over a given period (e.g., in response to thermal influences).

2.3.1 Waveform

RIMFAX is a Frequency Modulated Continuous Wave (FMCW) radar, in which a digitally synthesized long-duration waveform is swept over a frequency range, or bandwidth, over a time period, producing the emitted signal. The full RIMFAX bandwidth is 150 – 1200 MHz, but is configuratble within this range. The amplitudes of the received FMCW signals are digitized and compressed to a short pulse with a duration that is a function of the transmitted FMCW's bandwidth. The FMCW baseband signal is low-pass filtered before being sampled, which effectively removes deeper reflectors and yields an ambiguity-free range interval. A principle block diagram of the instrument is given in Figure 2.3.1.1.

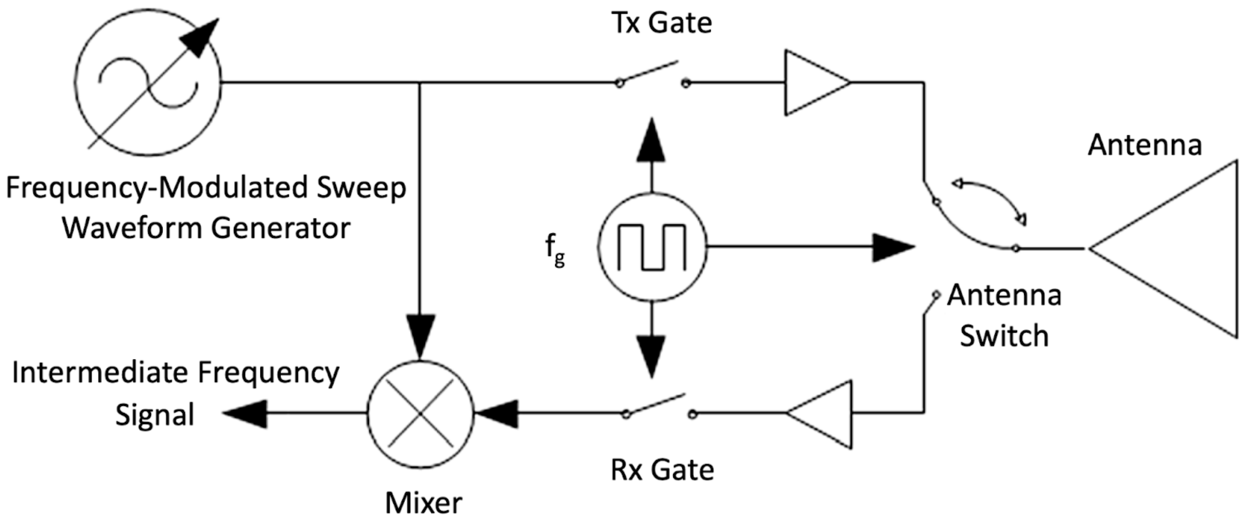

Figure 2.3.1.1 – Principle Block Diagram of the RIMFAX Instrument

The working principle of an FMCW radar is illustrated in Figure 2.3.1.2. A signal, *Tx*, is swept through the full bandwidth, *B*, of frequencies (from f_1 to f_2) over the time span, T_s (from t_1 to t_2,), and is transmitted through the antenna (as represented by the solid line *Tx*). A signal reflected from a distance, *d*, is received by the antenna delayed by the two-way travel time, *t*, equal to *2d/v*, where *v* is the wave velocity in the material. This delayed received signal, *Rx*, has a different frequency than the signal currently being transmitted (represented by the dashed line *Rx*). Multiplying the received signal with the signal currently being transmitted gives a baseband signal, $S_b = Rx \times Tx$. At any point in time, this baseband signal has a frequency equal to the frequency difference between the transmitted and received signals. For a stationary reflector this frequency difference is constant over the sweep. The frequency of this constant baseband signal, called the beat frequency, f_b, is proportional to the delay time, *t*, and thereby to the distance range, expressed as *2d/v*, to the reflector. The proportionality constant is given by the ratio between the sweep bandwidth and the duration of the sweep, or B/T_s. The frequency of the beat signal is thus:

$$f_b = 2Bd / vT_s \, .$$

Measuring the beat frequency thus yields the range to the reflector. The amplitude of the received sine-wave signal gives the reflection strength. If several reflectors are present the baseband signal will be a summation of all the different reflected signals. Spectral estimation techniques like Fourier transforms can calculate the reflected signal.

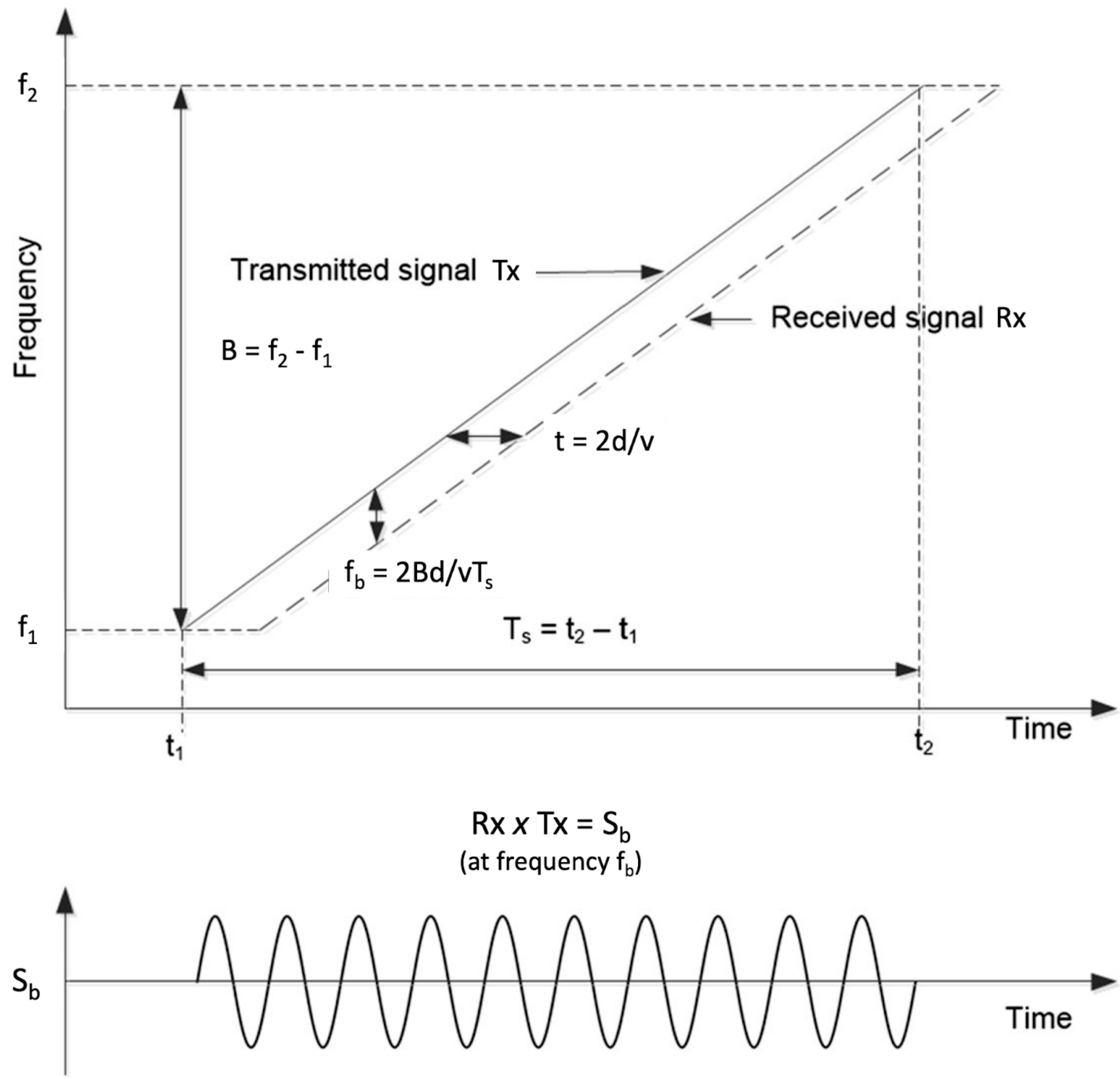

Figure 2.3.1.2 – RIMFAX Signal Genertion, Including Beat Frequency (*fb*) and Baseband Signal Amplitude (*Sb*)

2.3.2 Gating

The RIMFAX FMCW waveform uses a gating technique that allows a single antenna to be used both as a transmitter and receiver. The FMCW signal is gated in a switch before being amplified and fed to the antenna through the antenna switch (Figure 2.3.1.1). The gating switches the FMCW signal on and off with a duty cycle up to 50%. The gating frequency is much lower than the transmitted-signal frequency and higher than the baseband signal spectrum. The reflected signal response will be a convolution between the gated, square-wave transmitted signal and the square wave of the receiver gating. This response function will be a triangular waveform producing an effective linear gain on the received signal as a function of depth. Typically the maximum of the gating function will correspond to the maximum instrumented range. After the gating peak a linear reduction in amplitude will be combined with the spherical loss and attenuation in the media reducing the reflected signal rapidly.

If the receiver gating waveform is turned on with a slight delay after the transmitter gating signal turns off, there will be a time window where no signal is entering the receiver. This is illustrated in Figure 2.3.2.1, in which the receiver gate signal delay time is represented by T_R. Any reflected signal from the exterior or subsurface that arrives during the time-delay window from 0 to T_R does not enter the receiver. The radar response as a function of time will then be a symmetric triangular shape with a flat-peaked top of time-length T_R, giving a linear gain with travel time and depth. If the frequency of the square wave gating signal is F_G, then the total gating window length in time is:

$$T_G = 1 / F_G .$$

The gating makes it possible to remove strong reflectors from the receiver signal before the signal is digitized, effectively increasing the dynamic range coverage of the radar system.

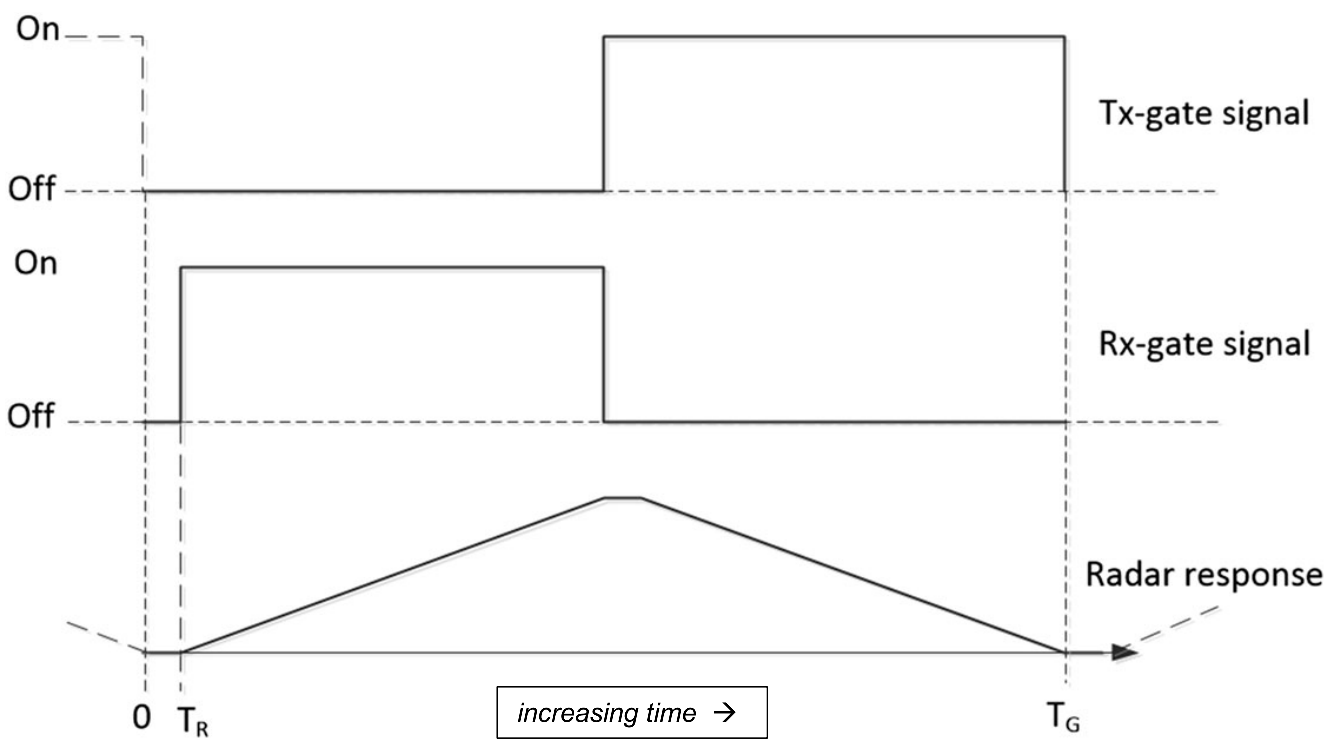

Figure 2.3.2.1 – RIMFAX Gating

2.3.3 Calibration

The RIMFAX electronics unit has two different outputs for transmitting the FMCW signal: an antenna port, where the antenna is connected via the antenna cable running through the rover bulkhead, and the calibration port, where a 2.8-m calibration cable is connected. The calibration cable is placed close to the RIMFAX electronics, inside the rover, and is shorted at the end to produce a reflection from the end of the cable. An electronic switch controls whether the calibration cable or the antenna is used.

The main purpose of the calibration cable is to provide measurements of gain variations in the transmitter and receiver. During operations on Mars the calibration cable measurements will be performed at specific distances during a traverse, for example every 10 meters, or at specific time intervals during stationary activities, for example every hour. The reflected signal from the calibration cable termination will be used to calibrate for temperature-dependent variations in radar amplitude and timing.

2.3.4 Other Considerations

To reduce instrument complexity and maximize resources for high-resolution soundings, the RIMFAX antenna transmits and receives in the same polarization orientation. It is capable of measuring the polarity (sign) of the received signals, though not the depolarization.

Because the antenna is mounted above the surface, it is anticipated that sounding data at depths of less than 30 cm may be affected by surface clutter (signal returned from reflections off of variously oriented surroundisng surfaces and objects above the surface, e.g., rocks). Another source of signal present in each sounding may be reflections off of parts of the rover, especially the wheels and suspension, which may vary with their relative locations and orientations. However, clutter and rover reflections are independent of how data is collected, and are considered in post-processing and interpretation of the data.

2.4 Surface Operation and Data Collection

During surface operations, RIMFAX can collect data both when the rover is stationary and when it is traversing, over all types of terrain. RIMFAX is designed to operate in different modes, in which radar parameters are set to optimize data collection for different subsurface conditions and depths. The functional flexibility to program RIMFAX with multiple, updateable modes greatly increases the scope of what can be investigated. Modes and their parameters can be updated on any uplink Sol, but it is the hope that only minor tweaks will seldom be needed, once effective modes are established early in the mission.

Typically while driving, three nominal modes (Surface, Shallow, Deep) are grouped, and a group of soundings (1 sounding per mode) is commanded at a fixed interval of traversed distance (typically every 10 cm), set by the group_spacing parameter. At the beginning and end of every drive, and elsewhere when the rover is stationary, several soundings of each mode are collected, sometimes along with higher-precision long integration deep soundings and/or passive measurements. Table 2.4.1 lists the standard data-collection sequences. New measurement types and modes may be developed and/or existing ones may be updated with experience gained as the mission progresses.

Table 2.4.1 – RIMFAX Standard Data Collection Sequences

Driving Sols		**Stationary Sols**	
Rover Movement	**RIMFAX Measurements** *nominal modes = Surface, Shallow, Deep*	**Rover Movement**	**RIMFAX Measurements** *nominal modes = Surface, Shallow, Deep*
Stationary (Pre-Drive)	Sets of repeated soundings, 1 set of each nominal mode (and respective calibrations)	Stationary (No Drive) (may be repeated over multiple times of day)	Sets of repeated soundings, 1 set of each nominal mode (and respective calibrations)
	+/- Long integration deep sounding (and calibration)		Long integration deep sounding (and calibration)
	Passive sounding (and calibration)		Passive sounding (and calibration)
Rover Starts (During Drive)	Calibration of each nominal mode, repeated every ~10 m		
	Group of soundings, one sounding of each nominal mode, repeated every ~10 cm		
Rover Halts (Post-Drive)	Sets of repeated soundings, 1 set of each nominal mode (and respective calibrations)		
	Long integration deep sounding (and calibration)		
	Passive sounding (and calibration)		

RIMFAX starts to return the science data as soon as the sounding is complete. Therefore, the Flight System must be ready to receive sounding data within 100 milliseconds of sending a sounding command. The length of science data can take eight different values dependent on the current RIMFAX mode set up. Table 2.4.2 lists the different data lengths together with the corresponding UART transfer times.

