MARSIS

System Functional Requirements Document

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0.91	October 15, 1999	For use as submittal to IPDR
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0.95	May 22, 2000	Removed descriptions modified structure
0.98	September 11, 2000	Included Test and Requirements Matrix
0.99	September 20, 2000	Corrected Operative Modes
1.0	October 23, 2000	Ripple reqs. added, Acquisition db table
1.1	February 1, 2000	Corrections per Picardi suggestions

Table of Contents

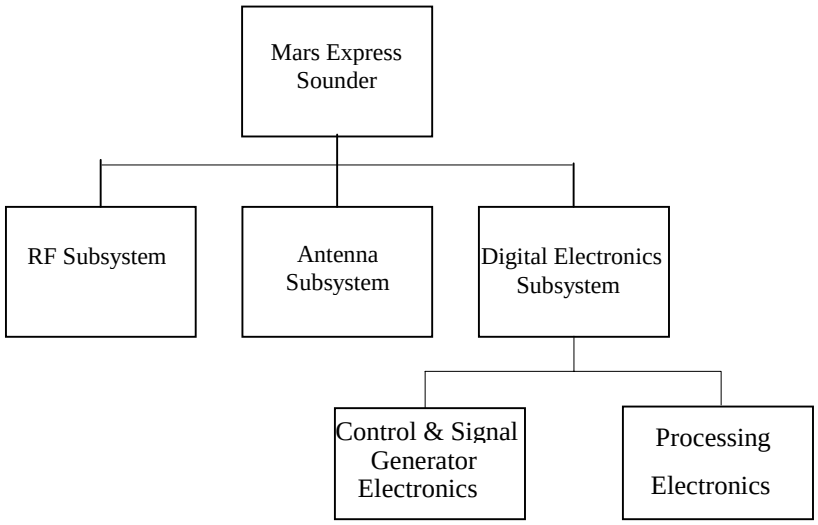
Chapter 1 Introduction

1.1 Purpose

The purpose of this document is to set forth the requirements for the **M**ars **A**dvanced **R**adar for **S**ubsurface and **I**onospheric **S**ounding (MARSIS) to be flown on the Mars Express mission. MARSIS is an experimental sounder to explore the subsurface of Mars using a low frequency sounder. This document also partitions the sounder system into separate well-defined subsystems for the purpose of separating implementation responsibilities.

1.2 System Architecture

For the purpose of this document, MARSIS is composed of three subsystems. The Digital Electronics Subsystem, the RF Subsystem and the Antenna Subsystem. The Digital Electronics Subsystem interfaces with the spacecraft, provides control functions to the other subsystems and provides the frequencies for use by all the subsystems.



The RF transmitter resides within the Antenna Subsystem due to critical coupling between the radiating elements and a matching network. The RF subsystem generates the power to excite the transmitter as well as amplifying the return echoes and converting them to digital format. The antenna Subsystem consists of two separate antennas for the main sounder functions and clutter cancellation. The Digital Electronics Subsystem consists of the Control and Signal Generator Electronics and the Processing Electronics. The Control and Signal Generator Electronics consists of the reference oscillator, the timing circuits to control the sounder functions as well as the interface electronics with the spacecraft. The Processing Electronics, within the Digital Electronics Subsystem, buffers the digitally converted echoes and process the high rate digital data according to

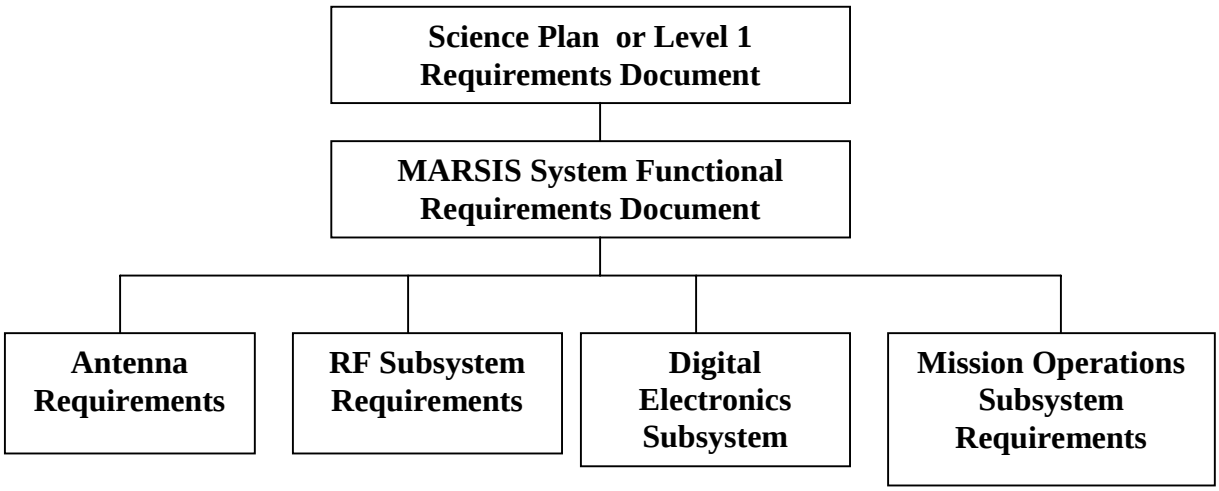
the operative mode (Subsurface Sounding or Ionospheric Sounding) to get subsurface echo profiles or ionosphere profiles. Processed data are then transferred to the spacecraft and subsequently to the Earth. The sounder as described in section 2.1.2 consists of two separate channels, one for the main sounder and the other for surface clutter cancellation.

1.2.1 Hardware redundancy

MARSIS is mass limited and does not require redundancy in any subsystem.

1.3 Requirements Tree

This document converts the requirements in the Science Plan, or top-level requirements document, into the next level requirements for each subsystem. Based on the requirements levied in this document, it is expected that each subsystem will derive and document its own requirements with traceability established to this SFRD. Note that the partitioning of sibling documents are based on the system architecture derived in the previous section.



1.4 Applicable Documents

1.4.1 MARSIS Science Plan.

1.4.2 MARSIS Calibration/On-Orbit Checkout Plan.

1.4.3 PAYLOAD INTERFACE DOCUMENT - PID-A, MEX-MMT-SP-0007

1.4.4 ELECTRICAL INTERFACE REQUIREMENT SPECIFICATION, PID/URD-ANNEX

1.5 Reference Documents

1.5.1 MARS ADVANCED RADAR FOR SUBSURFACE AND IONOSPHERE SOUNDING (MARSIS): MODELS AND SYSTEM ANALYSIS; Info -Com Technical Report MRS-007/005/99, October 15, 1999.

1.5.2 Mars Express: Subsurface Sounding Radar/Altimeter Proposal INFOCOM doc. n. 188-23/2/1998

1.5.3 MARSIS DESIGN, DEVELOPMENT AND VERIFICATION PLAN, PLN-MAR-0001-INF

1.5.4 MARSIS DESIGN DESCRIPTION, SCIENCE ANALISYS AND PERFORMANCE, RPT-MAR-0004-INF

1.5.5 MARSIS PID-A COMPLIANT MATRIX, SOC-MAR-0003-INF

1.5.6 MARSIS/DES ACQUISITION AND TRACKING ALGORITHMS DEFINITION, Infocom TR. 003/005/2000, September 22, 2000.

1.5.7 ADAPTIVE COMPENSATION OF MARS IONOSPHERE DISPERSION, Infocom TR. 009/005/00, October 8, 1999.

CE DOCUMENT - PID-A, MEX-MMT-SP-0007

1.6 Document Organization

This requirements document is organized by subsystem. Each requirement first identifies the subsystem followed by the section within the subsystem and then a sequential number for identification purposes. Any text within the requirement section, which is in ***Italics***, is for informational purposes only and does not constitute a part of the requirement.

1.7 System Description

The MARSIS instrument is designed to be flown on the ESA Mars Express spacecraft to orbit the planet Mars in 2004. After orbit insertion and antenna deployment, the spacecraft will be in an elliptical orbit with a periapsis of 250 kilometers and an apoapsis of 10124 kilometers over the Martian surface. The sounder is to acquire science data when the orbiter altitude is below 1200 kilometers over the Martian surface. At an altitude of 1200 kilometers ionospheric sounding is performed until the altitude over the Martian surface reaches 800 kilometers. Below this altitude, subsurface sounding is the primary mode of data acquisition. Due to the ionospheric distortion of the E/M wave, the sounding ability of MARSIS is significantly better when the periapsis is on the night side of Mars.

Sounder Instrument

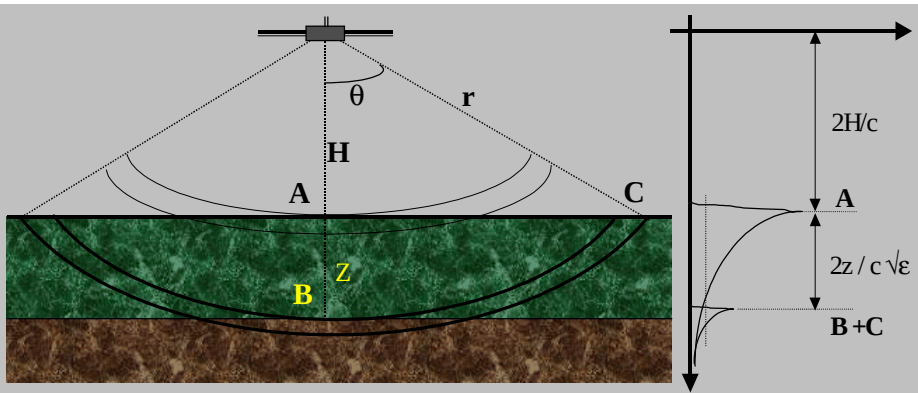


Fig. 1.1: MARSIS observation geometry and principle of operation

The MARSIS instrument is a low-frequency nadir-looking pulse limited radar sounder and altimeter with ground penetration capabilities, which uses synthetic aperture techniques and a secondary-receiving antenna to isolate subsurface reflections. The basic observation geometry and the principle of operation are depicted in Fig. 1.1. The operational altitudes of MARSIS are up to 800 km for subsurface sounding and up to 1200 kilometers for ionospheric sounding above the surface of Mars. In standard operative mode the instrument will be able to operate in any of the following bands: 1.3-2.3 MHz (centered at 1.8 MHz), 2.5-3.5 MHz (centered at 3.0 MHz), 3.5-4.5 MHz (centered at 4.0 MHz) and 4.5-5.5 MHz (centered at 5.0 MHz).

MARSIS consists of two electronics assemblies and two antennas mounted on the Mars Express Orbiter. A simple block diagram of the sounder is shown in Figure 1.2: Operation of the sounder is as follows. After receipt of a turn on command from the spacecraft and the instrument has cycled through its turn on process, the Control Electronics generates a linear frequency modulated chirp, which is amplified by the transmitter, and the energy radiated by a nadir looking dipole antenna. At this point, both receivers are protected from the transmit event. After the transmit pulse is completed, the return signal from the Martian surface is received by both antennas and the receiver protectors are disabled. The dipole antenna is then connected to the receiver, which amplifies the return signal, that is downconverted to range offset video prior to conversion to digital form by the Analog to Digital Converter. A secondary monopole antenna, oriented along the nadir axis will receive mostly the off-nadir surface returns, that could be thus subtracted in the ground re-processing, further reducing the surface clutter level (about ~15-20 dB) [Ref. Sec 1.5.1]. This channel receives signals from the surface, which are not in the local nadir direction as this antenna exhibits a null in its antenna directivity in this direction. These surface clutter returns are then amplified

by a receiver with a dynamic gain response, downconverted to range offset video in identical form to that of the Simple Sounder channel and converted to digital format by the Analog to Digital Converter. The digital signals from both channels are then sent to the on-board digital processor for processing the data to a sounder format. These signals are then sent to the spacecraft for relaying to the earth.