Table 2.4.2 – RIMFAX Sounding Data Size and Transfer Time

Data Acquisition Mode	Data Length (KB)	UART Transfer Time (ms)
Sounding data length 1	19.1	1865
Sounding data length 2	9.5	932
Sounding data length 3	4.8	466
Sounding data length 4	2.4	233
Sounding data length 5	1.2	117
Sounding data length 6	0.6	58
Sounding data length 7	0.3	29
Sounding data length 8	0.1	15

The RIMFAX gating makes it possible to omit the recording of close-range reflections, typically from the antenna and surface, which would otherwise limit the dynamic range. The removal of these reflections makes it possible, when desired, to increase the radar's gain to capture weak subsurface reflections. Shifting the receiver dynamic range window particularly to each mode effectively increases the radar's total dynamic range when soundings from different modes are considered together.

1. Surface Mode

   The antenna reflection is captured in the receiver window.

   Measures the surface reflection and the very upper subsurface only.

2. Shallow Mode

   The antenna reflection is removed from the receiver window.

   Measures the surface reflection and the shallow subsurface.

3. Deep Mode

   The antenna and surface reflections are removed from the receiver window.

   Measures reflections from the upper subsurface (~1 m depth) through the instrumented range.

Figure 2.4.1 illustrates how these modes operate in relation to one another and how they are implemented over a typical traverse (paralleling the pattern in Table 2.4.1). The fundamental data-collection sequence consists of a Traverse activity between identical pre- and post-drive Stationary activities. The Stationary activity currently includes ~5 repeated soundings of each mode (not shown), and in the near future may also contain passive and long integration measurements. Calibrations for each type of measurement are also run. The traverse simply repeats the group of three sounding modes at a set interval (group spacing, e.g., 10 cm), until the drive is finished. Calibrations for each mode are interleaved at a slower cadence (e.g., 10 m).

Together, these three modes extend the dynamic range of RIMFAX up to 62 dB above the dynamic range of a single mode, giving an approximate total dynamic range of 160 dB. For stationary measurements, the dynamic range can be further increased by doing a Long Integration Sounding (LIS), in which a few to several hundred soundings are summed together (on the rover RCE) to increase the processing gain.

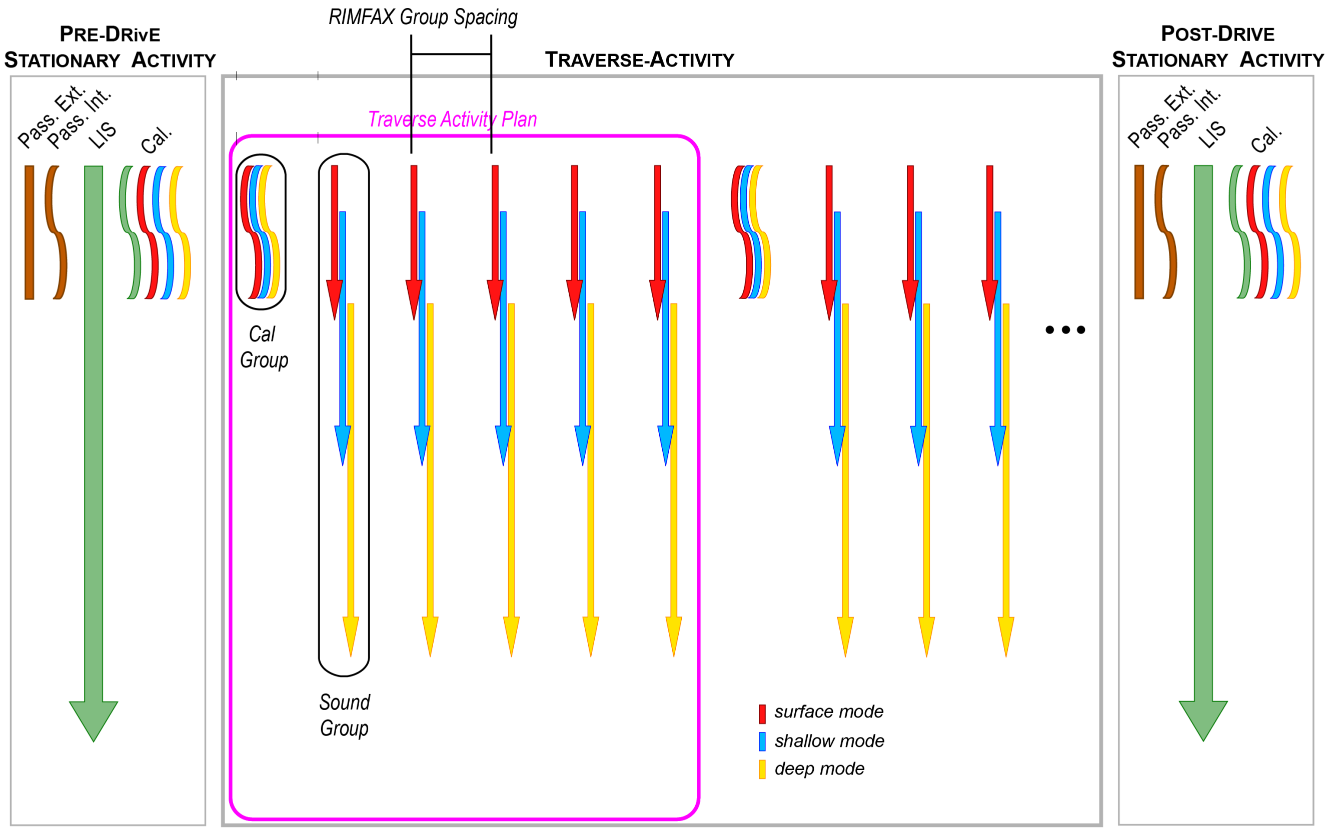

Figure 2.4.1 – GPR Acquisition of Sounding Data in Multiple Modes

Instrumented range and resolution can be determined for each mode to optimize measurements based on subsurface composition and penetration depth. This is accomplished by choosing combinations of frequency range (i.e., bandwidth) and the time period of one sweep of the waveform over the bandwidth (Table 2.4.3). The choice of these two parameters then determines the number of data samples, the frequency-resolution of each data sample, and the data volume of the sounding.

Table 2.4.3 – RIMFAX Instrumented Range (in free space) and Sounding Data Volume, as a Function of Bandwidth and Sweep Time

		Swep time [ms]							
		100	50	25	12.5	6.25	3.125	1.5625	0.78125
Bandwidth [MHz]	450	974 m	486 m	242 m	120 m	59 m	28 m	13 m	5.4 m
	750	583 m	291 m	144 m	71 m	34 m	16 m	6.9 m	2.3 m
	1050	416 m	207 m	102 m	50 m	24 m	11 m	4.3 m	1.0 m
Data volume [bytes]		19530	9764	4882	2440	1220	610	304	152

Typically, shallow modes, with smaller required penetration depths, feature shorter sweep times and use the full RIMFAX bandwidth, as most frequencies will be able to travel the entire, shallow instrumented range. For deep modes, a longer sweep time and narrower bandwidth limited to the lower part of the frequency range are used, because greater depths require greater instrumented range and only lower frequencies are expected to penetrate effectively. There is also a correlation between penetration depth and data volume, because longer sweep times produce more data samples.

Choices of individual sweep time are limited to the 8 values in Table 2.4.3. For any sounding, sweeps of the set time are repeated until the total signal-generation time is 100 ms. The received signal (at a given frequency) is averaged until the total collection time period (per frequency interval) reaches 100 ms. This practice ensures that the processing gain is equal for each sounding, independent of radar configuration.

The length of one sounding record, in number of recorded data samples, is restricted to 8 set values, corresponding to the 8 sweep times discussed above: 9765, 4882, 2441, 1220, 610, 305, 152, 76 samples. Samples in nominal soundings are two bytes, resulting in the possible sounding-record sizes listed along the bottom of Table 2.4.3.

Bandwidth can be set between 0 and 1050 MHz, within the frequency range 150-1200 MHz (i.e., not necessarily limited to values in Table 2.4.3).

The exact settings used for any measurement can be found in the EDR label files. Within the EDR data, modes are referred to as integer-valued configuration IDs. Higher ID numbers typically represent deeper modes, and calibration measurements typically have an integer ID one greater than the mode they are calibrating.

The nominal plan for operation on Mars is to collect soundings from each of three modes every 5-10 cm along the rover traverse. During a drive, the distance the antenna has moved is determined and tracked solely by the Rover Frame Manager, with no memory, modifications, or correction by RIMFAX. When the tactically planned interval distance (since the previous measurement) has been attained as the rover moves along its path, the RIMFAX Instrument Manager on the Rover Computer Element (RCE) commands RIMFAX to make the subsequent measurement.

2.4.1 Calibration Measurements

Surface calibration is part of the RIMFAX nominal operation and will be performed on a regular basis. Calibration measurements are collected by directing the radar output to the calibration cable instead of the antenna and measuring the response from the calibration cable. The calibration data is post-processed on earth and used to calibrate active sounding data after they are transmitted to earth. The calibration data give valuable information about the instrument health, though are not used to calibrate the instrument as such during surface operations.

When RIMFAX operates in the Traverse (mobile) mode, there will be stationary activities at the start and end of the traverse. Calibration cable measurements are collected as a part of these activities. Also, calibration cable measurements are collected at a specified cadence in distance, which typically is much longer than the cadence of active soundings. The cadence of calibration cable measurements depends on the degree of change to the environment and instrument response, and must be initially set based on experience from previous Traverse activities.

When RIMFAX operates in Stationary mode, the Rover is not moving for a longer period and calibration cable measurements will be collected at the start and end of the activity. As with Traverse mode, calibration cable measurements are collected at a specified cadence in time that is typically much longer than the cadence of active soundings. Again, the cadence of calibration cable measurements depends on the degree of change to the environment and instrument response, and must be initially set based on experience from previous Stationary activities.

With regard to resources, there is no difference between active or passive soundings through the antenna and passive or active calibration cable measurements, other than the reduced overall data volume of calibration cable measurements due to the increased cadence in distance or time. The data formats are exactly the same, and the measurement data are therefore treated equally.

A reflection of this signal arises from the shorted distal end of the cable and is received back in the RIMFAX receiver. Given that this cable is to remain a constant during the mission, the timing and amplitude of the calibration cable reflections serve as a reference to determine instrument performance and temperature effects on the electronics box.

2.4.2 Passive Measurements

In addition to nominal, active operation in which generated radar signal is routed through the antenna and radiated to the Martian environment, the RIMFAX radar receiver can also be used without any prior signal generation to collect Passive measurements . In this receive-only, or "listen-only", mode, an ambient spectrum can be measured either through the antenna from the Martian environment or from the calibration cable. Antenna observations may be used to monitor the electromagnetic noise environment, such as noise generated by the rover, and thermally generated emission from the ground, mimicking a passive radiometer. Calibration cable measurements are used as an estimation of self-induced noise and can be used as an input to signal processing that may increase system performance. The measurement types arising from the four possible combinations of signal-generation and receival-source configurations are summarized in Table 2.4.2.1.

Table 2.4.2.1 – Basic Sounding Measurement Configurations

Signal Generation	Receival Source	General Purpose
Active	Antenna	Detect reflections from subsurface dielectric interfaces, (along with any othe the other radiofrequency noise from the Mars environment or rover)
Active	Calibration Cable	Track instrument performance and temperature effects on the electronics box
Passive	Antenna	Determine radiofrequency noise contributions from all sources, including potential natural emissions at Mars
Passive	Calibration Cable	Determine internal radiofrequency noise contributions from the rover

2.4.3 Housekeeping Measurements

RIMFAX continuously collects information about its current state, configuration, and encountered errors, called housekeeping data. When RIMFAX is on, the spacecraft's RCE can obtain a snapshot of the housekeeping data at any time, as returned from the STATUS-command sent to RIMFAX. In nominal operation, reading the housekeeping data will be added into the measurement cadence to be performed each time the radar collects a calibration measurement. The content of the Housekeeping data is described in Section 4.3.3.

3. GENERAL PDS4 DATA PRODUCTS

3.1 Data Processing Levels

This SIS uses the "Planetary Data System Standard 4" (PDS4) data processing level system (Table 3.1.1). Instrument data products referred to in this document as EDRs are considered "Raw". The EDRs are reconstructed from "Telemetry" data, which are the telemetry packets within the project specific Standard Formatted Data Unit (SFDU) record. The EDRs are assembled into complete, decompressed RIMFAX data products, but measurement values are not radiometrically corrected or otherwise procressed.

Instrument data products [formerly] referred to as RDRs may be "Partially Processed", "Calibrated", or "Derived", in the PDS4 level system. RDRs may be constructed from "Raw" data, or processed from other RDR data levels. RIMFAX "Calibrated" data products (CDRs) and collections archived with PDS are delivered by UCLA and described in the RIMFAX CDR SIS [13].

Table 3.1.1 – PDS4 Processing Levels for Instrument Experiment Data Sets

Processing Level for PDS4 Archive	Operations Data Product Name	Description
Telemetry	n/a	An encoded byte stream used to transfer data from one or more instruments to temporary storage where the raw instrument data will be extracted. PDS does not archive telemetry data.
Raw	EDR (Experiment Data Record, heritage term based on MSL mission)	Original data from an instrument. If compression, reformatting, packetization, or other translation has been applied to facilitate data transmission or storage, those processes will be reversed so that the archived data are in a PDS approved archive format.
Partially Processed	RDR (Reduced Data Record, heritage term based on MSL mission)	Data that have been processed beyond the raw stage, but which have not yet reached calibrated status.
Calibrated	RDR	Data converted to physical units, which makes values independent of the instrument.
Derived	RDR	Results that have been distilled from one or more calibrated data products (for example, maps, gravity or magnetic fields, or ring particle size distributions). Supplementary data, such as calibration tables or tables of viewing geometry, used to interpret observational data should also be classified as "derived" data if not easily matched to one of the other three categories.

3.2 Data Product Label Descriptions

3.2.1 Overview of Labels

There are two different sets of product labels associated with RIMFAX EDR products: a) detached ODL (Object Description Language)-format files utilized internally for mission operations (and not archived with the PDS), and b) detached PDS4-format, XML files that accompany all mission data that is archived with the PDS.

The PDS4 label may contain items (such as comments, attributes, class, etc.) that are named differently than counterparts in the ODL label, or may omit some items altogether.

The primary label supporting operations is the detached ODL label, though it is not destined to be part of the PDS archive. ODL is the format used by the PDS3 labels that have since been obsoleted by PDS. Therefore, from a syntactic point of view, they look identical to PDS3 labels and can be processed using most PDS3 tools. Keywords in the ODL labels are not validated and are not guaranteed to be in the PDS Data Dictionary. Every attempt is made to keep the ODL keywords and PDS4 attributes the same, but there are some discrepancies.

While formats, content, and item names may differ between the ODL and PDS4 label types, both can be reliably used to extract metadata.

The primary label from the archive perspective is the detached PDS4 label. This is a separate file with the same base name as the data file, with an ".xml" extension. The detached label references the EDR filename via an attribute. This label is fully compliant with all PDS4 archive standards.

More information on labels is given in Appendix B.

3.2.2 PDS4 Labels

RIMFAX EDR data products have detached PDS4 labels stored as ASCII. A PDS4 label is object-oriented and describes the objects in the data file. The PDS4 label contains attributes for product identification and for table object definitions. The label also contains descriptive information needed to interpret or process the data objects in the file.

PDS4 labels are written in eXtensible Markup Language (XML) and have a file name ending with the extension "xml". PDS4 label statements have the form of "<attribute>value</attribute>".

Figure 3.2.2.1. shows the general structure of a PDS4 label, simplified to typical components (though not every component will be in all labels, depending on the data product, mission, etc). "XML Declaration and Schema Reference" is a few lines of XML overhead required for label implementation; the remainder of the label is defined by the PDS4 Information Model [7]. **Root Tag,File_Area_Definition**, and **End Tag** are placeholders, which vary among labels; the first points to the data object, the second describes format and content of the associated physical file(s) if present, while the third marks the end of the label. **Identification_Area** provides 'fingerprints' and historical information about the product, **Observation_Area** provides information on how the data (or equivalent) were acquired. **Reference_List** points to other sources of information about the product that a user may wish to pursue. **File_Area_Definition** describes format and objects contained in the associated physical file(s). Most of the top-level components have nested classes that are not shown.

The PDS4 labels include many XML classes and attributes defined in the PDS4 Common Data Dictionary [6], the PDS4 Mars 2020 Mission Dictionary [8], and other PDS data dictionaries [9-11]. The dictionaries are represented by XML schema, which are listed at the top of every PDS4 label.

XML Declaration and Schema Reference
Root Tag
- Identification_Area
  - Alias_List
  - Citation_Information
  - Modification_History
- Observation_Area
  - Time_Coordinates
  - Primary_Result_Summary
  - Investigation_Area
  - Observing_System
  - Target_Identification
  - Mission_Area
  - Discipline_Area
- Reference_List
  - Internal_Reference
  - External_Reference
  - Source_Product_Internal
  - Source_Product_External
- File_Area_Definition
  - File
  - Data_Object_Definition

End Tag

Figure 3.2.2.1 – Simplified PDS4 Label Structure

3.3 Binary Data Storage Conventions

3.3.1 Byte Ordering and Format

Any PDS non-byte instrument data (which includes 8-bit unsigned shorts, 16-bit signed shorts, 32-bit signed ints, and 32- and 64-bit IEEE floating-point numbers) may be stored in either Most Significant Byte (MSB) first ("big-endian", as used by e.g. Mac and Sun computers and Java), or Least Significant Byte (LSB) first ("little-endian", as used by e.g. Linux and Windows computers). In a given EDR product, the instrument data can have only one ordering, but it is dependent on the host platform where the data was processed. Binary header data can have a different ordering than the instrument data. This follows both the PDS/ODL and VICAR file format conventions.

The only RIMFAX EDR data products that are stored in binary format are those that contain GPR Sounding data. These RIMFAX binary files contain "EDR" in their filename and have the suffix ".DAT". All other RIMFAX EDR data products, and all labels, are ASCII text files.

Nominal RIMFAX Sounding data has 16-bit precision and is stored in 2-byte couplets. Within each byte pair, the MSB is listed first and the LSB is listed next. LIS Sounding data, which has 32-bit precision, consists of 4 immediately adjacent bytes, listed from MSB (first) to LSB (last). (Originally, the first two data Releases, in 2021, were released in a different format – see SIS v 1.12, Sections 3.3 and 4.4.)

Within bytes, RIMFAX binary data is most-significant-bit-first. The high-order bit of the MSB is the sign bit and is set to 1 for negative values. Negative values are represented in two's complement.

4. RIMFAX EDR DATA PRODUCTS

For M2020 (with the exception noted in Section 1.3) the experimental data record (EDR) data product is the fundamental instrument data archive product. M2020 instrument EDRs described in this document are generated within an automated pipeline process by JPL's Multimission Instrument Processing Laboratory (MIPL) under the IDS subsystem of the M2020 GDS Realtime Operations (RTO) element.

4.1 EDR Processing Flow

Ground data flow resulting in EDR generation begins with packetized instrument telemetry data that resides on JPL's Telemetry Delivery System (TDS) in the form of Standard Format Data Units (SFDUs). A software application developed by the Advanced Multi-mission Operations System (AMMOS), called AMMOS Mission Data Processing and Control Subsystem (AMPCS), is used to perform depacketization of the data. During this process, the SFDU wrapping is removed and the data is restructured to build a binary ".dat" data product (DP) comprised of one or more Data Product Objects (DPOs). An associated ".emd" Earth meta-data file is also generated for each DP. The Setup file(s) is generated by the RIMFAX team and contains the radar parameters for each Config ID (or Mode). The DP and meta-data are written by AMPCS to the Operations Cloud Store (OCS), to be ingested by IDS's EDR generator software "m20edrgen" and processed with a DPO Dictionary and APID Dictionary provided by M2020 Flight Software (FSW) and with SPICE kernels provided by NAIF. The EDR will be generated within 60 seconds after the JMS message describing the OCS location of the respective the binary data product and associated Earth meta-data file has been received by the IDS pipeline system. This data flow is illustrated in Figure 4.1.1, and is elaborated in Section 4.4.

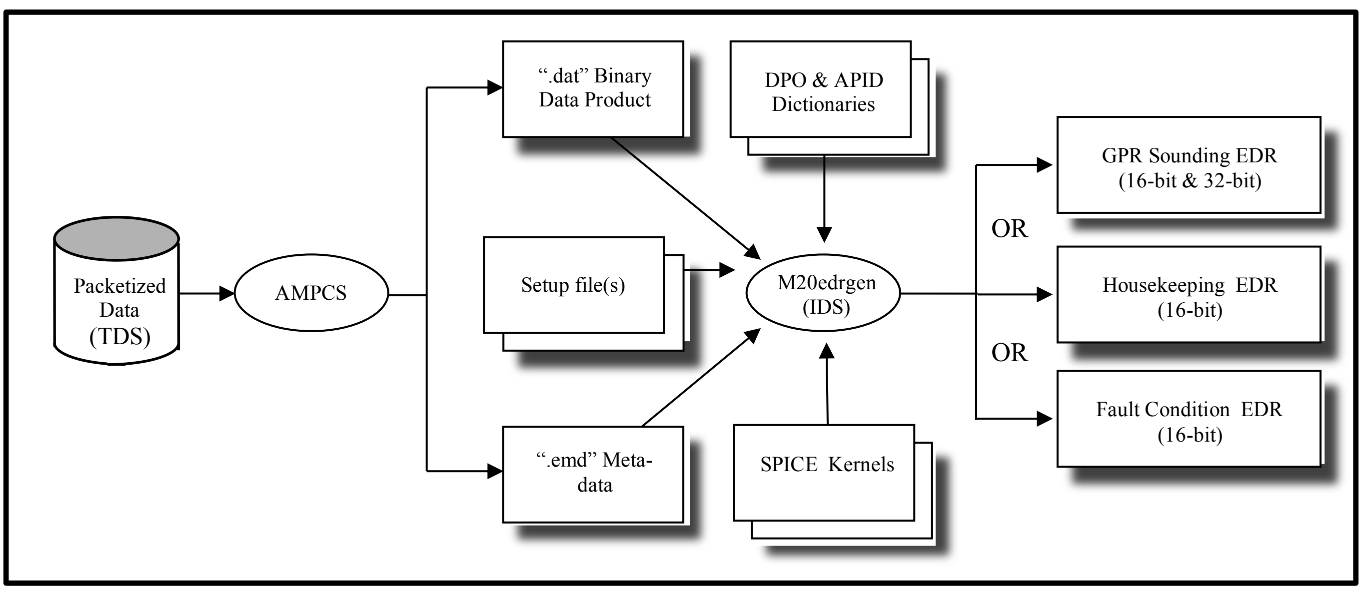

Figure 4.1.1 - EDR Processing Flow

In all EDR cases, missing packets will be identified and reported for retransmission to the ground as "partial datasets". Prior to retransmission, the missing EDR data will be filled with zeros. The EDR data will be reprocessed only after all "partial datasets" are retransmitted and received on the ground. In these cases, the EDR version will be incremented so as not to overwrite any previous EDR versions. The EDR data product will be placed into FEI for distribution and to facilitate the archiving process.

4.2 EDR Dataset Structure

RIMFAX EDR data products are generated on the ground through processing of telemetered data products (DPs) received from the rover. This section describes the structure of the overall RIMFAX EDR datasest and of the constituent data product files, including labels.

RIMFAX EDRs are structured into three main types based on the type of information they contain:

1. GPR Sounding measurements,
2. Housekeeping measurements,
3. Fault Condition information (not archived with PDS).

For description purposes in this SIS, "GPR Sounding" products or data are taken to encompass any RIMFAX science measurement (even though eg passive measurements don't involve typical sounding technique or radar functionality, and are better described as radiometry).

Table 4.2.1 provides a mapping between the different EDR types and the types of instrument DPs acquired onboard the spacecraft and sent to Earth via telemetry (see Appendix A for a more detailed mapping). These mappings are not meant to imply a 1-file to 1-file correspondence between a DP and an EDR. While a DP may contain data collected from multiple modes/configuration IDs, an EDR product is created for each unique mode/configuration ID on a per-activity basis.

Table 4.2.1 – Telemetered DP and EDR Types

EDR Type (Ground)	Telemetered Instrument DP Type (Onboard)	DP Binary Format
"GPR Sounding"	Rfax_Sounding_TypeN*	16 bit
	Rfax_LIS	32 bit
	Rfax_Summary	16 bit
"Housekeeping"	Rfax_SciEng	16 bit
"Fault Condition" *(not PDS-archived)*	Rfax_Fault	16 bit

* N may be 1-7, representing different types, priorities, or modes of soundings.

Figure 4.2.1 schematically represents the overarching dataset structure comprising the three types of EDRs. It also depicts the individual components within the EDR types, visually illustrating both their parallel internal structure as well as differences in file format, associated metadata, and accompanying labels. Each EDR product is labeled with the 3-letter product id designator found in the filename (Section 5.5.1) its data format (binary or ASCII text), and its file extension (also listed in label depictions).

Both Sounding and Housekeeping EDR types include both Data and Metadata EDR products, all of which have two label versions: a detached ODL-format Operations label (which is not included in the

PDS archive) and a detached PDS4-compliant Archive label (Sections 3.2, 4.3.5). The Fault Condition EDR type has no metadata EDR product, no PDS4-format label, and is not included in the PDS archive. Sounding data EDRs consist of unprocessed, uncalibrated instrument measurements stored in binary format (Sections 3.3, 4.4). All other data and metadata products consist of unprocessed instrument, rover, and/or ancillary data stored as ASCII text with various formats.

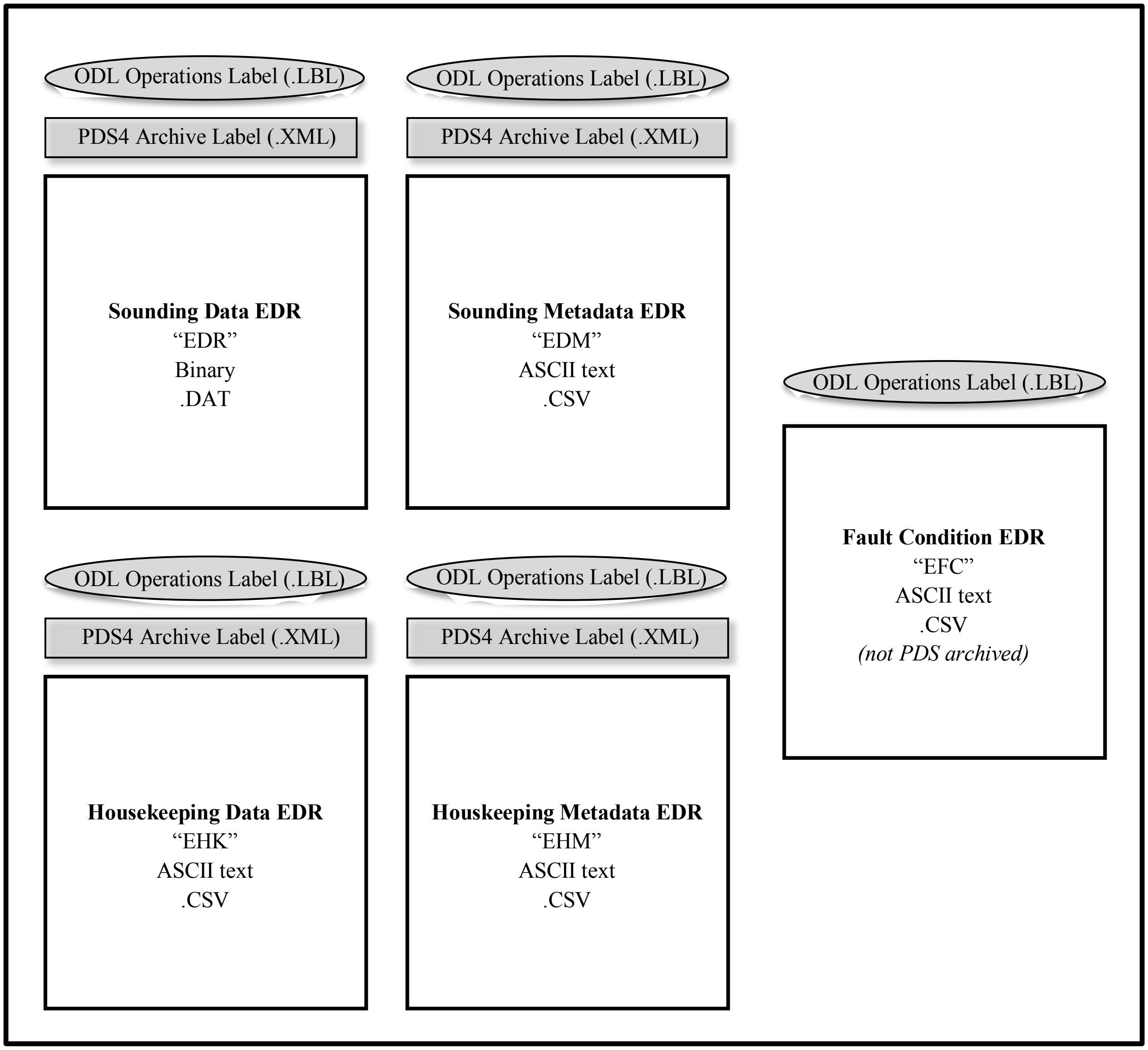

Figure 4.2.1 - EDR Dataset Structure and Product Components

Each EDR type and the EDR data products they contain are briefly summarized in the following subsections (and in Table 4.3.1). The following Section 4.3 details the contents of each EDR data product that become archived with the PDS (Sounding and Housekeeping types only).

4.2.1 Sounding EDRs

Sounding data, as referred to in this SIS, comprises all science data taken by RIMFAX, including Active and Passive measurements, Traverse/Mobile and Stationary soundings, Antenna and Calibration Cable receival sources, nominal and high (LIS) precisions, and all modes. These sounding types and their collection by the instrument on the rover are described in Section 2. The Sounding EDR type includes a binary file of the sounding data itself ("EDR") and a corresponding ASCII-text metadata file ("EDM").

4.2.2 Housekeeping EDRs

Housekeeping data contains information returned from the STATUS-command sent to RIMFAX. This command is typically sent with a certain cadence or as part of an activity. The Housekeeping EDR type includes a file of the housekeeping data itself ("EHK") and a corresponding metadata file ("EHM"), both of which are ASCII text.

4.2.3 Fault Condition EDRs

Fault Condition DPs and EDRs, representing the instrument's state of health, are generated when the RCE detects an error. The RCE performs fault handling which includes sending a STATUS message to RIMFAX. The content of the Fault Condition EDR ("EHC") is therefore the same as that of a Housekeeping EDR ("EHK") containing only one measurement. As a housekeeping-out-of-range flag could trigger the generation of an EFC, the voltage and temperature values will be examined closely, in addition to the error-counters. Fault Condition EDRs (one ASCII-text file) are not archived with the PDS.

4.3 Archived EDR Data Products

This section desctibes the information content of each of the archived EDR data products (Sounding and Housekeeping types only; summarized in Table 4.3.1).