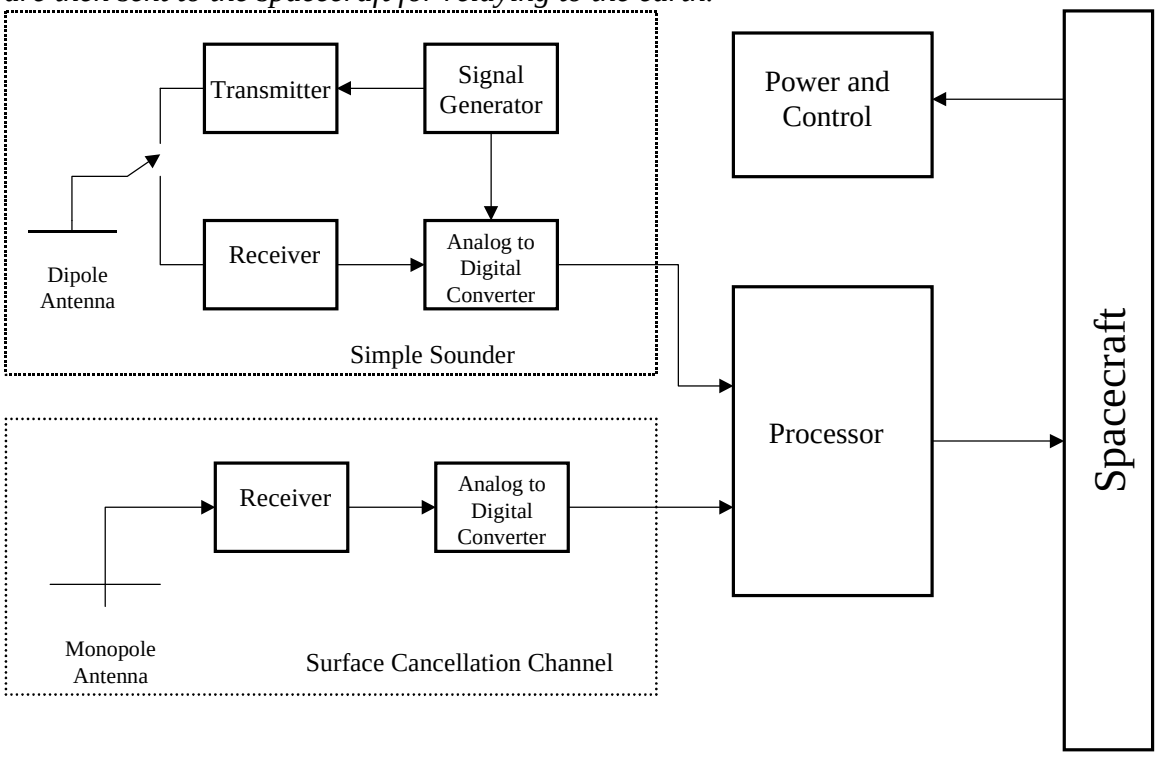


Fig. 1.2: MARSIS block diagram

Chapter 2 – System Requirements

2.1 Radar Sounder Modes

The MARSIS instrument is designed to operate as both a subsurface sounder and an ionospheric sounder. During subsurface sounding, MARSIS will operate in one of five sounding modes, which depend on the selection of different processing options, and selection of antennas. This section sets requirements for transmit/receive options, operational modes and any support modes required to initialize the sounder be only described here.

MARSIS modes are classified as "SUPPORT" modes and the "OPERATION" modes. In the Operation Modes the radar performs its main tasks i.e. acquisition, tracking, calibration, sounding etc. In the Support Modes the instrument performs all the other tasks, i.e. initializing, testing, recovery from failure etc. Support modes are summarized in Table 2.1-1.

Support Modes				
Mode	**DES**	**RFES**	**Transmitter**	**Comments**
Off	Off	Off	Off	Spacecraft Control
Check/INIT	On	Off	Off	Spacecraft Control
Standby	On	Off	Off	DES Control
WA-UP1	On	On	Off	DES Control
WA-UP2	On	On	On	No RF Radiation

Table *2.1*-1 MARSIS Support Modes of Operation

2.1.1 In the Support Modes, MARSIS shall perform all the tasks that will prepare the instrument to work in the proper way (initializing, testing, recovery from failure, power-up etc) during the Operation Modes.

2.1.2 In the OFF mode, all subsystems shall be off.

2.1.3 In Reset/Wait Mode DES *shall* be ON, and RFS (both RX and TX) shall be OFF.

2.1.4 During normal operations, in Standby Mode DES shall be ON (running state), with the RFS (both RX and TX) subsystems turned off.

2.1.5 Only in the standby mode, MARSIS shall be capable of receiving Telecommands.

2.1.6 WARM-UP 1 and WARM-UP 2 Modes shall be used to perform a warm up for the subsystems as required before science data acquisition.

2.1.7 Data Frames. During the data acquisition phase of the MARSIS orbit, the operation of the sounder shall be divided into sequential frames. Each frame consists of a series of transmit/receive sequences, which perform the following functions:

a) Determination of Ionospheric correction or calibration parameters.
b) Synthetic aperture data acquisition
c) Echo tracking updates
d) Passive ionospheric sounding.

2.1.8 The Calibration or Raw Data mode, the first of the Operation Modes, shall acquire unprocessed sounding data for a minimum of 1900 pulse repetition intervals (PRI).

2.1.9 Subsurface sounding modes. Five different sub-modes, SS1 to SS5, shall be used during the orbiter phase of the mission (separately or in the same flyby).

During any of these modes the following are performed:

-Real time calibration of distortions due to Ionosphere,
-Acquisition and tracking of the surface echo time delay.
-Passive ionospheric measurement (embedded in the subsurface sounding)
-Range and Doppler processing for detection of subsurface features
-Limited raw (un-processed) data appended for ground processing monitoring.

For the synthetic aperture data acquisition, the submodes are as follows:

Operating Modes						
Mode	Frequencies	Clutter Cancel	Pre-Sum	Doppler Filters	Data Rate Kb/Sec	Comments
SS1	2	Y	N	1	26.1	Complex data on ground
SS2	2	N	N	1	13	Amplitude only on ground
SS3	2	N	N	3	39	Multilook on ground
SS4	1	Y	N	5	65.2	Dual Channel coherent cancellation on ground
SS5	1	Y	Y	3	39	Presum 30 microsecond pulses. Avoid sidelobe problems
AIS	160	N/A	N/A	N/A	33	Active Ionospheric Mode
Raw Data	1/2		N	N/A	25.4	Raw Data Two Channel. Buffered

2.1.9.1 SS-1 Sub MODE. In this submode, MARSIS shall transmit and receive two frequencies on the dipole antenna and receive two frequencies on the monopole antenna. Complex data shall be transmitted to the ground to allow optional clutter cancellation.

Complex samples of each of the single Doppler filter per channel are synthesized and transferred in the science source packet data format.

2.1.9.2 SS-2 Sub MODE. In this submode, MARSIS shall transmit and receive two frequencies on the dipole antenna. The processing in this mode, echoes from the dipole channel provide on board multilook processing of five individual Doppler filters to a single combined channel per frequency.

Echoes from the monopole antenna are not processed. The power detected multilooked data streams are transferred in the science source packet data format.

2.1.9.3 SS-3 Sub MODE. In this submode, MARSIS shall transmit and receive two frequencies on the dipole antenna. The echoes shall be processed from three Doppler filters on board and the information from each of the two processed channels transferred to the science source packet data.

Only data from the processed channels are returned to the ground.

2.1.9.4 SS-4 Sub MODE. In this submode, MARSIS shall transmit a single frequency and echoes received from both the dipole and monopole channels. Echoes shall be processed from each of five Doppler channels and the complex data transferred to the science source packet data. Clutter cancellation shall be processed on the ground.

2.1.9.5 SS-5 Sub Mode. In this submode, MARSIS shall transmit a single frequency and echoes received from both the dipole and monopole channels. Echoes shall be presumed over groups of four to increase the signal to noise ratio. These presummed echoes shall be processed to synthesize three Doppler filters for each channel.

2.1.10 In the Active Ionospheric Mode MARSIS shall sweep a range of frequencies to allow acquisition of ionospheric plasma frequency profiles.

2.2 Sounder Requirements

2.2.1 Subsurface Sounding Frequencies. MARSIS operation in the subsurface sounding mode shall operate in 4 selectable frequency bands. These are:

Band 1	1.3 to 2.3 MHz
Band 2	2.5 to 3.5 MHz
Band 3	3.5 to 4.5 MHz
Band 4	4.5 to 5.5 MHz

2.2.2 Ionospheric Sounding Frequencies. The sounder, in the active ionospheric sounding mode shall operate over a 0.1 MHz to 5.5 MHz range.

2.2.3 The bandwidth of each of the subsurface sounder operating bands shall be 1 MHz.

2.2.4 Pulse Repetition Frequency. The transmit pulse timing for the subsurface sounding modes of MARSIS shall be in the range of 125 to 130 pulse sets per second with one to four pulses transmitted within a pulse set.

2.2.5 The transmit/receive timing diagram shall allow for a sequence of transmit pulses to correspond to the frequencies required in the Subsurface Modes (SS Modes) before opening the receive window for echo reception.

The receive window shall also allow for a passive ionospheric receive gate.

2.2.6 The transmitted signal for the subsurface sounding mode shall be a linear increasing frequency modulated chirp with a 1 Mhz bandwidth. The frequency limits of each transmitted signal shall be compatible with the frequency limits set forth in 2.2.1.

2.2.7 The MARSIS sounder shall incorporate two pulse widths for the subsurface sounding mode and a single pulse width for the ionospheric sounding mode.

2.2.8 The transmit pulse widths for the subsurface sounding mode shall be programmable in the range of 10 to 350 microseconds.

For subsurface sounding modes SS-1 to SS-4, the chirp length is 250 μsec. For the subsurface sounding mode SS-5, the chirp length is 30 μsec

2.2.9 The transmitted signal for the ionospheric sounding mode shall be unmodulated CW pulses.

2.2.10 The transmit pulse width for the ionospheric sounding mode shall be 95 ± 5 μsec.

2.2.11 The overall system impulse response shall have peak sidelobes that are limited to values as shown in Figure 2.2.

The overall system impulse response includes the weighting using the MARSIS reference weighting function described in 2.6 and amplitude and phase correction by the on-board processor.