Table 4.3.1 – Archived EDR Types, Data Products, and Formats

EDR Type	EDR Data Product	Product ID *	Size per Record	Bits per Samp/Char	Format Description (See Sect. 4.4)	File Suffix
GPR Sounding	Sounding Data	EDR	76 to 9,765 samples	16 (nominal soundings) 32 (high-precision LIS)	Binary: 16-bit samples stored as 2-byte pairs, with MSB listed first and LSB immediately following; 32-bit samples consist of 4 immediately adjacent bytes, listed from MSB (first) to LSB (last).	.DAT
	Sounding Metadata	EDM	38 cols	8 / char	ASCII Text: table of comma-separated values (1 header row).	.CSV
Housekeeping	Housekeeping Data	EHK	30 cols	8 / char	ASCII Text: table of comma-separated values (1 header row).	.CSV
	Housekeeping Metadata	EHM	41 cols	8 / char	ASCII Text: table of comma-separated values (1 header row).	.CSV

4.3.1 Sounding Data EDRs

Sounding data EDRs ("EDR") contain only the sounding measurement data, with no header or other information. One sounding data EDR is produced per mode per commanded Rimfax Activity. Within an EDR, each record is one sounding, ordered sequentially in time of execution. Data is recorded and given in the frequency domain: each data sample covers an equal-sized increment of frequency, and samples are ordered sequentially from lowest frequency to highest frequency, over the measured bandwidth. The frequency increment represented by each sample can be determined as follows, from parameters listed in an EDR's corresponding label file (complete list in Table 4.3.5.1):

$$sample\_increment = (stop\_frequency - start\_frequency) / number\_of\_samples$$

Sample values in sounding data EDRs correspond to an uncalibrated digital number (produced by the instrument's analog-to-digital converter, ADC) that is proportional to the voltage detected by RIMFAX in response to the received signal. Thus, sounding data consists of signal amplitude as a function of signal frequency, known as the "frequency domain".

The internal configuration and binary format of the data file is described in Section 4.4. Information about the rover, instrument, and measurements that applies to all sounding data within a given EDR, including parameters constituting the sounding mode, can be found in the corresponding label file (Sections 3.2, 4.3.5). The naming convention of EDR files also contains information pertaining to the sounding data within it (Section 5.5).

4.3.2 Sounding Metadata EDRs

One record of metadata is generated for each sounding, essentially simultaneously to it. Thus, a sounding metadata file ("EDM") contains the same number of rows (excluding its one header row) as the number of soundings and records in the corresponding binary sounding data file ("EDR"). Sounding metadata includes information on the time of the measurement and the number of soundings made (Table 4.3.2.1). It also includes information gathered from other rover sources on the position, attitude, and status of the RIMFAX antenna, the rover, and select rover hardware components. This information may be of interest in determining the precise configuration, on a per-sounding basis, of the antenna with respect to surroundings and rover components, which may influence radar signal radiation and return.

Table 4.3.2.1 – Parameters within Sounding Metadata Files

The parameters listed in the rows of this table are listed across the columns of the header row of the comma-separated-value table in the metadata file. Parameters in bold are unique to the Sounding metadata; the rest are present in both the Sounding and Hosuekeeping metadata.

Parameter	Description	Unit	Format
SCLK	Spacecraft clock time in seconds [Time 0 = midnight on Jan 1, 1980]	s	Integer
SCLK_subsecond	Spacecraft clock time fractions of a second		Integer
rfax_sounding_counter	Absolute total count of soundings since start of M2020 *Perseverance* mission		Integer
sounding_number	Count of soundings since RIMFAX was last powered on (ie since last execution of "Power-On" Activity)		Integer
rfax_antt_x	X-coordinate of RIMFAX antenna frame origin position in the current SITE frame	m	Float
rfax_antt_y	Y-coordinate of RIMFAX antenna frame origin position in the current SITE frame	m	Float
rfax_antt_z	Z-coordinate of RIMFAX antenna frame origin position in the current SITE frame	m	Float
rfax_antt_az	Azimuth angle of the RIMFAX antenna frame orientation, measured from North = 0	deg	Float
rfax_antt_pitch	Pitch angle of the RIMFAX antenna frame orientation, measured from Horizontal = 0	deg	Float
rfax_antt_roll	Roll angle of the RIMFAX antenna frame orientation, measured from Horizontal = 0	deg	Float
system_sclk_seconds	Spacecraft clock time in seconds [Time 0 = midnight on Jan 1, 1980]	s	Integer
system_sclk_subseconds	Spacecraft clock time fractions of a second		Integer
system_sapp_p0	X-coordinate of rover (RNAV) position in the current SITE frame	m	Float
system_sapp_p1	Y-coordinate of rover (RNAV) position in the current SITE frame	m	Float
system_sapp_p2	Z-coordinate of rover (RNAV) position in the current SITE frame	m	Float
system_sapp_q0	Scalar coefficient of attitude quaternion array of current rover attitude relative to the current SITE frame		Float
system_sapp_q1	Coefficient along unit vector I (X-axis) of attitude quaternion array of current rover attitude relative to the current SITE frame		Float
system_sapp_q2	Coefficient along unit vector J (Y-axis) of attitude quaternion array of current rover attitude relative to the current SITE frame		Float
system_sapp_q3	Coefficient along unit vector K (Z-axis) of attitude quaternion array of current rover attitude relative to the current SITE frame		Float
rover_sapp_quality	Surface Attitude, Position, and Pointing (SAPP) quality flag		Integer
system_rmc_site	Site rover motion counter (RMC 1)		Integer
system_rmc_drive	Drive rover motion counter (RMC 2)		Integer
system_rmc_pose	Pose rover motion counter (RMC 3)		Integer
system_rmc_arm	Arm rover motion counter (RMC 4)		Integer
system_rmc_drill	Drill rover motion counter (RMC 6)		Integer
system_rmc_sha	SHA rover motion counter (RMC 5)		Integer

system_rmc_bit_carousel	Bit Carousel rover motion counter (RMC 9)		Integer
system_rmc_sealing_station	Sealing Station rover motion counter (RMC 10)		Integer
system_rmc_rsm	RSM rover motion counter (RMC 7)		Integer
system_rmc_hga	HGA rover motion counter (RMC 8)		Integer
rover_steer_lf	Steer angle of left-front wheel	rad	Float
rover_steer_rf	Steer angle of right-front wheel	rad	Float
rover_steer_lr	Steer angle of left-rear wheel	rad	Float
rover_steer_rr	Steer angle of right-rear wheel	rad	Float
rover_left_bogie	Angle of left bogie joint	rad	Float
rover_right_bogie	Angle of right bogie joint	rad	Float
rover_left_differential	Angle of left differential joint	rad	Float
rover_right_differential	Angle of right differential joint	rad	Float

4.3.3 Housekeeping Data EDRs

Housekeeping data EDRs ("EHK") contain information from the STATUS-commands sent to RIMFAX. This command is typically sent with a certain cadence or as part of an activity. Housekeeping data primarily includes voltage levels, temperatures, and error counts pertinent to RIMFAX, along with the currently active setup file and sounding count (Table 4.3.3.1). Voltage and temperature values are given in terms of Digital Number (DN) from the Analog-to-Digital Converter and need to be translated into volts and degrees. The error counters are different types of communication errors and state violations, and should all be 0 in nominal operations.

Table 4.3.3.1 – Parameters within Housekeeping Data Files

The parameters listed in the rows of this table are listed across the columns of the header row of the comma-separated-value table in the data file.

Parameter	Description	Unit	Format
config	Identifier for the currently active RIMFAX Setup file on the rover.		Integer
nSoundings	Count of soundings since RIMFAX was last powered on (ie since last execution of "Power-On" Activity)		Integer
hkAdcA0	Voltage V3v3_D1	DN	Integer
hkAdcA1	Voltage V2v5_D2	DN	Integer
hkAdcA2	Voltage V1v5_D3	DN	Integer
hkAdcA3	Voltage V3v3_A1	DN	Integer
hkAdcA4	Voltage V2v5_A2	DN	Integer
hkAdcA5	Voltage V5v_A3	DN	Integer
hkAdcA6	Voltage Vm5v_A4	DN	Integer
hkAdcA7	Voltage_reference	DN	Integer
hkAdcB0	Voltage V3v_A8	DN	Integer
hkAdcB1	Voltage Vm3V_A9	DN	Integer
hkAdcB2	Temperature Term_D1 prts	DN	Integer
hkAdcB3	Temperature Term_RF1	DN	Integer
hkAdcB4	Temperature Term_RF2	DN	Integer
hkAdcB5	Temperature Term_P1	DN	Integer
hkAdcB6	Temperature Term_P2	DN	Integer

hkAdcB7	Temperature Term_D2	DN	Integer
framingErrors	Error count		Integer
overrunErrors	Error count		Integer
invalidErrors	Error count		Integer
parityErrors	Error count		Integer
invalidErrorsCtrlTypes	Error count		Integer
invalidResStatusFlags	Error count		Integer
invalidCmdCondCodes	Error count		Integer
invalidDataLength	Error count		Integer
invalidCRC	Error count		Integer
invalidData	Error count		Integer
stateViolation	Error count		Integer
buildId	Identifer for FPGA build version (static and not re-programmable; constant over mission)		Integer

4.3.4 Housekeeping Metadata EDRs

One record of metadata is generated for each housekeeping measurement, essentially simultaneously to it. Thus, a housekeeping metadata file ("EHM") contains the same number of rows (excluding its one header row) as the number of housekeeping measurements and rows in the corresponding housekeeping data file ("EHK"). Housekeeping metadata includes information on the temperature and current levels pertinent to RIMFAX (Table 4.3.4.1). It also includes the same items of information as the sounding metadata gathered from other rover sources on the position, attitude, and status of the RIMFAX antenna, the rover, and select rover hardware components.

Table 4.3.4.1 – Parameters within Housekeeping Metadata Files

Only parameters unique to the Housekeepig metadata are listed in this table; the Houskeeping metadata also shares, in common with the Sounding metadata, all of the non-bold parameters listed in Table 4.3.2.1. The parameters listed in the rows of this table are listed across the columns of the header row of the comma-separated-value table in the metadata file.

Parameter	Description	Unit	Format
avg_temp	Temperature of VAMP UHFA/RMFX base, a 10-second average	degC	Float
avg_temp_status	Status of the temperature data		Integer
pwr_switch_state	Power state		Integer
bcb1_rpam_a_i_eu	Current for BCB1 RPAM A	amp	Float
bcb2_rpam_a_i_eu	Current for BCB2 RPAM A	amp	Float
bcb1_rpam_b_i_eu	Current for BCB1 RPAM B	amp	Float
bcb2_rpam_b_i_eu	Current for BCB2 RPAM B	amp	Float

4.3.5 EDR Label Content

Labels contain information about the rover, instrument, and measurements that applies to all sounding data within a given EDR, including parameters constituting the sounding mode. Each of the above four EDR products in Sections 4.3.1-4.3.4 has two corresponding labels: an ODL-format label for Operations use and an PDS4-format label for archiving at PDS (Section 3.2, Figure 4.2.1). Most label content is the same for the respective labels of each EDR product. The bulk of this information describes mission- and rover-wide status, or transmission, processing, and archiving aspects, as defined in the tables listed in Appendix B.

RIMFAX-specific label parameters (found under RIMFAX Mode Elements in ODL labels and under RIMFAX_Parameters in PDS4 labels) are listed and described in Table 4.3.5.1. While Housekeeping-type EDRs do not contain sounding data and may or may not be made in conjunction with sounding measurements, these RIMFAX parameters as present in Housekeeping-type EDR labels refer to the most recent sounding measurement that RIMFAX has made. The exception is *number_of_soundings*, which is only in Sounding-type EDR Labelss and not Housekeeping-type EDR Labels.

Table 4.3.5.1 – RIMFAX-Specific Parameters within EDR Label Files

Parameter	Description	Unit	Format
config_id	Identifier of RIMFAX configuration mode		integer
decimation	Onboard decimation of acquired soundings, in number of soundings removed per each sounding downlinked		integer
setup_file	Name of current/applicable RIMFAX setup file		string
calibration	Calibration cable switch control - Indicates measured signal is: 0 = from the Antenna, 1 = from the Calibration Cable		integer
gate_frequency	Frequency of the gate signal	kHz	float
number_of_samples	Number of frequency-domain data samples measured in one sounding		integer
number_of_sweeps	Number of bandwidth sweeps integrated into one recorded measurement, or sounding		integer
receive_only	Passive measurement switch control - Indicates measured signal is: 0 = returned/received from Active transmission, 1 = ambient/received with no prior transmission, ie Passive or "listen only"		integer
rx_delay	Time delay of receiver gate	ns	integer
rx_attenuation	Attenuation in the receive path, higher values represent more dampening of the received signal	dB	integer
start_frequency	Starting frequency of measured bandwidth range	MHz	integer
stop_frequency	Ending frequency of measured bandwidth range	MHz	integer
sweep_time	Duration of one individual radar-signal generation (or, for Passive: receive-only) sweep through the set frequency bandwidth	ms	float
tx_delay	Time delay of transmitter gate	ns	integer
tx_attenuation	Attenuation in the transmit path, higher values represent lower output power	dB	integer
group_spacing	Commanded distance between sounding groups. A group includes one soundig of each mode, each executed in immediate sequence (ie, effectively at the same location). Actual distance between measurements may deviate slightly.	cm	integer
sinetable	Name of current/applicable RIMFAX sinetable file		string
lis_soundings	Indicates measurement is: 0 = Nominal precision (16 bits), 1 = High precision (LIS, 32 bits)		integer
number_of_soundings (in labels for “EDR”, “EDM” only, not “EHK”, “EHM”)	Count of soundings recorded in corresponding Sounding EDR (1 per row)		integer

4.4 EDR Product Format

This section details the specifics of the internal data format of RIMFAX EDR data products, along with guidelines for estimating file size.

The initial telemetered DPs will contain cruise content. Thereafter, surface content will make up the bulk of received data for normal operations. Figure 4.4.1 illustrates the internal components of Cruise and Surface telemetered DPs (first section of figure) and Cruise EDRs, Surface EDRs, and Surface Metadata EDRs (second section of figure).

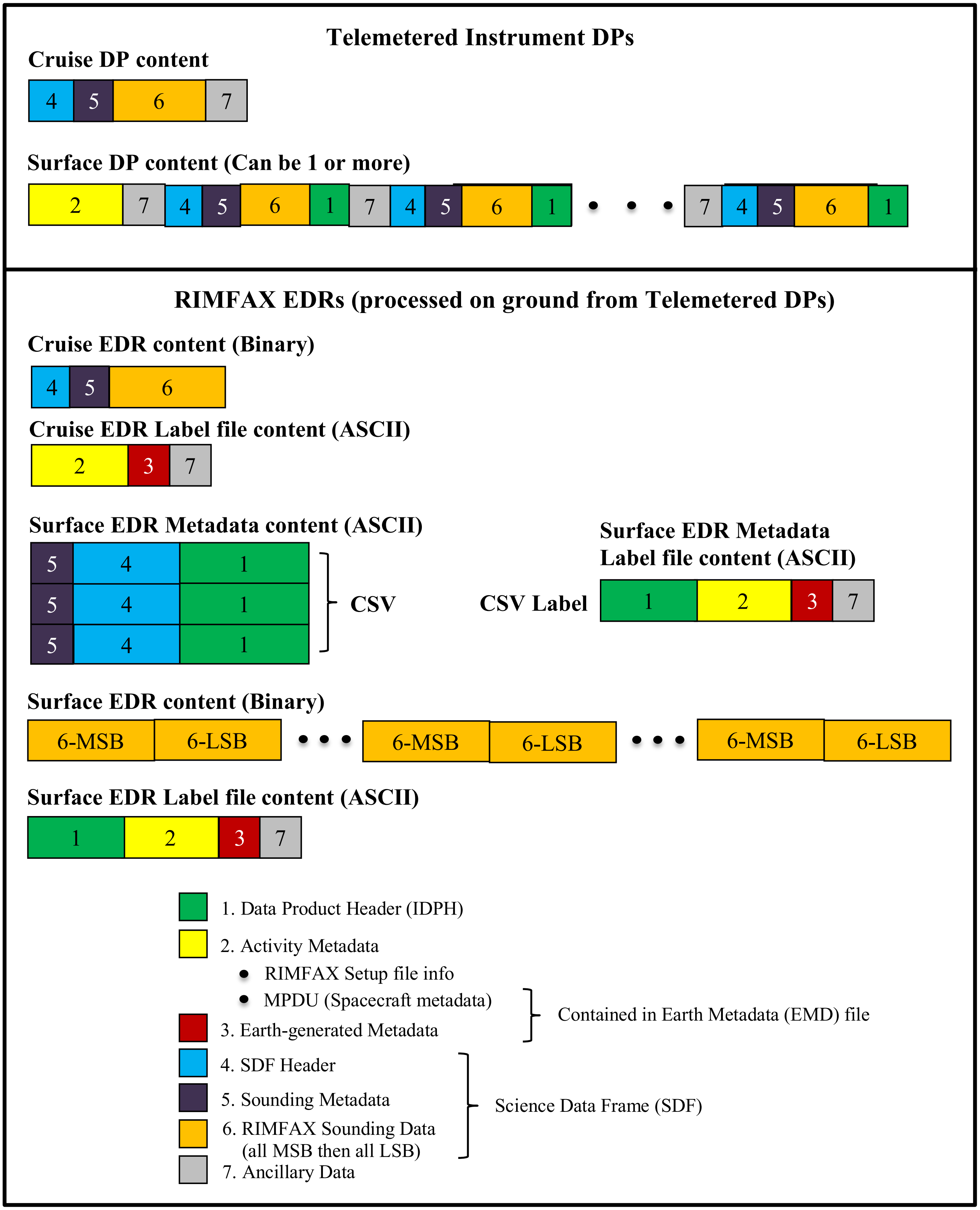

Figure 4.4.1 – DP and EDR Internal Components and Format

Within the binary Sounding data EDRs, each record contains one sounding. Each sounding is made up of data samples containing an uncalibrated digital number proportional to the voltage measured by RIMFAX in response to the received signal. Each data sample covers an equal-sized increment of frequency, and samples are ordered sequentially within a sounding record from lowest frequency to highest frequency, over the measured bandwidth.