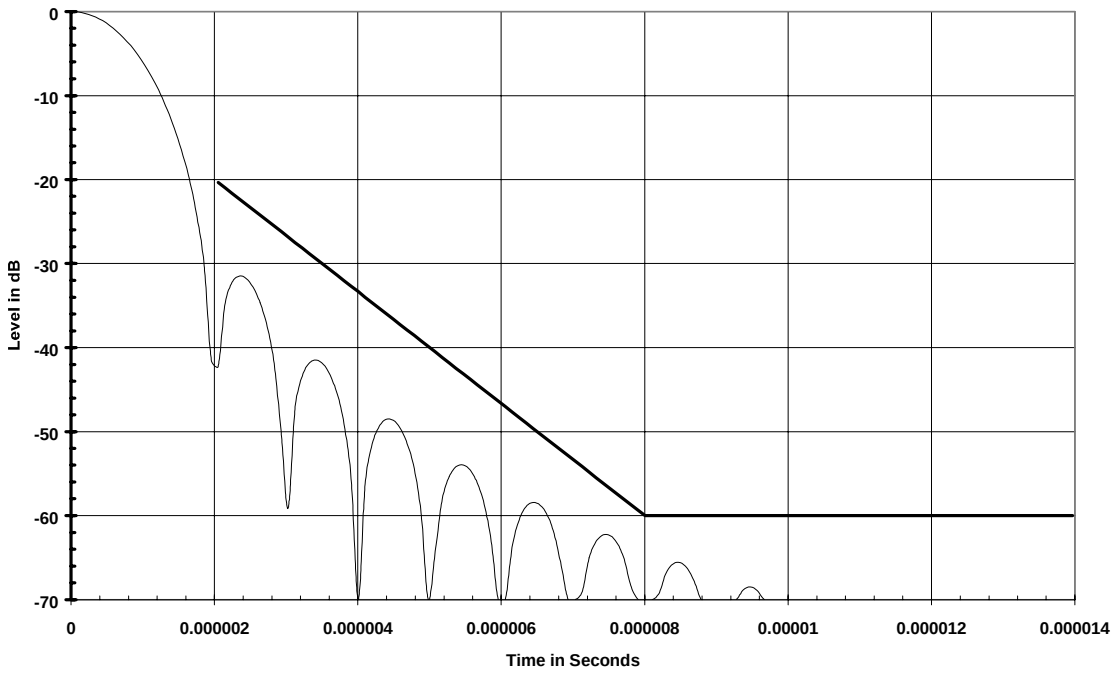


Figure 2.2 System Peak Sidelobe Requirement

2.2.12 The sounder system shall be linear over the minimum following dynamic range in order to preserve signal integrity:

Receive section to Analog to Digital Converter	24 dB
Analog to Digital Converter	36 dB
Processor	70 dB

2.2.13 The sounder system noise level shall be less than or equal to one-half the local galactic noise level.

2.3 Spacecraft Interfaces

This section describes the interfaces between MARSIS and the Mars Express spacecraft and is presented for reference only. The Interfaces are described in detail and covered in the MEX-PID-B document.

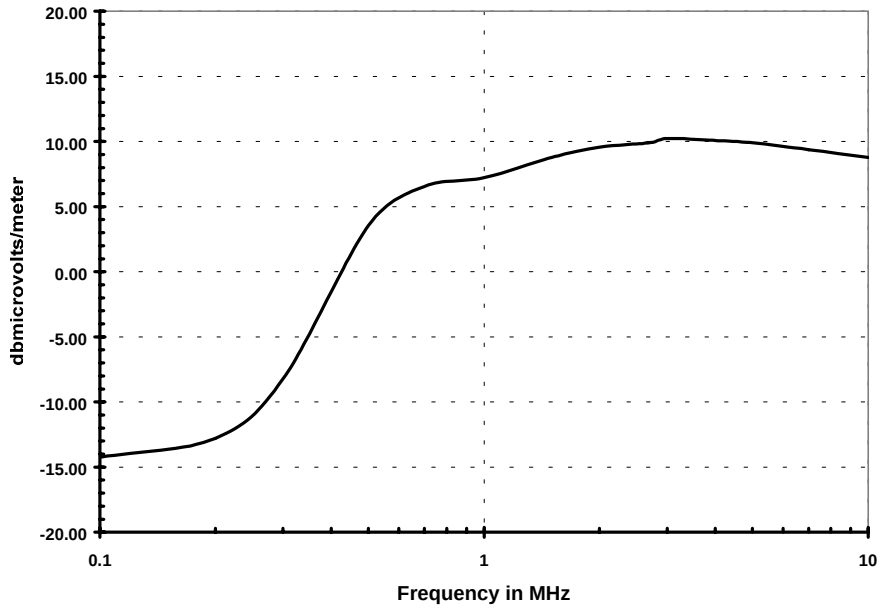
2.3.1 MARSIS is a power-constrained instrument. The total power used by the instrument shall not exceed 70 watts. The power allocation to the subsystems is detailed in EICD issue 3 and is shown in Table 2.3.1. by in each operative mode:

SUBSYSTEM	*OFF*	*CHECK/INIT*	*STANDBY*	*WA-UP1*	*WA-UP2*	*CALIBRATION*	*SUBSURF SOUND.ING*	*ACTIVE IONOSPH. SOUNDING*
RFS (RX)	*0*	*0*	*0*	*3*	*3*	*3*	*3*	*3*
RFS (TX)	*0*	*0*	*0*	*0*	*1*	*15*	*15*	*15*
DES	*0*	*25*	*25*	*25*	*25*	*37*	*37*	*37*
Margin	*0*	*0*	*0*	*0*	*0*	*4*	*4*	*4*
TOTAL	*0*	*25*	*25*	*28*	*29*	*59*	*59*	*59*

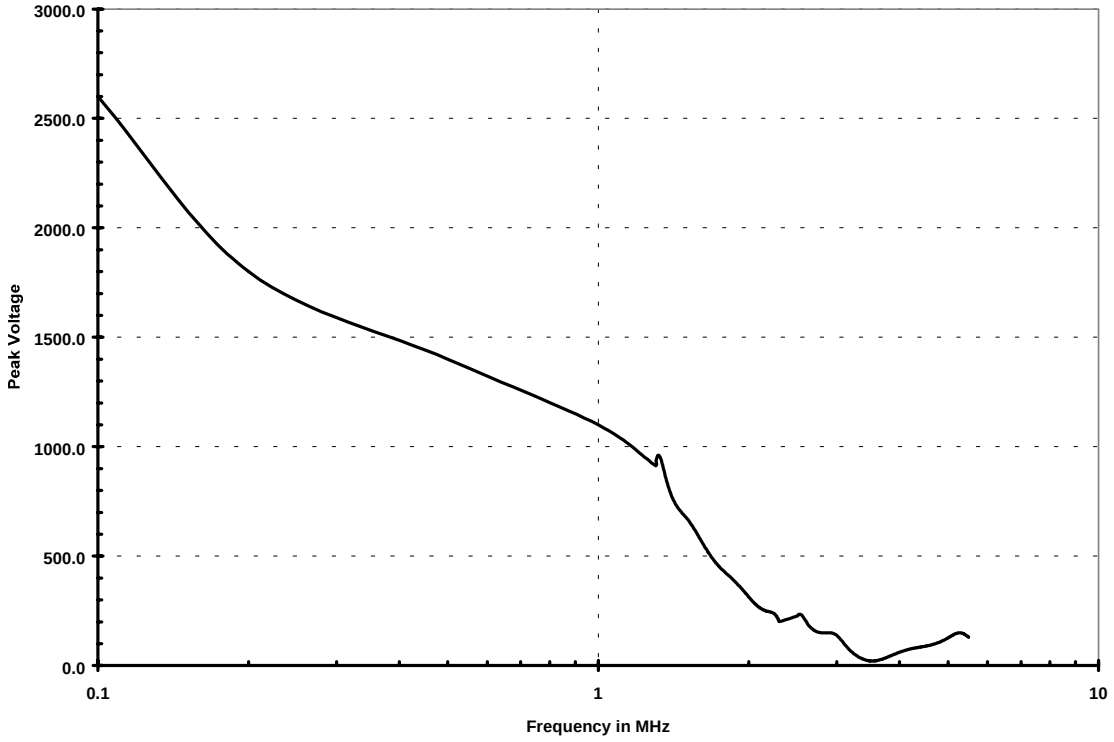
Table 2.3.1 DC Power Allocation [W]

2.3.2 MARSIS is a mass constrained instrument. The total mass shall not exceed 15 kilograms.

2.3.3 Noise sources generated by the spacecraft and other related systems in the frequency band of MARSIS in the vicinity of the antennas shall be limited by the following Emission limit curve.



2.3.4 MARSIS, in the process of generating a high power RF pulse, generates high electric fields in order to obtain measurable return energy from the subsurface. The voltages generated by MARSIS between the dipole elements at the base of the antenna is as shown in the following chart:



2.4 Link Tables

The link tables included here are for information purposes only and do not constitute any requirements.

The radio frequency absorption due to the ionosphere is highly dependent on the electron density and collision frequency profile between the antenna and the surface of Mars. The electron frequency in particular is strongly affected by the solar zenith angle. For the purposes of estimating the signal levels of MARSIS returns, the electron density reference profile for Bands 1 and 2 is as shown in Figure 2.4.1. For Bands 3 and 4, the reference electron density profile is as shown in Figure 2.4.2. The collision frequency profile is as shown in Figure 2.4.3.

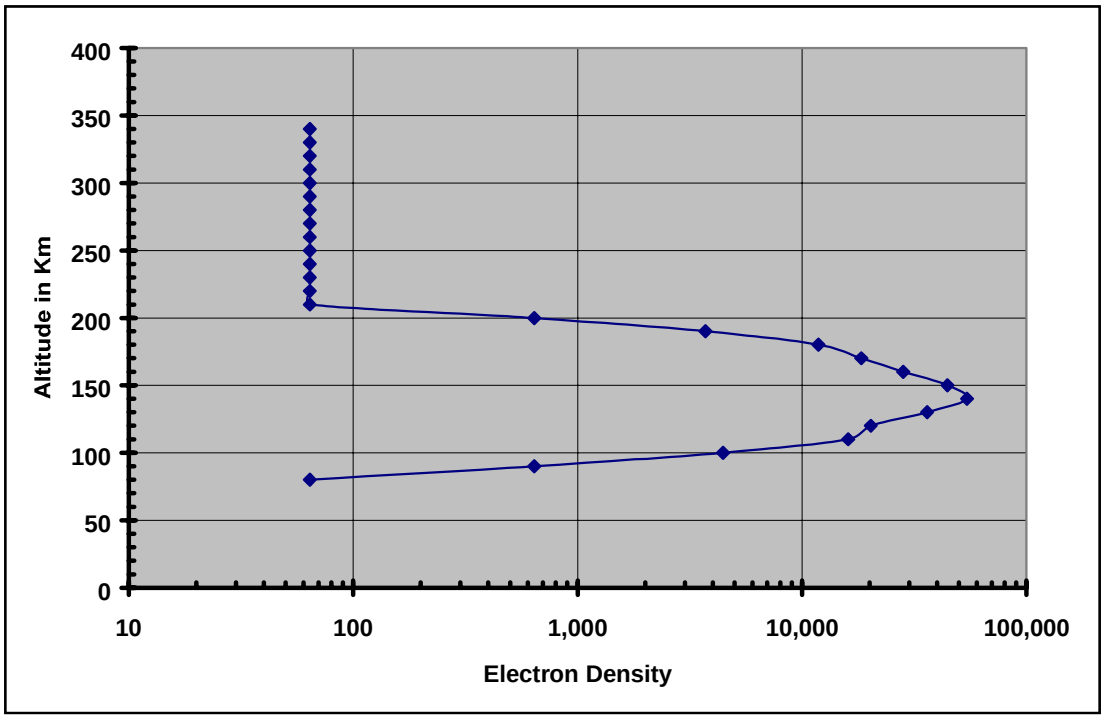


Figure 2.4.1 Day Electron Density Profile (Plasma Frequency 2 MHz)

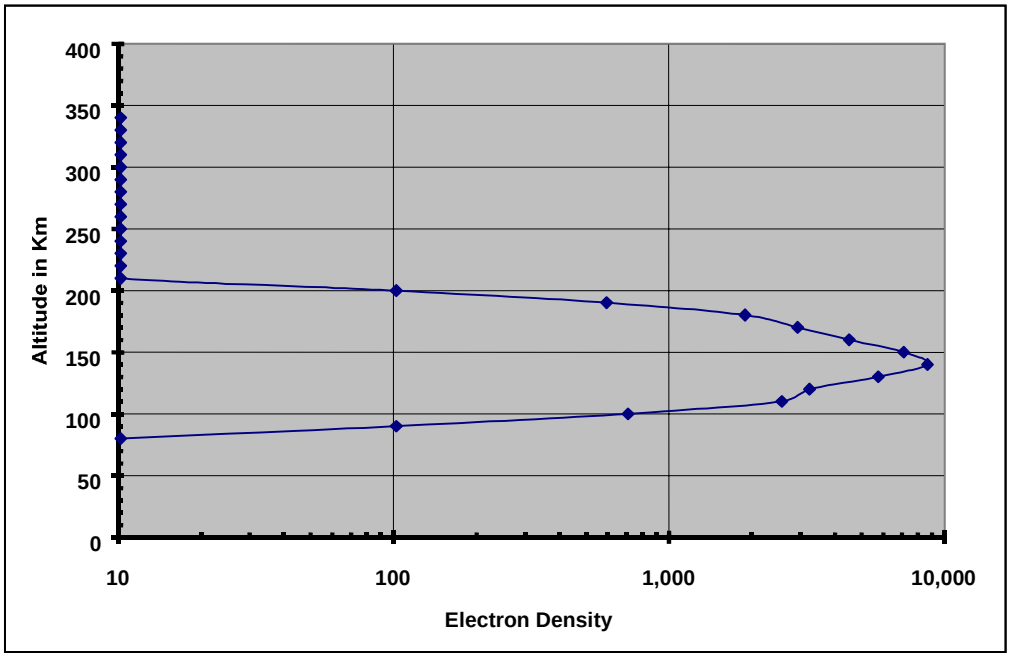


Figure 2.4.2 Night Electron Density Profile (Plasma Frequency 0.5 MHz)

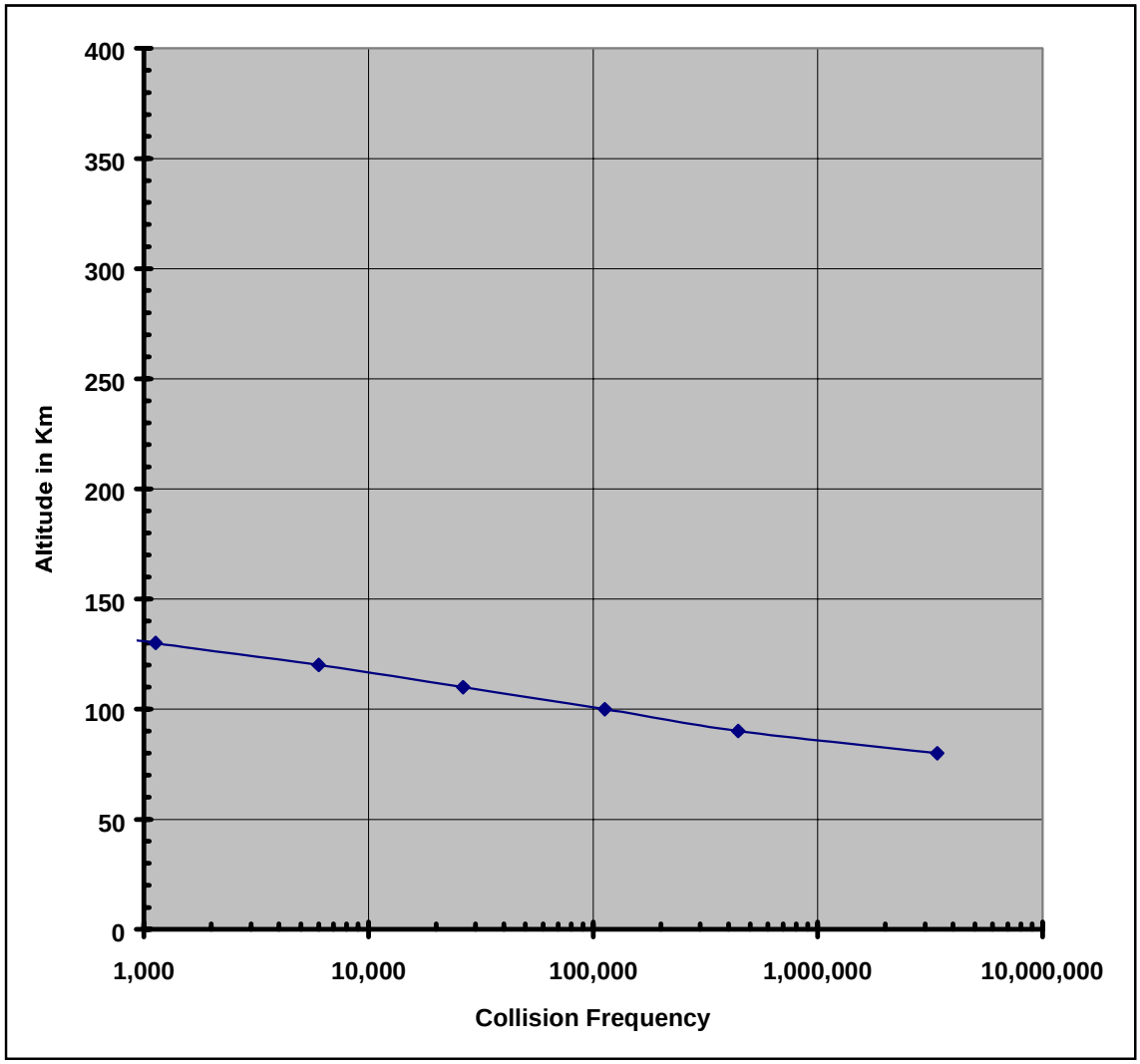


Figure 2.4.3 Collision Frequency Profile (Based on Pathfinder Data)

2.4.1 Band 1 Sounder Specular Link Tables

Sounder Parameters				5-Dec-00
Frequency Band	1			
Plasma Frequency	0.5			
Specular Return				
Parameter	**Value**		**dB**	
	H=250 Km	**H=800 Km**	**H=250 Km**	**H=800 Km**
Transmit Power	46	46	16.6	16.6
Antenna Gain squared	2.6	2.6	4.2	4.2
Antenna Losses	0.004	0.004	-24.0	-24.0
Wavelength squared	27778	27778	44.4	44.4
Reflection Coefficient	0.16	0.16	-8.0	-8.0
(1/8pi*Altitude^2)	0.000	2.5E-15	-136.0	-146.1
Ionosphere Attenuation	0.38	0.38	-4.1	-4.1
Filtering Losses	0.71	0.71	-1.5	-1.5
Received Power			**-108.3**	**-118.5**
Electronics Gain			70	70
Power at A/D			**-38.3**	**-48.5**
Range Compression Ratio	135	135	21.3	21.3
Ionospheric Defocusing	0.8	0.8	-0.9	-0.9
Azimuth Compression	1	1	0.0	0.0
Processor Filtering	0.97	1	-0.2	-0.2
Power at Processor Output			**-18.1**	**-28.2**
Noise				
Parameter	**Value**		**dB**	
	H=250 Km	**H=800 Km**	**H=250 Km**	**H=800 Km**
Galactic Noise	3.5E-11	3.5E-11	-104.6	-104.6
Radiated Emissions	3.5E-11	3.5E-11	-104.6	-104.6
Antenna Losses	6.3E-02	6.3E-02	-12.0	-12.0
Filtering Losses	7.1E-01	7.1E-01	-1.5	-1.5
Noise at Receiver Input			**-115.1**	**-115.1**
Receiver Noise	1.38E-13	1.38E-13	-128.6	-128.6
ISLR Noise	6.3E-15	6.1E-16	-142.0	-152.1
Electronic Gain	10000000	10000000	70.0	70.0
Noise at A/D Input			**-44.9**	**-44.9**
A/D Converter Noise	2.00E-06	2.00E-06	-57.0	-57.0
Processor Filtering	0.008	0.005	-20.9	-23.4
Noise at Processor Output			**-65.5**	**-68.0**
SNR at Receiver Input			**6.7**	**-3.4**
SNR at A/D input			**6.5**	**-3.6**
SNR at Processor Output			**47.4**	**39.8**
				12/5/00

2.4.2 Band 2 Sounder Specular Link Tables

Sounder Parameters				5-Dec-00
Frequency Band	2			
Plasma Frequency	0.5			
Specular Return				
Parameter	**Value**		**dB**	
	H=250 Km	**H=800 Km**	**H=250 Km**	**H=800 Km**
Transmit Power	44	44	16.4	16.4
Antenna Gain squared	2.6	2.6	4.2	4.2
Antenna Losses	0.048	0.048	-13.2	-13.2
Wavelength squared	10000	10000	40.0	40.0
Reflection Coefficient	0.16	0.16	-8.0	-8.0
(1/8pi*Altitude^2)	0.000	2.5E-15	-136.0	-146.1
Ionosphere Attenuation	0.70	0.70	-1.6	-1.6
Filtering Losses	0.63	0.63	-2.0	-2.0
Received Power			**-100.1**	**-110.2**
Electronics Gain			70	70
Power at A/D			**-30.1**	**-40.2**
Range Compression Ratio	135	135	21.3	21.3
Ionospheric Defocusing	1.0	1.0	-0.2	-0.2
Azimuth Compression	1	1	0.0	0.0
Processor Filtering	0.85	1	-0.7	-0.7
Power at Processor Output			**-9.7**	**-19.8**
Noise				
Parameter	**Value**		**dB**	
	H=250 Km	**H=800 Km**	**H=250 Km**	**H=800 Km**
Galactic Noise	1.8E-11	1.8E-11	-107.6	-107.6
Radiated Emissions	3.5E-11	3.5E-11	-104.6	-104.6
Antenna Losses	2.2E-01	2.2E-01	-6.6	-6.6
Filtering Losses	6.3E-01	6.3E-01	-2.0	-2.0
Noise at Receiver Input			**-111.4**	**-111.4**
Receiver Noise	1.38E-13	1.38E-13	-128.6	-128.6
ISLR Noise	4.2E-14	4.1E-15	-133.8	-143.9
Electronic Gain	10000000	10000000	70.0	70.0
Noise at A/D Input			**-41.3**	**-41.3**
A/D Converter Noise	2.00E-06	2.00E-06	-57.0	-57.0
Processor Filtering	0.010	0.006	-19.8	-22.3
Noise at Processor Output			**-61.0**	**-63.5**
SNR at Receiver Input			**11.3**	**1.2**
SNR at A/D input			**11.2**	**1.1**
SNR at Processor Output			**51.3**	**43.7**
				12/5/00