Nominal RIMFAX Sounding data has 16-bit precision and is stored in 2-byte couplets. Within each byte pair, the MSB is listed first and the LSB is listed next. LIS Sounding data, which has 32-bit precision, consists of 4 immediately adjacent bytes, listed from MSB (first) to LSB (last). Within each sounding record, the byte-pairs of every sample are given in correct sample sequence (i.e., from the sample corresponding to the lowest-frequency increment to the sample corresponding to the highest-frequency increment).

Note that the separated bytes are unsigned but the combined two-byte value is signed. The high-order bit of the MSB is the sign bit and is set to 1 for negative values. Negative values are represented in two's complement.

The size of a RIMFAX Sounding EDR data product varies with sounding mode settings (e.g., start and stop frequency, number of samples), traverse distance, and the commanded distance between soundings (configured with the parameter *group_spacing*). The length of one sounding record, in number of samples, is restricted to 8 set values: 76, 152, 305, 610, 1220, 2441, 4882, 9765. Each sample in a nominal sounding is 16-bit precision; Long Integration Sounding (LIS) samples are 32 bits. The data size of one sounding in the binary Sounding EDR can be determined from this information (also reflected in Table 4.3.1). All soundings within a single EDR are of the same mode, and thus have the same number of samples.

The total number of parameters, and hence columns, in a Sounding metadata EDR is 38 (Table 4.3.1), All fields contain numerical integer or float values (besides the character-string header row). The total size of a Sounding metadata EDR is directly related to the number of GPR soundings in the corresponding EDR data file.

The total number of parameters, and hence columns, in a Housekeeping data EDR is 30 (Table 4.3.1), all of which contain numerical integer values only (besides the character-string header row). The total size of a Housekeeping data EDR is directly related to the number of Housekeeping measurements contained.

The total number of parameters, and hence columns, in a Housekeeping metadata EDR is 41 (Table 4.3.1). All fields contain numerical integer or float values (besides the character-string header row). The total size of a Housekeeping metadata EDR is directly related to the number of Housekeeping measurements in the corresponding EHK data file.

4.5 EDR Product Validation

Validation of the M2020 RIMFAX EDRs will fall into two primary categories: automated and manual. Automated validation will be performed on every EDR product produced for the mission. Manual validation will only be performed on a subset.

Automated validation will be performed as a part of the archiving process and will be done simultaneously with the archive volume validation. Validation operations performed will include such things as a validation of the PDS4 syntax of the label, a check of the label values against the database, and checks for internal consistency of the label items. The latter include such things as verifying that the product creation date is later than the earth received time. As problems are discovered and/or new possibilities identified for automated verification, they will be added to the validation procedure.

Manual validation of the GPR sounding measurements will be performed both as spot-checking of data through-out the life of the mission, and comprehensive validation of a sub-set of the data (for example, a couple of days' worth of data). These products will be viewed by a human being. Validation in this case will include inspection of the sounding product or other data object for errors (like missing records) not specified in the label parameters, verification that the product is assessable using the specified software tools, and a general check for any problems that might not have been anticipated in the automated validation procedure.

5. RIMFAX ARCHIVE ORGANIZATION, IDENTIFIERS, AND NAMING CONVENTIONS

This section describes the basic organization of the RIMFAX archive under the PDS4 Information Model [5, 7], including the naming conventions used for the bundle, collections, data product unique identifiers, and data product files.

5.1 Archive Structure

The highest level of organization for a PDS archive is the bundle. A bundle is a set of one or more related collections that may be of different collection types. A collection is a set of one or more related basic products that are typically all of the same product type. Bundles and collections are logical structures, not necessarily tied to any physical directory structure or organization. A product consists of a file containing one or more digital objects (e.g., a table of data, an image, or a document) and described by an accompanying label file.

5.2 Logical Identifiers

Every product in PDS is assigned a Logical Identifier (LID)that allows it to be uniquely identified across the system. Each product also has a Version Identifier (VID) that allows different versions of a specific product to be referenced uniquely. A product's LID and VID are defined as separate attributes in the product label. For convenience they may be combined in a single string called a LIDVID, with two colons between the LID and the VID. LIDs and VIDs are assigned by PDS and are formed according to the conventions described in Sections 5.2.1 and 5.2.2. The uniqueness of a product's LID and VID may be verified using the PDS Registry and Harvest tools.

5.2.1 LID Formation

LIDs take the form of a Uniform Resource Name (URN). LIDs are restricted to ASCII lower case letters, digits, dash, underscore, and period. Colons are also used, but only to separate prescribed components of the LID. Within one of these prescribed components dash, underscore, or period are used as separators. LIDs are limited in length to 255 characters.

M2020 RIMFAX LIDs are formed according to the following conventions:

- ***Bundle LIDs*** are formed by appending a bundle-specific ID to the base ID:

  urn:nasa:pds:<bundle ID>
  Example: urn:nasa:pds:mars2020_rimfax

  The bundle ID must be unique across all products archived with the PDS.

- ***Collection LIDs*** are formed by appending a collection-specific ID to the collection's parent bundle LID:

  urn:nasa:pds: <bundle ID>:<collection ID>
  Example: urn:nasa:pds:mars2020_rimfax:data_calibrated

Since the collection LID is based on the bundle LID, which is unique across PDS, the only additional condition is that the collection ID must be unique across the bundle. Collection IDs correspond to the collection type (e.g. “browse”, “data”, “document”, etc.). Additional descriptive information may be appended to the collection type (e.g. “data_raw”, “data_calibrated”, etc.) to ensure that multiple collections of the same type within a single bundle have unique LIDs.

- ***Product LIDs*** are formed by appending a product specific ID to the product’s parent collection LID:

  urn:nasa:pds: <bundle ID>:<collection ID>:<product ID>
  Example: urn:nasa:pds:mars2020_rimfax:data_calibrated:rimfax_calibrated_0001

  Since the product LID is based on the collection LID, which is unique across PDS, the only additional condition is that the product ID must be unique across the collection. Often the product LID is set to be the same as the data file name without the extension. See Section 5.5 below for examples of RIMFAX data product LIDs.

5.2.2 VID Formation

Product VIDs consist of major and minor components separated by a “.” (M.n). Both components of the VID are integer values. The major component is initialized to a value of “1”, and the minor component is initialized to a value of “0”. The minor component resets to “0” when the major component is incremented. The PDS Standards Reference [5] specifies rules for incrementing major and minor components.

5.3 RIMFAX Bundle

The complete M2020 RIMFAX archive is organized into a single bundle as described in Table 5.3.1 [14].

Table 5.3.1 –RIMFAX PDS Bundle

Bundle Logical Identifier	Description
urn:nasa:pds:mars2020_rimfax	The RIMFAX Bundle.

5.4 RIMFAX Collections

The RIMFAX Bundle contains the three collections listed in Table 5.4.1 [14].

Table 6.2.1 – RIMFAX PDS Collections

Collection Logical Identifier	Collection Type	Content Description
urn:nasa:pds:mars2020_rimfax:data_raw	Data	Contains RIMFAX raw data products, in binary and CSV formats.
urn:nasa:pds:mars2020_rimfax:data_hk	Data	Contains RIMFAX housekeeping data products, in varied formats.
urn:nasa:pds:mars2020_rimfax:data_calibrated	Data	Contains RIMFAX calibrated data products, in CSV format.
urn:nasa:pds:mars2020_rimfax:browse_radargram	Browse	Contains browse radargram products compiled from traverse sounding data for select calibrated data products, in PNG format.
urn:nasa:pds:mars2020_rimfax:document	Document	Contains documentation, including this CDRSIS, the EDR SIS, the Archive Bundle SIS, and the RIMFAX Calibrated Catalog.

5.5 File Naming Standards

The PDS4 standard is that the path and filename together are essentially limited to a character string length of 255. Use of three- character extensions, such as ".IMG" for image EDRs and RDRs and ".DAT" for spectrum (including frequency-domain RIMFAX Sounding data) EDRs and state-of-health EDRs, is consistent with the PDS4 standard.

The primary attributes of the filename nomenclature are:

a) Uniqueness - It must be unique unto itself without the file system's directory path. This Protects against product overwrite as files are copied/moved within the file system and external to the file system, if managed correctly.

b) Metadata - It should be comprised of metadata fields that keep file bookkeeping and sorting intuitive to the human user. Even though autonomous file processing will be managed via databases, there will always be human-in-the-loop that puts a premium on filename intuition. Secondly, the metadata fields should be smartly selected based on their value to ground processing tools, as it is less CPU-intensive to extract information from the filename than from the label.
NOTE: Metadata information in the filename also resides in the product label.

The metadata fields have been selected based on MSL lessons learned. In general, the metadata fields are arranged to achieve:

a) Sortability - At the beginning of the filename resides a primary time oriented field such as Spacecraft Clock Start Count (SCLK). This allows for sorting of files on the M2020 file system by spacecraft data acquisition time as events occurred on Mars.

b) Readability - An effort is made to alternate Integer fields with ASCII character fields to Optimize differentiation of field boundaries for the human user.

5.5.1 EDR Filename

Each M2020 RIMFAX EDR data product can be uniquely identified by incorporating into the product filename at minimum the Instrument ID, SCLK (or UTC), Product Type identifier, and Version number. The convention is illustrated in Figure 5.5.1.1 below.

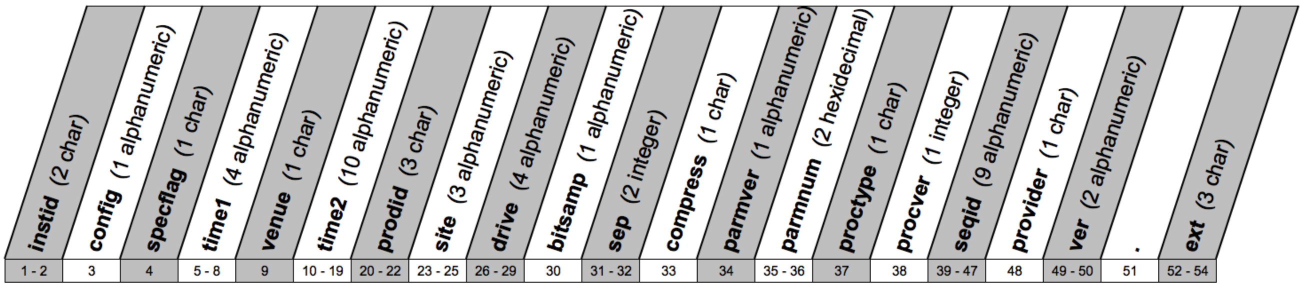

Figure 5.5.1.1 – EDR Filename Convention

where,

instid = (2 character) Instrument ID, denoting the source M2020 science or engineering payload instrument that acquired the data. 1st character is primary Instrument identifier. 2nd character is Instrument state, or simply secondary Instrument identifer if no state.

Valid values for Instrument IDs are:

"**XM**" - RIMFAX Mobile
"**XS**" - RIMFAX Stationary

Valid values for Instrument IDs not described in this SIS:

"**FL**" - Front Hazcam Left (String A)
"**FR**" - Front Hazcam Right (String A)
"**RL**" - Rear Hazcam Left (String A)
"**RR**" - Rear Hazcam Right (String A)
"**BL**" - Front Hazcam Left (String B)
"**BR**" - Front Hazcam Right (String B)
"**NL**" - Navcam Left
"**NR**" - Navcam Right
"**ZL**" - Mastcam-Z Left
"**ZR**" - Mastcam-Z Right
"**WE**" - MEDA Environment (Weather)
"**WS**" - MEDA SkyCam
"**OX**" - MOXIE
"**PC**" - PIXL Context Cam (MCC)
"**PS**" - PIXL Spectrometer
"**SC**" - SHERLOC Context Cam (ACI)
"**SS**" - SHERLOC Spectrometer
"**SI**" - SHERLOC Imaging
"**SL**" - SuperCam Laser
"**SP**" - SuperCam Passive
"**SR**" - SuperCam RMI (camera)
"**SD**" - SuperCam Diagnostic
"**SM**" - SuperCam Scan Mode
"**SA**" - SuperCam Microphone (Audio)
"**EA**" - EDLcam Parachute Uplook Cam A
"**EB**" - EDLcam Parachute Uplook Cam B
"**EC**" - EDLcam Parachute Uplook Cam C
"**ED**" - EDLcam Rover Downlook Cam
"**EU**" - EDLcam Rover Uplook Cam
"**EL**" - EDLcam Lander Vision System (LVS)
"**ES**" - EDLcam Descent Stage Downlook Cam
"**CC**" - Sample Cache Cam
"**HN**" - Helicopter Navigation Cam
"**HS**" - Helicopter Return To Earth Cam

config = (1 alphanumeric) Instrument Configuration, an operational attribute of the Instrument that assists in characterizing the data.

Valid values for RIMFAX configurations:

Configuration

Values	Param Table Version Range
"**1**" - "**4**"	For RCE side A, the configuration types are: 1 = Antenna ACTIVE 2 = Calibration Cable ACTIVE 3 = Antenna PASSIVE 4 = Calibration Cable PASSIVE
"**5**" - "**8**"	For RCE side B, the configuration types are: 5 = Antenna ACTIVE 6 = Calibration Cable ACTIVE 7 = Antenna PASSIVE 8 = Calibration Cable PASSIVE

specflag = (1 character) Special Processing flag, applicable to RDRs only.

The Special Processing character is used to indicate off-nominal or special processing of the data. Examples include a) use of different calibration parameters, b) special processing to enhance received signal, c) reprocessing with different FFT configuration, etc.

The meaning of any individual character in this field will be defined on an ad-hoc basis as needed during the mission. Within one Sol or a range of Sol's, the character will be used consistently. So, this field can be used to group together all derived products resulting in one kind of special processing. An attempt will be made to maintain consistency across different Sol's as well, but this may not always be possible; thus the meaning of characters may change across different individual or ranges of Sol's, depending on the definition.

A ".txt" ASCII text file will be maintained containing all special processing designators that are used, the Sol's they relate to, and a description of the special processing that was done. This file will be included in the PDS archive.

This field has the following rule-of-thumb:

Best Tactical - If value is character "**T**", it indicates "best tactical" if other than nominal processing. The intent of this is to retain a copy of the Special product best suited for tactical planning (at the discretion of Instrument team in consultation with tactical planners). Such products should have ordinary special processing flag documented as described here, but be copied with flag "**T**" (incrementing version if necessary) if they are to be used for tactical planning.

If there is no "**T**", then the nominal "_" should be used for tactical planning.

Valid values are:

Special Processing	EDR Value	RDR Value
none	"_"	"_"
Special method types A-S and U-Z	n/a	"**A**" – Frequency Domain Calibrated "**B**" – Frequency Domain Calibrated and Windowed "**C**" – Time Domain Calibrated and Windowed . . – Include background removal, compensation of . rover appendages, etc. (TBD) . "**Z**" – If needed
Best tactical Special method	n/a	"**T**"

time1 = (4 alphanumeric) Primary Timestamp that is of coarser granularity than the Secondary timestamp (documented later). Value type is based on either of four scenarios:

Flight Cruise

Year-DOY (4 alphanumeric) - This field stores two metadata items in the order:

a) One alpha character in range “A-Z” to designate Earth Year portion of the UTC-like time value, representing Years 2017 to 2042
b) Three integers in range “001-365” representing Day-of-Year (DOY)

Flight Surface

Sol (4 integer) - This field stores the 4-integer Sol (Mars solar day) of the first (i.e., lowest Clock time) acquired instrument data.