2.4.3 Band 3 Sounder Specular Link Tables

Sounder Parameters				5-Dec-00
Frequency Band	3			
Plasma Frequency	2.0			
Specular Return				
Parameter	**Value**		**dB**	
	H=250 Km	**H=800 Km**	**H=250 Km**	**H=800 Km**
Transmit Power	102	102	20.1	20.1
Antenna Gain squared	2.6	2.6	4.2	4.2
Antenna Losses	0.017	0.017	-17.6	-17.6
Wavelength squared	5625	5625	37.5	37.5
Reflection Coefficient	0.16	0.16	-8.0	-8.0
(1/8pi*Altitude^2)	0.000	2.5E-15	-136.0	-146.1
Ionosphere Attenuation	0.04	0.04	-14.3	-14.3
Filtering Losses	0.71	0.71	-1.5	-1.5
Received Power			**-115.6**	**-125.7**
Electronics Gain			70	70
Power at A/D			**-45.6**	**-55.7**
Range Compression Ratio	135	135	21.3	21.3
Ionospheric Defocusing	0.8	0.8	-0.9	-0.9
Azimuth Compression	1	1	0.0	0.0
Processor Filtering	0.97	1	-0.2	-0.2
Power at Processor Output			**-25.4**	**-35.5**
Noise				
Parameter	**Value**		**dB**	
	H=250 Km	**H=800 Km**	**H=250 Km**	**H=800 Km**
Galactic Noise	9.5E-12	9.5E-12	-110.2	-110.2
Radiated Emissions	3.5E-11	3.5E-11	-104.6	-104.6
Antenna Losses	1.3E-01	1.3E-01	-8.8	-8.8
Filtering Losses	7.1E-01	7.1E-01	-1.5	-1.5
Noise at Receiver Input			**-113.8**	**-113.8**
Receiver Noise	1.38E-13	1.38E-13	-128.6	-128.6
ISLR Noise	1.2E-15	1.2E-16	-149.3	-159.4
Electronic Gain	10000000	10000000	70.0	70.0
Noise at A/D Input			**-43.7**	**-43.7**
A/D Converter Noise	2.00E-06	2.00E-06	-57.0	-57.0
Processor Filtering	0.012	0.007	-19.2	-21.7
Noise at Processor Output			**-62.6**	**-65.2**
SNR at Receiver Input			**-1.8**	**-11.9**
SNR at A/D input			**-1.9**	**-12.0**
SNR at Processor Output			**37.3**	**29.7**
				12/5/00

2.4.4 Band 4 Sounder Specular Link Tables

Sounder Parameters				5-Dec-00
Frequency Band	4			
Plasma Frequency	2.0			
Specular Return				
Parameter	**Value**		**dB**	
	H=250 Km	**H=800 Km**	**H=250 Km**	**H=800 Km**
Transmit Power	75	75	18.8	18.8
Antenna Gain squared	2.6	2.6	4.2	4.2
Antenna Losses	0.016	0.016	-18.0	-18.0
Wavelength squared	3600	3600	35.6	35.6
Reflection Coefficient	0.16	0.16	-8.0	-8.0
(1/8pi*Altitude^2)	0.000	2.5E-15	-136.0	-146.1
Ionosphere Attenuation	0.12	0.12	-9.3	-9.3
Filtering Losses	0.68	0.68	-1.7	-1.7
Received Power			**-114.4**	**-124.6**
Electronics Gain			70	70
Power at A/D			**-44.4**	**-54.6**
Range Compression Ratio	135	135	21.3	21.3
Ionospheric Defocusing	1.0	1.0	-0.2	-0.2
Azimuth Compression	1	1	0.0	0.0
Processor Filtering	0.87	1	-0.6	-0.6
Power at Processor Output			**-24.0**	**-34.1**
Noise				
Parameter	**Value**		**dB**	
	H=250 Km	**H=800 Km**	**H=250 Km**	**H=800 Km**
Galactic Noise	5.9E-12	5.9E-12	-112.3	-112.3
Radiated Emissions	3.5E-11	3.5E-11	-104.6	-104.6
Antenna Losses	1.3E-01	1.3E-01	-9.0	-9.0
Filtering Losses	6.8E-01	6.8E-01	-1.7	-1.7
Noise at Receiver Input			**-114.6**	**-114.6**
Receiver Noise	1.38E-13	1.38E-13	-128.6	-128.6
ISLR Noise	1.5E-15	1.5E-16	-148.1	-158.2
Electronic Gain	10000000	10000000	70.0	70.0
Noise at A/D Input			**-44.4**	**-44.4**
A/D Converter Noise	2.00E-06	2.00E-06	-57.0	-57.0
Processor Filtering	0.014	0.008	-18.7	-21.2
Noise at Processor Output			**-62.9**	**-65.4**
SNR at Receiver Input			**0.1**	**-10.0**
SNR at A/D input			**0.0**	**-10.1**
SNR at Processor Output			**38.9**	**31.3**
				12/5/00

2.4.5 Band 1 Sounder Acquisition Link Table

Sounder Parameters		5-Dec-00
Frequency Band	**1**	
Plasma Frequency	0.5	

Specular Return Acquisition Mode				
Parameter	**Value**		**dB**	
	H=250 Km	**H=800 Km**	**H=250 Km**	**H=800 Km**
Transmit Power	46	46	16.6	16.6
Antenna Gain squared	2.6	2.6	4.2	4.2
Antenna Losses	0.004	0.004	-24.0	-24.0
Wavelength squared	27778	27778	44.4	44.4
Reflection Coefficient	0.158	0.16	-8.0	-8.0
(1/8pi*Altitude^2)	2.5E-14	2.5E-15	-136.0	-146.1
Ionosphere Attenuation	0.522	0.522	-2.8	-2.8
Filtering Losses	0.708	0.708	-1.5	-1.5
Received Power			**-107.0**	**-117.1**
Electronics Gain			70	70
Power at A/D			**-37.0**	**-47.1**
Transmit Pulse Width	2.50E-04	2.50E-04	-36.0	-36.0
Bandwidth	200000	200000	53.0	53.0
Ionospheric Defocusing	0.6	0.6	-2.2	-2.2
Azimuth Compression	1	1	0.0	0.0
Processor Filtering	0.97	0.97	-0.2	-0.2
Power at Processor Output			**-22.4**	**-32.5**

Noise				
Parameter	**Value**		**dB**	
	H=250 Km	**H=800 Km**	**H=250 Km**	**H=800 Km**
Galactic Noise	5.6E-12	5.6E-12	-112.5	-112.5
Radiated Emissions	3.5E-11	3.5E-11	-104.6	-104.6
Antenna Losses	6.3E-02	6.3E-02	-12.0	-12.0
Filtering Losses	7.1E-01	7.1E-01	-1.5	-1.5
Noise at Preamp Input			**-117.4**	**-117.4**
Receiver Noise	1.38E-13	1.38E-13	-128.6	-128.6
ISLR Noise	3.140E-15	3.067E-16	-145.0	-155.1
Electronic Gain	10000000	10000000	70.0	70.0
Noise at A/D Input			**-47.1**	**-47.1**
A/D Converter Noise	2.00E-06	2.00E-06	-57.0	-57.0
Processor Filtering	0.016	0.016	-18.1	-18.1
Noise at Processor Output			**-64.7**	**-64.7**

SNR at Receiver Input	**10.4**	**0.3**
SNR at A/D input	**10.1**	**0.0**
SNR at Processor Output	**42.3**	**32.2**
		12/5/00

2.4.6 Band 2 Sounder Acquisition Mode Link Table

Sounder Parameters		5-Dec-00
Frequency Band	**2**	
Plasma Frequency	0.5	

Specular Return Acquisition Mode				
Parameter	**Value**		**dB**	
	H=250 Km	**H=800 Km**	**H=250 Km**	**H=800 Km**
Transmit Power	44	44	16.4	16.4
Antenna Gain squared	2.6	2.6	4.2	4.2
Antenna Losses	0.048	0.048	-13.2	-13.2
Wavelength squared	10000	10000	40.0	40.0
Reflection Coefficient	0.158	0.16	-8.0	-8.0
(1/8pi*Altitude^2)	2.5E-14	2.5E-15	-136.0	-146.1
Ionosphere Attenuation	0.755	0.755	-1.2	-1.2
Filtering Losses	0.631	0.631	-2.0	-2.0
Received Power			**-99.8**	**-109.9**
Electronics Gain			70	70
Power at A/D			**-29.8**	**-39.9**
Transmit Pulse Width	2.50E-04	2.50E-04	-36.0	-36.0
Bandwidth	200000	200000	53.0	53.0
Ionospheric Defocusing	0.6	0.6	-2.2	-2.2
Azimuth Compression	1	1	0.0	0.0
Processor Filtering	0.85	0.85	-0.7	-0.7
Power at Processor Output			**-15.7**	**-25.8**

Noise				
Parameter	**Value**		**dB**	
	H=250 Km	**H=800 Km**	**H=250 Km**	**H=800 Km**
Galactic Noise	2.7E-12	2.7E-12	-115.6	-115.6
Radiated Emissions	3.5E-11	3.5E-11	-104.6	-104.6
Antenna Losses	2.2E-01	2.2E-01	-6.6	-6.6
Filtering Losses	6.3E-01	6.3E-01	-2.0	-2.0
Noise at Preamp Input			**-112.8**	**-112.8**
Receiver Noise	1.38E-13	1.38E-13	-128.6	-128.6
ISLR Noise	1.674E-14	1.635E-15	-137.8	-147.9
Electronic Gain	10000000	10000000	70.0	70.0
Noise at A/D Input			**-42.7**	**-42.7**
A/D Converter Noise	2.00E-06	2.00E-06	-57.0	-57.0
Processor Filtering	0.016	0.016	-18.1	-18.1
Noise at Processor Output			**-60.6**	**-60.6**

SNR at Receiver Input	**13.1**	**3.0**
SNR at A/D input	**12.9**	**2.9**
SNR at Processor Output	**44.9**	**34.8**
		12/5/00