Ground Test in which SCLK in NOT reset

When SCLK continuously increments and does NOT repeat, there are two variants:

a) Year-DOY (4 alphanumeric) - This field stores two metadata items in the order:
   1. One alpha character in range “A-Z” to designate Earth Year portion of the UTC-like time value, representing Years 2017 to 2042
   2. Three integers in range “001-365” representing Day-of-Year (DOY)

– OR –

b) Sol (4 integer) - This field stores the 4-integer Sol (Mars solar day) of the first (i.e., lowest Clock time) acquired instrument data.

Ground Test in which SCLK is reset

When SCLK is reset and repeats, we lose time “uniqueness”. So, we have to change from SCLK to using “wall clock” derived from ERT and represent with a UTC-like format:

DOY-Year (4 alphanumeric) - This field stores two metadata items in reverse order compared to the previous “Year-DOY” cases, indicating that the Secondary Time field (described later) contains ERT

a) Three integers in range “001-365” representing Day-of-Year (DOY)
b) One alpha character in range “A-Z” to designate Earth Year portion of the UTC-like time value, representing Years 2017 to 2042

The valid values, in their progression, are as follows (non-Hex):

Scenario	Time Type	Value Format	Valid Values	Time Range
Flight Cruise	Year-DOY	[A-Z]<ddd>	“**A001**”, “**A002**”, **…** “**A365**”, “**B001**”, “**B002**”, **…** “**B365**”, • • • “**Z001**”, “**Z002**”, **…** “**Z365**”	2017 - Days 1 to 365, 2018 - Days 1 to 365, • • • 2042 - Days 1 to 365

		<aaaa>	“_ _ _ _” (4 underscores)	Value is out of range
Flight Surface	Sol	<nnnn>	“**0000**”, “**0001**”, **…** “**9999**”	0 thru 9999
		<aaaa>	“_ _ _ _” (4 underscores)	Value is out of range
Ground Test where SCLK is NOT reset	Year-DOY	(same as Flight Cruise)	(same as Flight Cruise)	(same as Flight Cruise)
	Sol	<nnnn>	“**0000**”, “**0001**”, **…** “**9999**”	0 thru 9999
		<aaaa>	“_ _ _ _” (4 underscores)	Value is out of range
Ground Test where SCLK is reset	DOY-Year	<ddd>[A-Z]	“**001A**”, “**002A**”, **…** “**365A**”, “**001B**”, “**002B**”, **…** “**365B**”, • • • “**001Z**”, “**002Z**”, **…** “**365Z**”	Days 1 to 365 - 2017, Days 1 to 365 - 2018, • • • Days 1 to 365 - 2042
		<aaaa>	“_ _ _ _” (4 underscores)	Value is out of range

venue = (1 character) Venue type denoting the data processing context or activity. Valid types are Flight (Cruise, Surface), Test / VSTB, Testbed, ATLO, Thread Test, Design Sim, ORT.

Venue also denotes the Instrument Model type (Flight vs Engineering).

NOTE: Characters “**I**” and “O” are NOT used to avoid confusion in readability with Numeric Values “1” and “0” in adjacent Filename fields.

See the following table of valid values:

Venue	Value	Instrument Model
Flight (see Sol field)	“_”	Flight
Test / VSTB	“**A**”	Flight
	“**B**”	Engineering
Testbed	“**C**”	Flight
	“**D**”	Engineering
	“**E**”	Flight

ATLO	“**F**”	Engineering
Thread Test (TT)	“**G**”	Flight
	“**H**”	Engineering
Design Sim	“**J**”	Flight
	“**K**”	Engineering
Ops Readiness Test (ORT)	“**L**”	Flight
	“**M**”	Engineering

time2 = (10 alphanumeric) Secondary Timestamp that is of finer granularity than the Primary timestamp. Value type is based on either of four scenarios:

Flight Cruise

SCLK – This field stores the 10-integer SCLK (seconds). Which specific SCLK count (Start or End) is used depends on the instrument, but nominally it is the starting count of the first (i.e., lowest Clock time) acquired instrument data.

Flight Surface

SCLK – Same as for “Flight Cruise”

Ground Test in which SCLK in NOT reset

SCLK – Same as for “Flight Cruise”

Ground Test in which SCLK is reset

ERT - This field stores the ERT time portions Month, Day-of-month, Hour and Seconds as 10 integers in a UTC-like format

The valid value formats are as follows:

Scenario	**Time Type**	**Value Format**	**Valid Values**	**Time Range**
Flight Cruise	SCLK	<ssssssssss> (Seconds)	“**0000000000**”, “**0000000001**”, • • • “**9999999999**”	0 thru 9999999999
		<aaaaaaaaaa> (Alphabetic)	“__________” (10 underscores)	Value is out of range
Flight Surface	SCLK	(same as Flight Cruise)	(same as Flight Cruise)	(same as Flight Cruise)
Ground Test where SCLK is NOT reset	SCLK	(same as Flight Cruise)	(same as Flight Cruise)	(same as Flight Cruise)
Ground Test where SCLK	ERT	<MMDDHHmmss>	“**0101010000**”, “**0101010001**”, •	January 1, 01:00:00 thru

is reset		(Month, Day-of-month, Hour, Minute, Second)	• • “**1231235959**”	December 31, 23:59:59
		<aaaaaaaaaa> (Alphabetic)	“__________” (10 underscores)	Value is out of range

prodid = (3 character) Product Type identifier.

This field has the following rule-of-thumb:

Beginning “**E**” - Type of EDR, which is the first-order product with no processing applied, with the exception of decompression in the case that Instrument applied onboard compression.

If no beginning “E”, then product is an RDR.

Valid values for Product identifiers are listed below for EDRs:

Values	EDR Type
“**EDR**”	GPR Sounding Measurement Sample in Frequency domain
“**EDM**”	GPR Sounding Measurement Sample Metadata file
“**EHK**”	Housekeeping data
“**EHM**”	Housekeeping data Metadata file
“**EFC**”	Fault condition
“**EFM**”	Fault condition Metadata file

site = (3 alphanumeric) Site location count from the RMC for the Frame wherein the data was collected.

This field has the following rules-of-thumb:

If value is 3 underscores it denotes value is out-of-range

The valid Site values, in their progression, are as follows (non-Hex):

Values	Site Range
“**000**”, “**001**”, **…** “**999**”	000 thru 999
“**A00**”, “**A01**”, **…** “**A99**”	1000 thru 1099
“**B00**”, “**B01**”, **…** “**B99**”	1100 thru 1199
• • •	
“**Z00**”, “**Z01**”, **…** “**Z99**”	3500 thru 3599
“**AA0**”, “**AA1**”, **…** “**AA9**”	3600 thru 3609
“ **AB0**”, “**AB1**”, **…** “**AB9**”	3610 thru 3619
• • •	
“**AZ0**”, “**AZ1**”, **…** “**AZ9**”	3850 thru 3859

"**BA0**", "**BA1**", ... "**BA9**"	3860 thru 3869
"**BB0**", "**BB1**", ... "**BB9**"	3870 thru 3879
• • •	
"**ZZ0**", "**ZZ1**", ... "**ZZ9**"	10350 thru 10359
"**AAA**", "**AAB**", ... "**AAZ**"	10360 thru 10385
"**ABA**", "**ABB**", ... "**ABZ**"	10386 thru 10411
• • •	
"**ZZA**", "**ZZB**", ... "**ZZZ**"	27910 thru 27935
"**0AA**", "**0AB**", ... "**0AZ**"	27936 thru 27961
"**0BA**", "**0BB**", ... "**0BZ**"	27962 thru 27987
• • •	
"**7CA**", "**7CB**", ... "**7CZ**"	32720 thru 32745
"**7DA**", "**7DB**", ... "**7DV**"	32746 thru 32767
"_ _ _" (3 underscores)	Value is out of range

drive = (4 alphanumeric) Drive (position-within-Site) location count from the RMC, which may be last Drive prior to stationary data collection.

This field has the following rules-of-thumb:

If value is 4 underscores it denotes value is out-of-range

The valid Drive values, in their progression, are as follows (non-Hex):

Values	Drive Range
"**0000**", "**0001**", ... "**9999**"	0000 thru 9999
"**A000**", "**A001**", ... "**A999**"	10000 thru 10999
• • •	
"**Z000**", "**Z001**", ... "**Z999**"	35000 thru 35999
"**AA00**", "**AA01**", ... "**AA99**"	36000 thru 36099
• • •	
"**AZ00**", "**AZ01**", ... "**AZ99**"	38500 thru 38599
"**BA00**", "**BA01**", ... "**BA99**"	38600 thru 38699
• • •	
"**LJ00**", "**LJ01**", ... "**LJ35**"	65500 thru 65535
"_ _ _ _" (4 underscores)	Value is out of range

bitsamp = (1 alphanumeric) Bit Sampling.

Valid values are:

"**N**" - Normal (16-bit)
"**L**" - Long (32-bit)

sep = (2 integer) RIMFAX group spacing (cm).

The valid group spacing values, in their progression, are as follows (non-Hex):

Values	Group Spacing
"**00**", "**01**", **…** "**99**"	00 thru 99

compress = (1 character) Downlink Compression performed by RCE (not Instrument).

Valid values are:

"**A**" - Lossless "gzip"
"**B**" - Lossless LOCO
"**C**" - Lossy at 90% quality
"**D**" - Lossy at 80% quality
•
•
•
"**Z**" - TBD (as needed)

parmver = (1 alphanumeric) Parameter Table Version number.

The valid values for range 1-35, in their progression, are as follows (non-Hex):

Values	Param Table Version Range
"**1**", "**2**", **… "9"**	1 thru 9
"**A**", "**B**", **… "Z"**	10 thru 35
"**_**" (underscore)	36 and higher

parmnum = (2 hexidecimal) Parameter Mode numbers.

The valid values for range 0-255, in their progression, are as follows (Hex):

Type	Parameter Mode Values									
Integer Hex	(0) "**00**"	(1) "**01**"	(2) "**02**"	(3) "**03**"	(4) "**04**"	(5) "**05**"	(6) "**06**"	(7) "**07**"	(8) "**08**"	(9) "**09**"
Integer Hex	(10) "**0A**"	(11) "**0B**"	(12) "**0C**"	(13) "**0D**"	(14) "**0E**"	(15) "**0F**"	(16) "**10**"	(17) "**11**"	(18) "**12**"	(19) "**13**"
Integer Hex	(20) "**14**"	(21) "**15**"	(22) "**16**"	(23) "**17**"	(24) "**18**"	(25) "**19**"	(26) "**1A**"	(27) "**1B**"	(28) "**1C**"	(29) "**1D**"
Integer Hex	(30) "**1E**"	(31) "**1F**"	(32) "**20**"	(33) "**21**"	(34) "**22**"	(35) "**23**"	(36) "**24**"	(37) "**25**"	(38) "**26**"	(39) "**27**"
Integer	(40)	(41)	(42)	(43)	(44)	(45)	(46)	(47)	(48)	(49)

Hex	“**28**”	“**29**”	“**2A**”	“**2B**”	“**2C**”	“**2D**”	“**2E**”	“**2F**”	“**30**”	“**31**”
Integer	(50)	(51)	(52)	(53)	(54)	(55)	(56)	(57)	(58)	(59)
Hex	“**32**”	“**33**”	“**34**”	“**35**”	“**36**”	“**37**”	“**38**”	“**39**”	“**3A**”	“**3B**”
Integer	(60)	(61)	(62)	(63)	(64)	(65)	(66)	(67)	(68)	(69)
Hex	“**3C**”	“**3D**”	“**3E**”	“**3F**”	“**40**”	“**41**”	“**42**”	“**43**”	“**44**”	“**45**”
Integer	(70)	(71)	(72)	(73)	(74)	(75)	(76)	(77)	(78)	(79)
Hex	“**46**”	“**47**”	“**48**”	“**49**”	“**4A**”	“**4B**”	“**4C**”	“**4D**”	“**4E**”	“**4F**”
Integer	(80)	(81)	(82)	(83)	(84)	(85)	(86)	(87)	(88)	(89)
Hex	“**50**”	“**51**”	“**52**”	“**53**”	“**54**”	“**55**”	“**56**”	“**57**”	“**58**”	“**59**”
Integer	(90)	(91)	(92)	(93)	(94)	(95)	(96)	(97)	(98)	(99)
Hex	“**5A**”	“**5B**”	“**5C**”	“**5D**”	“**5E**”	“**5F**”	“**60**”	“**61**”	“**62**”	“**63**”
Integer	(100)	(101)	(102)	(103)	(104)	(105)	(106)	(107)	(108)	(109)
Hex	“**64**”	“**65**”	“**66**”	“**67**”	“**68**”	“**69**”	“**6A**”	“**6B**”	“**6C**”	“**6D**”
Integer	(110)	(111)	(112)	(113)	(114)	(115)	(116)	(117)	(118)	(119)
Hex	“**6E**”	“**6F**”	“**70**”	“**71**”	“**72**”	“**73**”	“**74**”	“**75**”	“**76**”	“**77**”
Integer	(120)	(121)	(122)	(123)	(124)	(125)	(126)	(127)	(128)	(129)
Hex	“**78**”	“**79**”	“**7A**”	“**7B**”	“**7C**”	“**7D**”	“**7E**”	“**7F**”	“**80**”	“**81**”
Integer	(130)	(131)	(132)	(133)	(134)	(135)	(136)	(137)	(138)	(139)
Hex	“**82**”	“**83**”	“**84**”	“**85**”	“**86**”	“**87**”	“**88**”	“**89**”	“**8A**”	“**8B**”
Integer	(140)	(141)	(142)	(143)	(144)	(145)	(146)	(147)	(148)	(149)
Hex	“**8C**”	“**8D**”	“**8E**”	“**8F**”	“**90**”	“**91**”	“**92**”	“**93**”	“**94**”	“**95**”
Integer	(150)	(151)	(152)	(153)	(154)	(155)	(156)	(157)	(158)	(159)
Hex	“**96**”	“**97**”	“**98**”	“**99**”	“**9A**”	“**9B**”	“**9C**”	“**9D**”	“**9E**”	“**9F**”
Integer	(160)	(161)	(162)	(163)	(164)	(165)	(166)	(167)	(168)	(169)
Hex	“**A0**”	“**A1**”	“**A2**”	“**A3**”	“**A4**”	“**A5**”	“**A6**”	“**A7**”	“**A8**”	“**A9**”
Integer	(170)	(171)	(172)	(173)	(174)	(175)	(176)	(177)	(178)	(179)
Hex	“**AA**”	“**AB**”	“**AC**”	“**AD**”	“**AE**”	“**AF**”	“**B0**”	“**B1**”	“**B2**”	“**B3**”
Integer	(180)	(181)	(182)	(183)	(184)	(185)	(186)	(187)	(188)	(189)
Hex	“**B4**”	“**B5**”	“**B6**”	“**B7**”	“**B8**”	“**B9**”	“**BA**”	“**BB**”	“**BC**”	“**BD**”
Integer	(190)	(191)	(192)	(193)	(194)	(195)	(196)	(197)	(198)	(199)
Hex	“**BE**”	“**BF**”	“**C0**”	“**C1**”	“**C2**”	“**C3**”	“**C4**”	“**C5**”	“**C6**”	“**C7**”
Integer	(200)	(201)	(202)	(203)	(204)	(205)	(206)	(207)	(208)	(209)
Hex	“**C8**”	“**C9**”	“**CA**”	“**CB**”	“**CC**”	“**CD**”	“**CE**”	“**CF**”	“**D0**”	“**D1**”
Integer	(210)	(211)	(212)	(213)	(214)	(215)	(216)	(217)	(218)	(219)
Hex	“**D2**”	“**D3**”	“**D4**”	“**D5**”	“**D6**”	“**D7**”	“**D8**”	“**D9**”	“**DA**”	“**DB**”
Integer	(220)	(221)	(222)	(223)	(224)	(225)	(226)	(227)	(228)	(229)
Hex	“**DC**”	“**DD**”	“**DE**”	“**DF**”	“**E0**”	“**E1**”	“**E2**”	“**E3**”	“**E4**”	“**E5**”
Integer	(230)	(231)	(232)	(233)	(234)	(235)	(236)	(237)	(238)	(239)
Hex	“**E6**”	“**E7**”	“**E8**”	“**E9**”	“**EA**”	“**EB**”	“**EC**”	“**ED**”	“**EE**”	“**EF**”
Integer	(240)	(241)	(242)	(243)	(244)	(245)	(246)	(247)	(248)	(249)
Hex	“**F0**”	“**F1**”	“**F2**”	“**F3**”	“**F4**”	“**F5**”	“**F6**”	“**F7**”	“**F8**”	“**F9**”
Integer	(250)	(251)	(252)	(253)	(254)	(255)				
Hex	“**FA**”	“**FB**”	“**FC**”	“**FD**”	“**FE**”	“**FF**”				

proctype = (1 character) Onboard Processing Type.