2.4.7 Band 3 Sounder Acquisition Mode Table

Sounder Parameters	
Frequency Band	**3**
Plasma Frequency	2

5-Dec-00

Specular Return Acquisition Mode

Parameter	**Value**		**dB**	
	H=250 Km	**H=800 Km**	**H=250 Km**	**H=800 Km**
Transmit Power	102	102	20.1	20.1
Antenna Gain squared	2.6	2.6	4.2	4.2
Antenna Losses	0.017	0.017	-17.6	-17.6
Wavelength squared	5625	5625	37.5	37.5
Reflection Coefficient	0.158	0.16	-8.0	-8.0
(1/8pi*Altitude^2)	2.5E-14	2.5E-15	-136.0	-146.1
Ionosphere Attenuation	0.064	0.064	-11.9	-11.9
Filtering Losses	0.708	0.708	-1.5	-1.5
Received Power			**-113.2**	**-123.3**
Electronics Gain			70	70
Power at A/D			**-43.2**	**-53.3**
Transmit Pulse Width	2.50E-04	2.50E-04	-36.0	-36.0
Bandwidth	200000	200000	53.0	53.0
Ionospheric Defocusing	0.6	0.6	-2.2	-2.2
Azimuth Compression	1	1	0.0	0.0
Processor Filtering	0.97	0.97	-0.2	-0.2
Power at Processor Output			**-28.6**	**-38.7**

Noise

Parameter	**Value**		**dB**	
	H=250 Km	**H=800 Km**	**H=250 Km**	**H=800 Km**
Galactic Noise	1.6E-12	1.6E-12	-118.0	-118.0
Radiated Emissions	3.5E-11	3.5E-11	-104.6	-104.6
Antenna Losses	1.3E-01	1.3E-01	-8.8	-8.8
Filtering Losses	7.1E-01	7.1E-01	-1.5	-1.5
Noise at Preamp Input			**-114.7**	**-114.7**
Receiver Noise	1.38E-13	1.38E-13	-128.6	-128.6
ISLR Noise	7.600E-16	7.421E-17	-151.2	-161.3
Electronic Gain	10000000	10000000	70.0	70.0
Noise at A/D Input			**-44.5**	**-44.5**
A/D Converter Noise	2.00E-06	2.00E-06	-57.0	-57.0
Processor Filtering	0.016	0.016	-18.1	-18.1
Noise at Processor Output			**-62.3**	**-62.3**

SNR at Receiver Input	**1.5**	**-8.6**
SNR at A/D input	**1.3**	**-8.8**
SNR at Processor Output	**33.8**	**23.7**
		12/5/00

2.4.8 Band 4 Sounder Acquisition Link Table

Sounder Parameters		5-Dec-00
Frequency Band	**4**	
Plasma Frequency	2	

Specular Return Acquisition Mode				
Parameter	**Value**		**dB**	
	H=250 Km	**H=800 Km**	**H=250 Km**	**H=800 Km**
Transmit Power	75	75	18.8	18.8
Antenna Gain squared	2.6	2.6	4.2	4.2
Antenna Losses	0.016	0.016	-18.0	-18.0
Wavelength squared	3600	3600	35.6	35.6
Reflection Coefficient	0.158	0.16	-8.0	-8.0
(1/8pi*Altitude^2)	2.5E-14	2.5E-15	-136.0	-146.1
Ionosphere Attenuation	0.158	0.158	-8.0	-8.0
Filtering Losses	0.676	0.676	-1.7	-1.7
Received Power			**-113.2**	**-123.3**
Electronics Gain			70	70
Power at A/D			**-43.2**	**-53.3**
Transmit Pulse Width	2.50E-04	2.50E-04	-36.0	-36.0
Bandwidth	200000	200000	53.0	53.0
Ionospheric Defocusing	0.6	0.6	-2.2	-2.2
Azimuth Compression	1	1	0.0	0.0
Processor Filtering	0.87	0.87	-0.6	-0.6
Power at Processor Output			**-29.0**	**-39.1**

Noise				
Parameter	**Value**		**dB**	
	H=250 Km	**H=800 Km**	**H=250 Km**	**H=800 Km**
Galactic Noise	1.0E-12	1.0E-12	-120.0	-120.0
Radiated Emissions	3.5E-11	3.5E-11	-104.6	-104.6
Antenna Losses	1.3E-01	1.3E-01	-9.0	-9.0
Filtering Losses	6.8E-01	6.8E-01	-1.7	-1.7
Noise at Preamp Input			**-115.1**	**-115.1**
Receiver Noise	1.38E-13	1.38E-13	-128.6	-128.6
ISLR Noise	7.639E-16	7.460E-17	-151.2	-161.3
Electronic Gain	10000000	10000000	70.0	70.0
Noise at A/D Input			**-44.9**	**-44.9**
A/D Converter Noise	2.00E-06	2.00E-06	-57.0	-57.0
Processor Filtering	0.016	0.016	-18.1	-18.1
Noise at Processor Output			**-62.7**	**-62.7**

SNR at Receiver Input	**2.0**	**-8.1**
SNR at A/D input	**1.8**	**-8.3**
SNR at Processor Output	**33.8**	**23.6**
		12/5/00

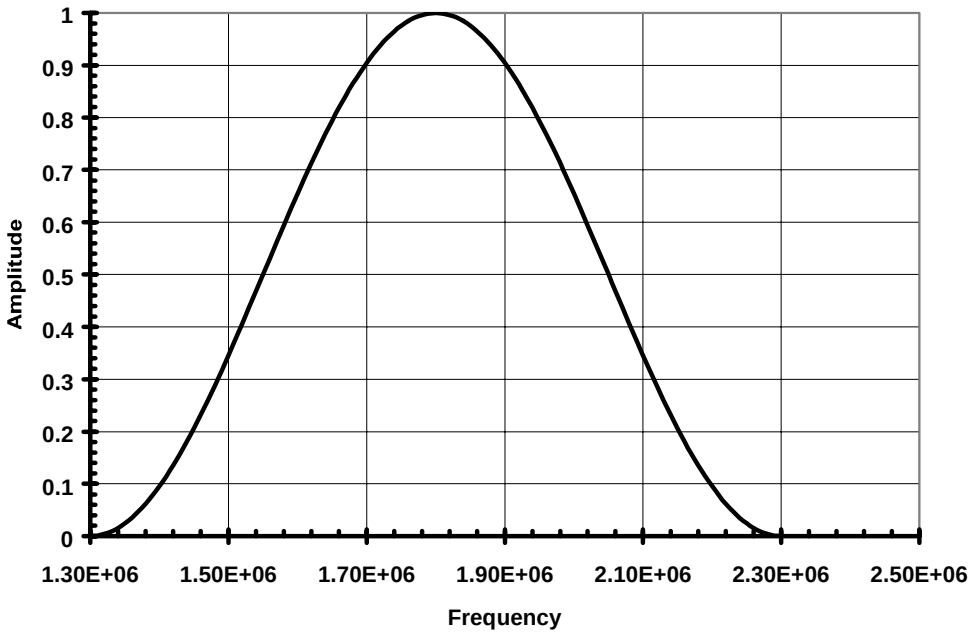
2.4.9 Ionospheric Sounding Mode Link Tables

Parameter	***Units***	***Frequency***			
		f=0.1 MHz	***f =0.3 MHz***	***f = 1.0 MHz***	***f = 3.0 MHz***
Radiated Power; Isotropic (P)	*Watts*	*8.9×10^{-5}*	*2.4×10^{-3}*	*9.6×10^{-1}*	*3.99*
Range (R)	*Km*	*500*	*500*	*500*	*500*
Reflection Coefficient (r)		*1.0*	*1.0*	*1.0*	*1.0*
Power Spectral Density ($\Delta S/\Delta f$)	*$Wm^{-2}Hz^{-1}$*	*3.5×10^{-22}*	*9.5×10^{-21}*	*3.8×10^{-18}*	*1.6×10^{-17}*
Electric Field Spec. Density ($E^2/\Delta f$)	*$V^2m^{-2}Hz^{-1}$*	*1.3×10^{-19}*	*3.6×10^{-18}*	*1.4×10^{-15}*	*6.0×10^{-15}*
Voltage Spectral Density ($V^2/\Delta f$)	*V^2Hz^{-1}*	*5.2×10^{-17}*	*1.4×10^{-15}*	*5.6×10^{-13}*	*2.5×10^{-12}*
Cosmic Noise Brightness (B)	*$Wm^{-2}Hz^{-1}Str^{-1}$*	*1.2×10^{-23}*	*1.5×10^{-22}*	*6.5×10^{-21}*	*1.4×10^{-20}*
Equiv. Power Spec. Density ($\Delta S_N/\Delta f$)	*$Wm^{-2}Hz^{-1}$*	*1.0×10^{-22}*	*1.25×10^{-21}*	*5.4×10^{-20}*	*1.2×10^{-19}*
Electric Field Spectral Density ($E_N^2/\Delta f$)	*$V^2m^{-2}Hz^{-1}$*	*3.8×10^{-20}*	*4.71×10^{-19}*	*2.0×10^{-17}*	*4.5×10^{-17}*
Voltage Spectral Density ($V_N^2/\Delta f$)	*V^2Hz^{-1}*	*1.5×10^{-17}*	*1.9×10^{-16}*	*8.0×10^{-15}*	*1.8×10^{-14}*
Signal to Noise Ratio (S/N)		*3.5*	*7.4*	*70*	*138*
Signal to Noise Ratio (S/N)	*dB*	*5.4*	*8.6*	*18.4*	*21.3*

2.5 MARSIS Reference Weighting Function

For the purpose of determining system performance and instrument response, the Hanning weighting function may be used.

Weighting function is applied in the Fourier transformed frequency domain assuming a digital matched filtering technique is implemented for the pulse range compression.



Chapter 3 – Antenna/TX Subsystem

This chapter describes the Antenna/TX subsystem and sets forth the requirements for this subsystem. The Antenna/TX subsystem consists of two antennas and a transmitter (TX) subassembly. The primary antenna is a deployable dipole antenna used for the transmission and reception of the basic sounder signals. The clutter cancellation monopole antenna is a low efficiency antenna with a null in the nadir direction which is used in a receive only mode for clutter cancellation and the passive ionospheric sounding mode. The transmitter is connected to the primary antenna via a suitable impedance matching network for the transmission of the sounding pulses. The transmitter and antenna subsystem design requirements are viewed as a single combined set of requirements because the performance characteristics of antennas and transmitter (along with those of the matching network) are intimately related to the overall system performance of the radar sounder.

The block diagram of the Antenna/TX subsystem is as shown below. The Antenna/TX subsystem consists of three main components: 1) A deployable dipole antenna or primary antenna with preamplifier, 2) a deployable clutter cancellation monopole antenna with preamplifier, and 3) a transmitter with matching network.