Valid values are:

“**R**” - Raw
“**D**” - Decimated
“X” - Summary Raw

procver = (1 alphanumeric) Onboard Processing Type Version. This supports scenario of multiple onboard processing versions of the same data telemetered to ground.

The valid values for range 1-35, in their progression, are as follows (non-Hex):

Values	Onboard Processing Type Version Range
"**1**", "**2**", **… "9"**	1 thru 9
"**A**", "**B**", **… "Z"**	10 thru 35
"**_**" (underscore)	36 and higher

seqid = (9 alphanumeric) Sequence or Activity or Component identifier from command process.

If Sequence ID, composed of a 4-char subfield and a 5-digit numeric subfield representing the 6-bit "Category" and 14-bit numeric components of the commanded Sequence ID, respectively.

provider = (1 character) Product Provider ID, identifying the institution that generated the EDR or RDR product.

See the following table of valid values:

Values	Description
"**J**"	IDS at JPL
"**P**"	Principal Investigator of Instrument … Instrument — Principal Investigator RIMFAX — UIO (Norway)
"**A**" - "**I**", "**K**" - "**O**", "**Q**" - "**Z**",	Co-Investigators (to be identified per Instrument at discretion of P.I.) Value — Co-Investigator "**U**" — UCLA

See the following table of Instruments not covered by this SIS:

Values	Description
"**P**"	Principal Investigator of Instrument … Instrument — Principal Investigator EECAM — JPL Mastcam-Z — ASU (Tempe, AZ) SuperCam spectroscopy — LANL (Los Alamos, NM) SuperCam imaging — IRAP (France) PIXL spectroscopy — JPL PIXL imaging — TBD SHERLOC spectroscopy — JPL SHERLOC imaging — JPL MEDA — Ministry of Education & Science (Spain) MOXIE — MIT (Cambridge, MA) EDLcam — JPL Helicopter camera — JPL
"**A**" - "**I**", "**K**" - "**O**", "**Q**" - "**Z**",	Co-Investigators (to be identified per Instrument at discretion of P.I.)

ver = (2 alphanumeric) Version identifier. The Version number increments by one whenever an otherwise-identical filename would be produced.

The valid values, in their progression that excludes "**0**" altogether, are as follows (non-Hex):

Range 1 thru 99	-	"**01**", "**02**", **… "99"**
Range 100 thru 109	-	"**A0**", "**A1**", **… "A9"**
Range 110 thru 135	-	"**AA**", "**AB**", **… "AZ"**
Range 136 thru 145	-	"**B0**", "**B1**", **… "B9"**
Range 146 thru 171	-	"**BA**", "**BB**", **… "BZ"**
Range 172 thru 181	-	"**C0**", "**C1**", **… "C9"**
Range 182 thru 207	-	"**CA**", "**CB**", **… "CZ"**

Note that not every version need exist, e.g. versions 1, 2 and 4 may exist but not 3. In general, the highest-numbered Version represents the "best" version of that product.

NOTE: To be clear, this field increments independently of all fields, including the Special Processing field.

ext = (2 to 3 characters) Product type extension.

The valid values for RIMFAX EDR products are:

"**DAT**" - Binary GPR sounding data (RIMFAX context)
"**CSV**" - ASCII comma-separated-values text file
"**TAB**" - Tablular data

Valid values for some other data products not covered by this SIS are:

"**IMG**" - Binary image data product, may include embedded IDS-generated VICAR label
"**VIC**" - Temp binary image EDR/RDR product from IDS's VICAR image processing SW
"**iv**" - Per-XYZ (Wedge) Terrain Mesh in Inventor format
"**ht**" - Per-XYZ (Wedge) Height Map in VICAR (IDS image processing SW) format
"**rgb**" - Per-XYZ (Wedge) "texture" (Terrain Mesh skin) product in RGB format
"**LBL**" - Detached Ops product label file in ODL (ASCII) format
"**JPG**" - JPEG-compressed formatted binary product (no label)
"**TIF**" - TIFF formatted binary product (no label)
"**PNG**" - PNG formatted binary product (no label)
"**TXT**" - Text file for Specially-processed file (see Filename field "Special Processing")
"**tar**" - Tar file
"**QUB**" - Multi-layer spectral cube data

Of the above, only "IMG", "LBL", "JPG", "TXT", "QUB", "CSV", "DAT" and "TAB" are currently supported by PDS4.

Example #1: XM1_0054_013760215EDR0870013N02A128R4RFAX09445J01.DAT

where,

instid	=	“**XM**”	=	RIMFAX Mobile
config	=	“**1**”	=	A-side, Antenna ACTIVE
specflag	=	“_”	=	No special processing
time1	=	“**0054**”	=	Sol 54
venue	=	“_”	=	Flight venue, "Flight" Instrument model
time2	=	“**013760215**”	=	Spacecraft Clock Start Count of 13760215 secs
prodid	=	“**EDR**”	=	"GPR Soundings Measurement Sample" EDR
site	=	“**087**”	=	Site 87
drive	=	“**0013**”	=	Drive 13
bitsamp	=	"**N**"	=	"Normal" (16-bit) sampling
sep	=	“**02**”	=	RIMFAX Group Spacing of 2 cm
compress	=	“**A**”	=	Lossless "gzip" type of RCE downlink compression
parmver	=	“**1**”	=	Parameter Table version 1
parmnum	=	“**28**”	=	Parameter Mode 28
proctype	=	“**R**”	=	Onboard Processing Type of "Raw"
procver	=	“**4**”	=	Onboard Processing Type version of 4
seqid	=	“**RFAX09445**”	=	Sequence ID "RFAX09445"
provider	=	“**J**”	=	Product generated by IDS (JPL)
ver	=	“**01**”	=	Product version 1
ext		“**DAT**”	=	"GPR sounding data" (within RIMFAX product set)

6. STANDARDS

Various standards apply to the RIMFAX EDR to enable verification and validation of the product's binary content and its metadata labels. The standards imposed include PDS (data archiving), Time (temporal context) and Coordinate Frame (spatial context).

6.1 PDS Standards

The RIMFAX EDR data product complies with Planetary Data System Four (PDS4) standards for file formats and labels, as specified in the PDS Standards Reference [5]. See Section 3 for a description of PDS4 standards, including the PDS Label and the specific conventions adopted by M2020.

6.2 Time Standards

The EDR PDS label uses keywords/attributes containing time values. Each time value standard is defined according to the keyword/attribute description (Table 6.2.1).

Table 6.2.1 – Time Formats

Time Format	Description
SCLK	Spacecraft Clock. This is an on-board 64-bit counter, in units of nano-seconds and increments once every 100 milliseconds. Time zero corresponds to midnight on 1-Jan-1980.
ERT	Earth Received Time. This is the time when the first bit of the packet containing the current data was received at the Deep Space (DSN) station. Recorded in UCT format.
CT	[Record] Creation Time. This is the time when the first telemetry packet, containing a given type of dataset, was created on the ground. Recorded in UTC format.
LMST, LST	Local Mean Solar Time (LMST) or Local Solar Time (LST). This is the local solar time defined by the local solar days (sols) from the landing date using a 24 “hour” clock within the current local solar day (HR:MN:SC). Since the Mars day is 24h 37m 22s long, each unit of LST is slightly longer than the corresponding Earth unit. LST is computed using positions of the Sun and the landing site from SPICE kernels. If a landing date is unknown to the program (e.g. for calibration data acquired on Earth) then no sol number will be provided on output LST examples: SOL 12 12:00:01 SOL 132 01:22:32.498 SOL 29
LTST, TLST	Local True Solar Time (LTST) or True Local Solar Time (TLST) is related to LMST/LST. It is the time of day based on the position of the Sun, rather than the measure of time based on midnight to midnight “day”. LST is specified in the metadata label of all IDS generated products.
Sol	Solar Day Number, also known as PLANET_DAY_NUMBER in the ODL label and SOL_NUMBER in the PDS4 label. This is the number of complete solar days on Mars since landing. The landing day therefore is SOL zero.

6.3 Coordinate Frame Standards

The M2020 Frame Manager defines several dozen coordinate frames, which can be used for commanding pointing among other things. Refer to the Rover Attitude, Positioning and Pointing (RAPP) Functional Design Description (FDD) [15] for more details on all these coordinate frames.

Four frames are central to rover operations on the surface of Mars and are used by the products and processes described in this SIS: the Rover Navigation frame (RNAV) which represents the current position and location of vehicle, the Rover Mechanical frame (RMECH) similar to but offset from RNAV, a Site frame fixed relative to the surface, and a Local Level frame which embodies attitude knowledge.

The origin of the Local Level frame always coincides with the origin of Rover Navigation frame but is aligned with the gravity vector and north on Mars. Each Site frame is defined to be coincident with the Local Level frame at the time of its creation, and is fixed relative to the planetary surface. These frames are described in detail in this section.

Table 6.3.1 – M2020 Coordinate Frames Pertinent to RIMFAX

Frame Name (ODL Label Keyword Value)	Short Name (SAPP FDD)	Reference Frame (Used to Define)	Coordinate Frame	
			Origin	Orientation
ROVER_NAV_FRAME	RNAV	Enclosing SITE_FRAME	Attached to rover	Aligned with rover
ROVER_MECH_FRAME	RMECH	Enclosing SITE_FRAME	Attached to rover	Aligned with rover
LOCAL_LEVEL_FRAME	LL	Enclosing SITE_FRAME	Attached to rover (coincident with Rover Nav Frame)	North/East/Nadir
SITE_FRAME	SITE(n)	Previous SITE_FRAME	Attached to surface	North/East/Nadir

6.3.1 Rover Navigation (Rover Nav) Frame

The Rover Nav frame (RNAV) is the one used for surface navigation and mobility. By definition, the frame is attached to the rover, and moves with it when the rover moves while on the surface. Its Y origin is centered on the rover and the X origin is aligned with the middle wheels' rotation axis for the deployed rover and suspension system on a flat plane. The Z origin is defined to be at the nominal surface, which is a fixed position with respect to the rover body. The actual surface will likely not be at exactly Z=0 due to the effects of suspension sag, rover tilt, rocker bogie angles, etc. The +X axis points to the front of the rover, +Y to the right side, and +Z down (perpendicular to the chassis deck). See Figure 6.3.1.1.

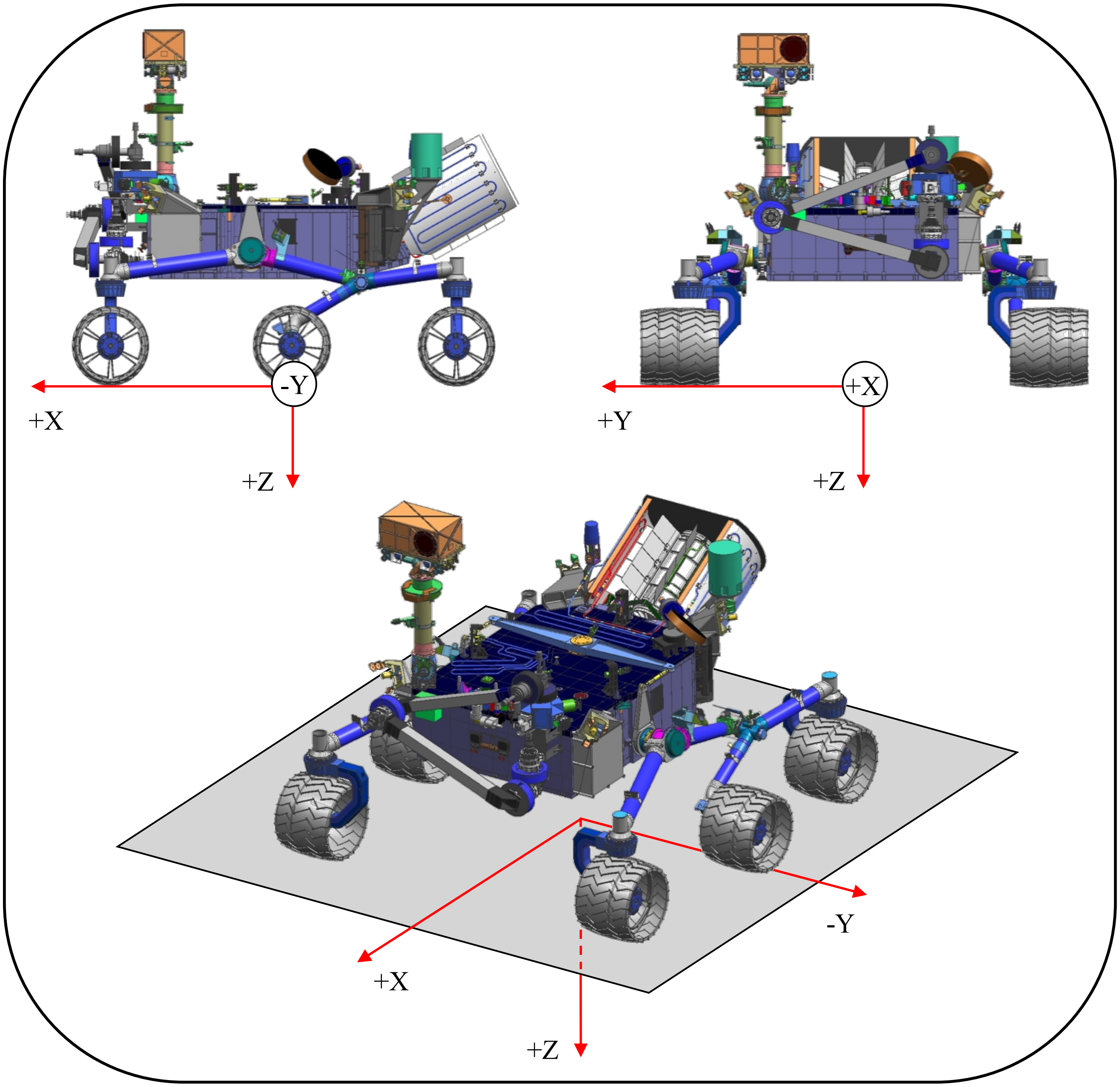

Figure 6.3.1.1 – Rover Navigation (RNAV) Coordinate Frame

The Rover Nav frame is specified via an offset from the current Site frame, and a quaternion that represents the rotation between the two. A new instance of the Rover Nav frame, with a potentially unique offset/quaternion, is created every time the ROVER_MOTION_COUNTER increments.

Orientation of the rover (and thus Rover Nav) with respect to Local Level or Site is also sometimes described by Euler angles as shown in Figure 6.3.1.2, where ψ is heading, θ is attitude or pitch, and ϕ is bank or roll.