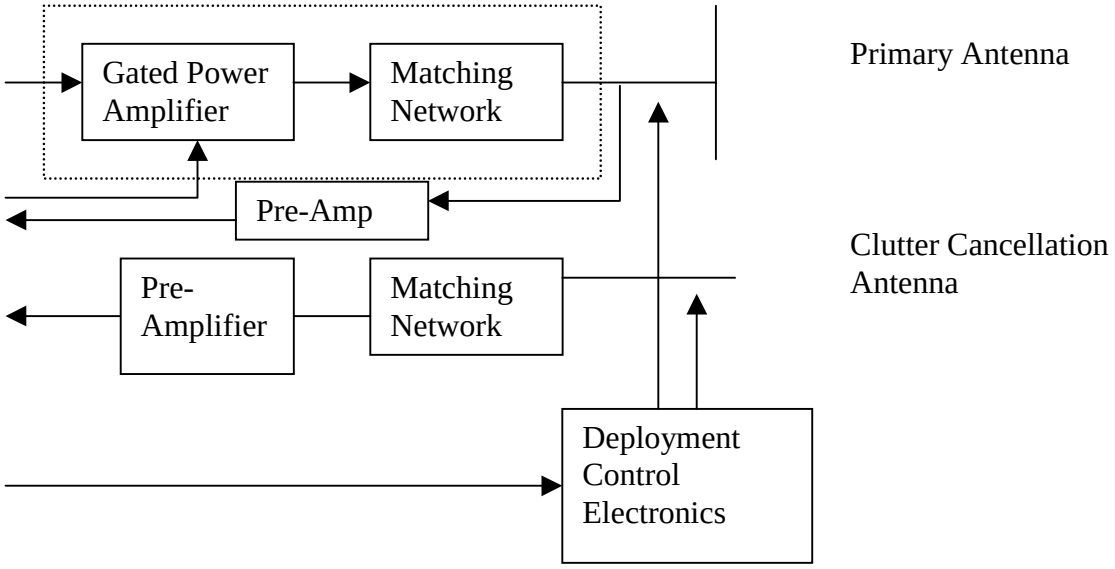


Figure 3.1 Antenna Subsystem Block Diagram

3.1 Antenna

3.1.1 The primary antenna shall consist of a deployable structure configured as a dipole with a radiation gain peak in the local nadir direction.

The antenna will interface with the transmitter/matching network and radiate in a vacuum environment.

3.1.2 The design of the antenna shall allow for operation over the 1.3 to 5.5 MHz range.

3.1.3 The antenna shall also be capable of operating down to a frequency of 0.1 MHz at reduced efficiency for ionospheric sounding.

3.1.4 Each dipole element shall be 20 meters in length.

3.1.5 The monopole element shall be a minimum of 5 meters in length.

3.1.6 The monopole shall consist of a deployable structure whose radiation null direction is in the local nadir direction.

This is a receive-only antenna with efficiency not considered a design factor. A high impedance low noise preamp is included with this antenna. In order to have sufficient sensitivity, due to severe limitations in available mass, a new self-deploying type of antenna will be used for the MARSIS dipole and monopole elements

3.1.7 The combined mass of dipole and monopole elements plus deployment containers shall be no greater than 7.5 kg.

3.1.8 Based on known spacecraft accommodation constraints, the antenna containers (preferentially packaged as a single unit) shall be mounted on the outside of the spacecraft near the bottom (engine end) of the +Y Lateral Wall as defined in the Mars Express PID -A.

The antenna deployment control consists of three pyrotechnic release mechanisms. For deployment, the associated pyro circuit will be enabled by the spacecraft as part of a special antenna deployment operation.

3.1.9 The polarization of the monopole antenna in the cross track direction shall be the same as the polarization of the primary or dipole antenna. The direction of the null and its variation with frequency is considered important and shall be kept to within 3 degrees or less in the spacecraft roll direction.

3.2 Transmitter

The transmitter, with its associated matching network, provides the amplification and high RF power necessary for radiation from the primary antenna. A gating function turns off the amplifier electronics after transmission during the reception of the surface, subsurface or ionosphere echoes.

3.2.1 The TX electronics shall be packaged within the available accommodation volume. *The current accommodation volume is 620 mm by 150 mm by 90 mm.*

3.2.2 The TX unit shall be mounted with one end of the unit near to the center of the antenna subassembly for electrical connection.

3.2.3 The TX electronics assembly shall not exceed 2.6 kg in total mass.

3.2.4 The nominal operating frequency and bandwidth of the Antenna/TX subsystem in the subsurface sounder modes shall be consistent with Requirement 2.2.3

The instantaneous bandwidth required is 1 MHz or greater for the subsurface sounding modes and 10 kHz for the ionospheric sounding. The operating frequencies in each of the bands are:

Subsurface Band 1	*1.3 to 2.3 MHz*
Subsurface Band 2	*2.5 to 3.5 MHz*
Subsurface Band 3	*3.5 to 4.5 MHz*
Subsurface Band 4	*4.5 to 5.5 MHz*
Ionospheric Band	*0.1 to 5.5 MHz*

3.2.5 The minimum average radiated power from the Antenna/TX subsystem shall meet the following requirements in the various frequency bands (mid-band):

Band	**Radiated Power (W)**
Subsurface Band 1	3.0
Subsurface Band 2	10.0
Subsurface Band 3	10.0
Subsurface Band 4	10.0
Ionospheric Band	10.0

Average radiated power is defined as the integrated power radiated divided by the transmit pulse duration. The radiated power is defined as the total power in the far field integrated over a sphere around the antenna.

3.2.6 The transmitter shall be designed for a duty cycle of 10 percent.

The subsurface sounding operates at a basic pulse repetition interval of 8 milliseconds and two transmit events of 250 microsecond duration.

3.2.7 The nominal transmitted signal shall be one of the following pulse sequences:

1. A single 250 microsecond transmitted pulse at the beginning of the interpulse interval.

2. Two 250 microsecond transmitted pulses separated by TBD microseconds at the beginning of the interpulse interval or
3. Four 30 microsecond transmitter pulses separated by TBD microseconds at the beginning of the interpulse interval.

The transmitter signal from the RF subsystem consists of a linear frequency modulated waveform with a 1 MHz bandwidth covering the frequency bands defined in Requirement 2.2.1.

3.2.8 The time jitter of the transmitted waveform shall be less than 50 nanoseconds from pulse to pulse.

3.2.9 The transmitted waveform amplitude and phase shall be consistent with the requirements set forth in Requirement 2.2.11.

The maximum amplitude of the ripple and phase deviation of the ripple across each of the bands must be in the following range:

Cycles across Spectrum	***Amplitude (percent)***	***Phase (degrees)***
2	*5.01*	*5.71*
3	*2.33*	*2.65*
4	*1.08*	*1.23*
5	*0.50*	*0.57*
6	*0.23*	*0.27*
7	*0.11*	*0.12*
8	*0.05*	*0.06*

It is acceptable to trade off errors in amplitude against phase errors.

3.2.10 The transmitter shall be designed to work over a load presenting any VSWR.

3.2.11 The maximum quiescent power required by the transmitter shall be 1.5 watts or less.

3.2.12 The transmitter shall be designed to operate in an environment as specified in the PID-A.

3.2.13 The Antenna/Transmitter switching requirements are:

Parameter	**Requirement**
Antenna Switching Networks Routing Requirement	Transmit Signal to Antenna Return from Antenna to Receiver
Antenna Switching Networks Frequency Response Requirement	0.1 MHz to 5.5 MHz
Antenna Switching Networks	50 μsec max

Switching Time Requirement	
Antenna Switching Networks Lifetime Requirement	some very large number
Antenna Switching Networks Switch Operation Selection Requirement	TX/RX Control Signal (true => TX / false => RX)
Antenna Switching Networks Port Isolation Requirement	TX to RX > 60 dB

The antenna and transmitter are to be used in a radar instrument where rapid switching between a high transmitter power to a highly sensitive receiver is of paramount importance.

3.2.14 The TX subassembly shall receive 28-volt DC power from the spacecraft LCL through DES.

For the TX electronics to operate, a electronic opto coupler relay contained in the TX assembly must be enabled by the DES.

3.2.15 Deleted.

3.2.16 The following control signals from DES shall control the transmitter:

Function	**Description**	**Lines**
XMIT_SEL i	Transmitter Select	3
SUB_SEL	Subsurface Sounder Select	1
IONO_SEL	Ionospheric Sounder Select	1
IOPWR_CNTL i	TX Maximum Voltage Set	4
TXRXCM	Transmit/Receive Contrl	1
TXPS_SYNC	TX Power Supply Sync	1
PRE-AMPBLK	Preamp Blanking Pulse	1
ON-OFFCMD	Power Relay Control (TX on/off)	1

3.2.17 Isolation between the DES and transmitter shall be accomplished through optocouplers located in the TX subassembly, with the exception of TX Power Supply Sync.

3.2.18 TX Power Supply Sync shall be transformer-coupled.

3.2.19 The Transmitter subassembly shall provide four conditioned signals to the RF electronics via preamplifiers.

Function	**Description**	**Signal Characteristic**
PRAMP1_OUT	Monopole Signal Out	50 Ohms, 0 dBm
PRAMP2_OUT	Subsurface Band 1 Out	50 Ohms, 0 dBm

PRAMP3_OUT	Subsurface Bands 2,3, and 4	50 Ohms, 0 dBm
PRAMP4_OUT	Ionospheric Band	50 Ohms, 0 dBm

3.2.20 The TX subassembly shall receive from the RX a signal designated LFTXSI, which is the output of the digital chirp generator (50 Ohms, +6 dBm, transformer-coupled).

Chapter 4 Digital Subsystem

The Digital Electronics Subsystem consists of two separate sections. The Timer, Control and Signal Generator Section, which controls the functions of the sounder, and the Processing Electronics Section which generates the processed sounding data and delivers them to the spacecraft.

4.1 Timer, Control and Signals Generation Section

The functions of Timer, Control and Signals Generation Section are:

1 interface with the spacecraft command and control subsystem,
2 generate the stable RF signal for use by the RF subsystem,
3 generate the stable timing signals for use by the RF and digital subsystems and
4 provide any necessary low rate engineering telemetry for diagnostics to the spacecraft.

The Sounder Timer Control and Signals Generation Section (TCSGS) controls the operation of the various modules in MARSIS, acquires housekeeping telemetry from these modules, generates all the necessary timing functions for the instrument, including the stable local oscillator, and provides the data interface with the spacecraft. Instrument operation, as commanded from the spacecraft, is under the management of TCSGS. In addition it provides the secondary voltage lines to whole instrument. The Digital Chirp Generator also resides within the TCSGS.

4.1.1 The Digital Chirp Generator Module's output power level shall be 0 dBm $\pm$ 0.5 dB when used in any mode.

4.1.2 The Digital Chirp Generator Module's bandwidth shall be 1 Mhz for all subsurface sounding modes except data acquisition. The frequency limits of each transmitted signal are in compliance with the frequency limits set forth in 2.2.1.

4.1.3 For the signal acquisition mode, the bandwidth shall be 0.2 Mhz.

4.1.4 The center frequency shall be consistent with Requirement 5.2.1.

4.1.5 The duration of the digital chirp frequency generator shall be programmable in the range of 10 to 350 microseconds.

4.1.6 The Digital Chirp generator shall also be capable of generating a continuous wave (CW) for use as a reference signal oscillator.

4.1.7 The duration of the signal generation when used in the CW mode as a reference signal shall be at least 350 microseconds.

4.1.8 In the active ionospheric mode, the Digital Chirp generator signal shall have programmable frequency range of 0.1 to 5.5 MHz, in compliance with Requirement 2.2.2.

4.1.9 In the active ionospheric mode, the constant frequency duration shall be 95 $\pm$ 5 microseconds in compliance with Requirement 2.2.10.

4.1.10 In the active ionospheric mode, the number of frequencies per sweep shall be 160.

4.1.11 The frequency stability of the DCG shall be better than 1 part per million.

4.1.12 The TCSGS shall provide the RF subsystem with two identical clock signals to drive the Analog to Digital Converters at a frequency of 2.8 MHz with a 50% $\pm$ 5% duty cycle.