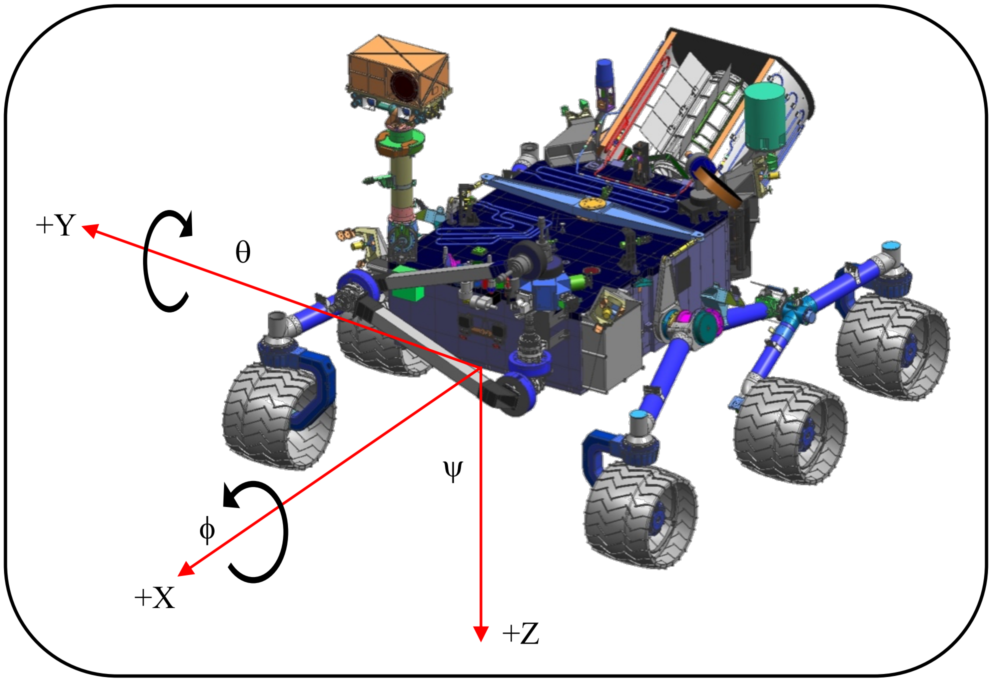

Figure 6.3.1.2 – Yaw, Pitch and Roll Definitions

6.3.2 Rover Mechanical (Rover Mech) Frame

The Rover Mechanical (RMECH) frame is oriented identically to the Rover Nav frame. The origin is forward of Rover Nav by x=0.09002 meters. In other words, given a point expressed in Rover Mech, if you add (0.09002, 0.0, 0.0) you will get the same point expressed in Rover Nav. Rover Mech is not used by any nominal products (EDR or RDR) but could appear in certain special products, generally having to do with arm kinematics.

6.3.3 Local Level Frame

The Local Level frame is coincident with the Rover Nav frame, i.e. they share the same origin at all times. The orientation is different, however. The +X axis points North, +Z points down to nadir along the local gravity vector, and +Y completes the right-handed system. Thus the orientation matches the orientation of Site frames.

Local Level frames are defined by an offset from the current Site frame, with an identity quaternion.

6.3.4 Site Frame

Site frames are used to reduce accumulation of rover localization error. They are used to provide a common reference point for all operations within a local area. Rover Nav and Local Level frames are specified using an offset from this origin. When a new Site is declared, that becomes the new reference, and the offset is zeroed. In this way, long-term localization error is relegated to the offset between Sites, becoming irrelevant to local operations, because the positions are reset with each new Site.

When a Site frame is declared, it is identical to the Local Level frame, sharing both orientation and position. However, the Site frame is fixed to the Mars surface; when the rover moves, Local Level moves with it but Site stays put. Therefore, for the Site frame, +X points North, +Z points down to nadir along the local gravity vector, and +Y completes the right-handed system.

Sites are indexed, meaning there are multiple instances. Site 1 by definition represents the landing location. New Sites are declared as needed during operations, as the rover moves away from the local area. See Figure 6.3.4.1.

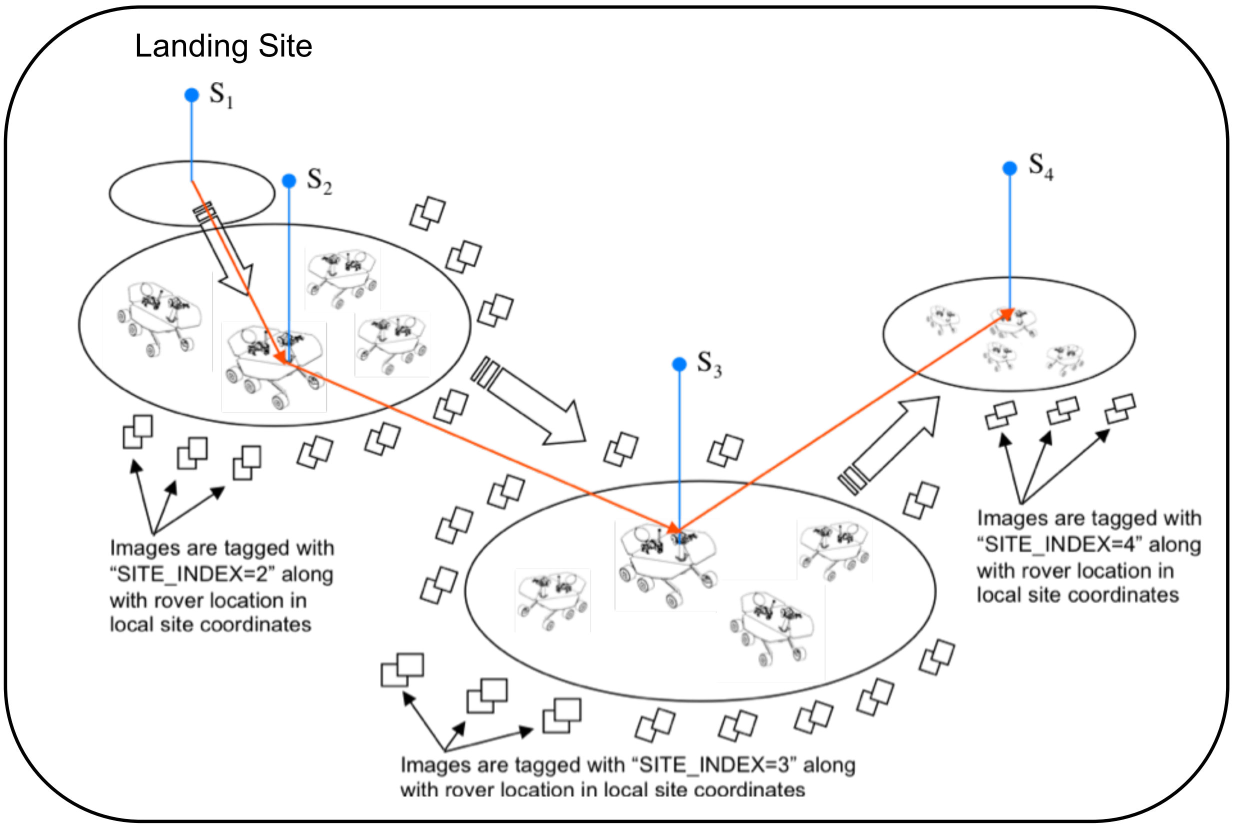

Figure 6.3.4.1 – Site and Rover Frames

6.3.5 RIMFAX Antenna Frame - Original

The RIMFAX Antenna Frame defines location and coordinate frame of RIMFAX antenna with respect to the Rover Mechanical Frame.

Table 6.3.5.1 – RIMFAX Antenna Frame Translational and Angular Offset

Frame	Reference Frame	Names	Translation and Rotational Offsets		
RIMFAX	Rover Mechanical	RIMFAX RIMFAX Antenna	X	-884.8	mm
			Y	0	mm
			Z	416.14	mm
			Rotation Matrix		
			0	1	0
			-0.773	0	-0.634
			-0.634	0	0.773

Table 6.3.5.2 – RIMFAX Antenna Frame Origin

Component	X RMECH	Y RMECH	Z RMECH
Origin	-884.80	0	416.14
X-Axis Vector	0	1	0
Y-Axis Vector	-sin(50.63 deg)	0	-cos(50.63 deg)
Z-Axis Vector	-cos(50.63 deg)	0	sin(50.63 deg)

The origin of the RIMFAX Antenna Frame is located on the external surface of the antenna chassis at the center of the 12.3 mm hole.

Table 6.3.5.3 – RIMFAX Antenna Frame Axes Definitions

Axis	Orientation
X	Parallel to the mounting interface, pointing away from the SMA connector from the center of the 9 mm slot in the center of the 11 mm slot
Y	Formed by the right-hand orthogonal basis from Z and X
Z	Normal to the mounting interface, pointing into the Antenna chassis

7. APPLICABLE SOFTWARE

The instrument data downlink processing software is focused on rapid reduction, calibration, and visualization (in the case of images) of products in order to make discoveries, to accurately and expeditiously characterize the geologic environment around the rover, and to provide timely input for operational decisions concerning rover navigation and Arm target selection. Key software tools have been developed at JPL as part of the IDS and APSS subsystems. This toolsets can be used to process data to yield substantial scientific potential in addition to their operational importance.

7.1 Utility Programs

Table 7.1.1 lists (in no particular order) the primary software tools that will be used to process and manipulate downlinked M2020 instrument payload data. Instrument data processing software executed by teams working the IDS and APSS subsytems at JPL will be capable of reading and writing image and spectra data in PDS format. Within IDS, the "M20edrgen" program will generate EDRs and the Mars Program Suite of VICAR programs will generate RDRs in PDS format. An IDS pipeline system will deliver the products to the FEI server for transfer to M2020's ODS as rapidly as possible after receipt of telemetry.

Table 7.1.1 - Key Software Toolsets

Name	Description	Primary Development Responsibility
M20edrgen	Fetches the image Data Product Object (DPO) records from M2020 telemetry Data Product (DP) files, reconstructing the RIMFAX file from the telemetry data into a ODL-labelled EDR data product. C++ code.	Hyun Lee (JPL / IDS)
DataDrive	DataDrive provides data access and distribution for a mission's data products and files in the Amazon Web Services (AWS) cloud utilizing the Operational Cloud Store (OCS). The CS3 (M2020 Common Software and Services Subsystem) Single Sign On (CSSO) provides authentication and authorization to DataDrive. DataDrive is synonymous to commercial tools such as Dropbox and Google Drive.	Stirling Algermissen (JPL / IDS)

7.2 Applicable PDS Software Tools

PDS-labeled images and tables can be viewed with the program PDS4 Viewer, developed by the PDS and available for a variety of computer platforms from the PDS web site http://sbndev.astro.umd.edu/wiki/PDS4_Viewer. A Python library of PDS4 tools, from which the PDS4 Viewer is built, is available at http://sbndev.astro.umd.edu/wiki/Python_PDS4_Tools. There is no charge for this software.

7.3 Software Distribution and Update Procedures

The FEI distribution tool and Mars Image Processing Program Suite are available to researchers and academic institutions. Refer to the MIPL Web site at http://www-mipl.jpl.nasa.gov for contact information. FEI is described in detail at http://www-mipl.jpl.nasa.gov/MDMS.html.

APPENDIX A. Telemetry Data Product (DP) Types Matched to EDR Product Types

Telemetry Data Product (DP)			EDR Product	
APID Name	DP Metadata: Metadata Source Type • "IDPH DPO" • "Ancillary Data DPO" • "SDF Header" (Mini-header)	DP Metadata: Metadata Source Type Name	3-char Product ID in Filename	Description
RfaxScidata (Cruise only)	Ancillary Data DPO	RfaxAncillarydataFrame	EDR	GPR Sounding Measurement or Housekeeping Measurement
RfaxFault (Cruise)	Ancillary Data DPO	RfaxAncillarydataFrame	EFC	Fault Condition
RfaxFault (Surface)	IDPH DPO	System	EFC	Fault Condition
	IDPH DPO	SystemMob		
	IDPH DPO	SystemRvrArmRsm		
	Ancillary Data DPO	RfaxAncillaryDataFrameTempsAndAmps		
RfaxSciEng (Surface only)	IDPH DPO	System	EHK	Housekeeping Measurement
	IDPH DPO	SystemMob		
	IDPH DPO	SystemRvrArmRsm		
	Ancillary Data DPO	RfaxAncillaryDataFrameTempsAndAmps		
RfaxSoundingTypeN (Surface only) where, N="1" thru "7"	IDPH DPO	System	EDR	GPR "Regular Sounding" Measurement of a Single Mode (16-bit per sample)
	IDPH DPO	SystemMob		
	Ancillary Data DPO	RfaxAncillaryDataFramePerSounding		
	Ancillary Data DPO	RfaxAncillaryDataFramePerActivity		
RfaxLIS (Surface only)	IDPH DPO	System	EDR	GPR "Long Integration Sounding" (LIS) Measurment of a Single Mode (32-bit per sample)
	IDPH DPO	SystemMob		
	Ancillary Data DPO	RfaxAncillaryDataFramePerSounding		
	Ancillary Data DPO	RfaxAncillaryDataFramePerActivity		
RfaxSummary (Surface only)	IDPH DPO	System	EDR	GPR "Regular Sounding" and/or "LIS" Measurement (DP may contain Mixed Modes but EDRs contain single Mode)
	IDPH DPO	SystemMob		
	Ancillary Data DPO	RfaxAncillaryDataFramePerSounding		
	Ancillary Data DPO	RfaxAncillaryDataFramePerActivity		

APPENDIX B. Product Label Keyword Definitions, Values, and Sources

As described in the main text, there are three types of label keywords: VICAR, ODL, and PDS4. The VICAR and ODL labels are virtually identical and are referred to here collectively as “VICAR” labels.

This Appendix describes several tables that will be useful for understanding the details of these keywords. All of the tables are in separate files within the Document Collection of this instrument’s PDS Archive Bundle. Each of the tables is provided in both HTML and PDF format. The files are:

- mars2020_rimfax_Labels_sort_pds.pdf
- mars2020_rimfax_Labels_sort_pds.html
- mars2020_rimfax_Labels_sort_vicar.pdf
- mars2020_rimfax_Labels_sort_vicar.html

PDS4 Keyword Tables

This set of tables describes the PDS4 keywords (classes and attributes in PDS 4 parlance). They include pointers to the matching VICAR keywords, as well as both the generic (multimission) definition of the keyword, and the specific “nuance” or supplemental information that applies only to Mars 2020.

These tables are created by examining a set of sample labels (incorporating all types of products being created) in order to determine the PDS4 classes and attributes that are actually used by the products described in this SIS. This list is then cross-referenced against the PDS4 data dictionaries in order to find the definitions, children, valid values, and data types. This list is then augmented with “property maps” that provide the Mars 2020-specific valid values, and the “nuance” definitions.

These tables are thus much more useful for most purposes than looking at the PDS4 data dictionaries directly, because they contain *only* the keywords that are *actually* used.

The first column contains the name of the PDS4 attribute (keyword) or class (container), and the PDS4 dictionary it comes from. Along with that, when applicable, are the VICAR keyword and property name(s) from which the values are derived. The property name is the section of the VICAR label. Not every entry has a VICAR keyword; some entries are merely containers, others contain constants or values that are derived in other ways. Some of the VICAR keywords refer to the class rather than the attribute; for example a VICAR vector keyword will typically refer to the vector’s class rather than the x,y,z attributes individually.

The second column contains the definition. There are two components to many definitions, as alluded to above. The first, which is always present, is the standard PDS4 definition that applies to all missions, from the PDS4 data dictionary. The second (in italics) is a Mars 2020-specific nuance to the definition, providing additional context that applies specifically to Mars 2020.

The third column is broken up into several pieces. The first is the XPath. This gives the “path” of where the item can be found in the label, tracing the hierarchy from the root (often but not always

Product_Observational) down to the item itself. Each level in this hierarchy is a hyperlink, which can be clicked on to go directly to that items' definition.

Underneath the XPath is a field whose content varies based on the type. For attributes ("keyword"), this contains the valid values, when such are defined either by the PDS4 data dictionary or the Mars 2020-specific property maps. For classes (containers), the valid children are listed. Those that are blue hyperlinks are actually used by Mars 2020; clicking on them will go to that item's definition. Those that are not blue are defined by the PDS4 data dictionary but are not used by Mars 2020.

Finally, also underneath the XPath field is another column containing (for attributes only) the data type and units. All attributes should have a data type, but only some have units defined.

These label tables are the primary source of information regarding the metadata in the labels. The rest of this document describes things at a high level; the label tables (along with the ops label table, above) define specifically what each label item means.

There are two versions of the table: sorted by PDS4 name, and sorted by VICAR keyword. The tables can be used in either direction. Given a label item you don't understand, you can look it up in the table (sorted by either PDS or VICAR name, depending on which you're looking at) to find the definition. In some cases you may need to go up the hierarchy to find a meaningful definition (for example the definition for "x" is not particularly useful, but the parent or grandparent should describe what the full x,y,z value is being used for. Alternatively, given an item in the table, you can find the item in the label by following the XPath – looking down the hierarchy of elements until you find the item. Note that not all keywords are in any given label; the table encompasses image products, browse images, mosaics, meshes, calibration, and documentation files.

The cross-reference between PDS4 name and VICAR keyword can also be useful for comparing values across similar missions (MSL, MER, Phoenix, etc) that use PDS3 (the VICAR and PDS3 keywords are generally the same).