4.2 Processing Electronics

The Digital Electronics Subsystem contains the Processor Electronics Section (PES) for converting the digital signals converted by the RF subsystem to processed data for telemetry to the ground. This processor operates on both receive channels each of which may contain multiple sets of data.

4.2.1 PES shall be able to process the digitized signals acquired by the sounder into sounding traces for transmission to the ground by the spacecraft data system as defined by the requirement in this document.

4.2.2 The processor, in response to mode control from the Sounder Timer, Control and Signal Generation Section, shall be capable of performing the functions as described below.

	Off	CHECK/INIT	Standby	Idle	WA-UP1	WA-UP2	Operational
Processor State	Off	Off	On	On	On	On	On

4.2.3 The subsurface sounding sub-modes as described in section 2.1.9 shall be processed.

Science data are processed according to the algorithms herein presented, packetised and transferred to the platform through the Science Data Handling Module.

4.2.4 The processing functionalities shown in figure 4.2.1 shall be implemented and made available for any of the subsurface Sounding sub-modes defined.

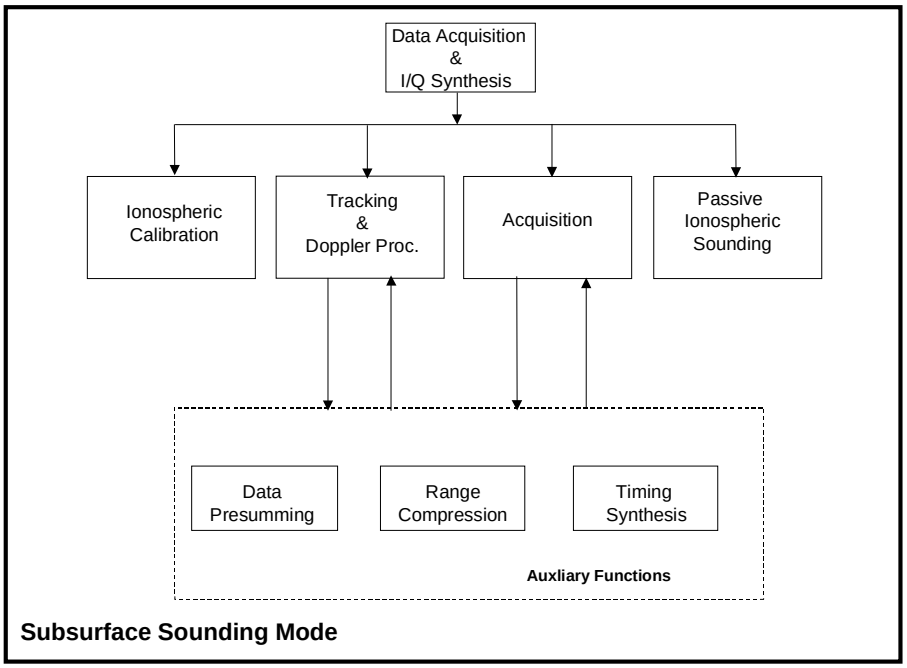


Figure 4.2.1 Subsurface Sounding Processing Functionalities

Within the "Acquisition" and " Tracking & Doppler Processing" functions the auxiliary functions "Data Presumming" , "Range Compression" and "Timing Synthesis" are common auxiliary functions used in support of the "Acquisition" and "Tracking/Doppler" Processing functions.

4.2.5 In the Sub Surface Sounding Mode the DES shall acquire digital data from either or both of the two RF channels.

4.2.6 In the Sub Surface Sounding Mode the DES shall convert the real range offset video to In-Phase/Quadrature (I/Q) format.

The processor for data processing will use this data.

4.2.7 PES shall be able to perform range tracking in order to determine the Time of flight (TOF) of the signal.

4.2.8 PES shall be able to use the TOF measurement to appropriately set the receiver delays time.

4.2.9 PES shall be able to compensate for the spacecraft radial velocity before aperture synthesis.

4.2.10 PES shall be able to track the power level of the signal and adjust the AGC settings.

4.2.11 PES shall be able to detect “bad tracking conditions”.

4.2.12 In case of “bad tracking conditions”, PES shall be able to command the DES back in to the acquisition phase to properly re-establish the tracking operations.

4.2.13 The option to disable the Loss of Lock Logic algorithm shall be implemented.

Ionospheric calibration is required to compensate for the frequency dependent time dispersion due to the Ionosphere at the time of subsurface data acquisition.

4.2.14 The Ionospheric Calibration data shall be obtained from the Dipole Channel received echoes at the frequencies selected for the Sub-Surface sounding submode.

4.2.15 The calibration of delay vs. frequency (dispersion) shall be applied to the dipole channel.

4.2.16 In the ionospheric calibration process, PES shall not introduce any jitter which is greater than 0.5 μs in the compressed signal.

This is to maintain frame to frame alignment for submodes which involve the multilooking operation.

4.2.17 PES shall be able to compensate for the delays introduced by the hardware at the aperture synthesis phase.

4.2.18 Data Presuming. For Sub Mode 5, Intrapulse Data Presuming shall be implemented to allow a coherent presuming, on a sample by sample basis, of the radar echoes available within the Pulse Repetition Interval.

4.2.19 PES shall be able to perform range compression on the return echoes to compensate for the dispersion of the returns due to the transmitted pulse.

4.2.20 Pulse compression shall be based on the digital matched filtering approach.

4.2.21 In the Sub Surface Sounding Mode, raw data collection shall be optionally operated for the acquisition of unprocessed data subsets during the synthetic aperture synthesis.

The purpose of the acquisition phase is to provide a coarse measurement of the radar signal time of flight (TOF) and echo power level for AGC setting in the receivers so that tracking can be started.

4.2.22 Multilook Averaging. For submode SS2, the output of the Doppler filters shall be power detected and combined prior to transferring to the science data packets.

4.2.23 Multilook Averaging. For submode SS2, the output of the Doppler filters shall be range-migrated to achieve range-alignment at a prescribed range.

4.2.24 Two passive noise measurement data sets shall be acquired on each interpulse interval either from either the Dipole or from the Monopole channel exclusively according to the DES configuration parameters using two out of the five receiver bandwidths available for this task.

Purpose of the Ionospheric sounding Mode is to provide detailed Ionosphere characterization through synthesis of Ionograms.

4.2.25 Active Ionospheric sounding shall be operated at the basic pulse repetition interval in agreement with Requirement 2.2.4.

4.2.26 Active Ionospheric sounding shall be operated at altitudes below 1120 kilometers.

4.2.27 Ionospheric Sounding Data shall be acquired from the Dipole channel.

4.2.28 Ionospheric sounding data shall be available as a real data stream as specified in Section 5.4.

4.2.29 The processor shall allow 8 bits per real data sample when coherent data is in the frequency domain.

4.2.30 In the passive ionospheric mode, the processor shall provide 256 linearly spaced frequency samples over the 0.1 to 5.5 MHz band.

4.2.31 The processor shall allow 16 bits per real data sample when coherent data is in the time domain.

Chapter 5 RF Electronics Subsystem (RFS)

The RF Electronics Subsystem - Receiver (RFS-RX) is an assembly mounted inside the spacecraft instrument bay on two mechanical slices and in physical contact with the Digital Electronics Assembly. The RF Electronics receiver consists of the CHIRP/LO distribution and the dual channel receiver, which down converts the returned echo from the dipole and monopole to baseband prior to conversion to digital form by the A/D converters.

The RFS-RX consists of a power divider, switches, two selectable bandpass filter banks, two amplifiers, two mixers, two lowpass filters, two Analog to Digital Converters, which provides for two receiver channels and CHIRP/LO power division. Figure 5-1 shows the RFS block diagram.

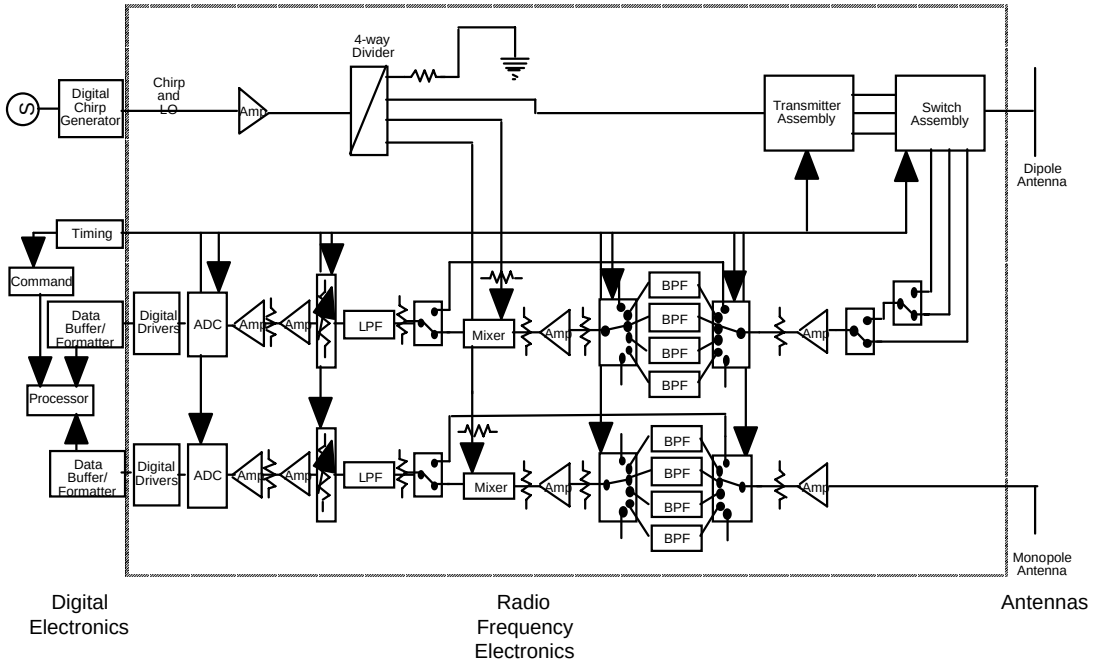


Figure 5-1*. RFS block diagram.*

5.1 Frequency Plan

The following table shows the IF frequency ranges and Local Oscillator frequencies for operation in the modes described in Chapter 2.

***Table 5-1.1**. Frequency plan.*

frequency band description	*RF frequency range (MHz)*	*IF frequency range (MHz)*	*LO frequency range (MHz) TBC*
Band 0 (ionospheric)	*0.1 to1.3*	*0.1 to 1.3*	*N/A*
Band 1	*1.3 to 2.3*	*0.1 to 1.3*	*2.5**
Band 2	*2.5 to 3.5*	*0.2 to 1.2*	*2.3*
Band 3	*3.5 to 4.5*	*0.2 to 1.2*	*3.3*
Band 4	*4.5 to 5.5*	*0.2 to 1.2*	*4.3*

** Down Chirp instead of Up Chirp in the DCG or Processor for Band 1 frequencies 1.3 MHz to 2.3 MHz using LO frequency of 2.5 MHz. (for Band 1 frequencies 2.3 MHz to 2.5 MHz using LO frequency 3.3 MHz (TBC))*

5.2 Bandpass Filters

5.2.1 A bandpass filter *shall* be selectable for each receiver channel, as described in section 2.1.2, during each sounding band as shown in Table 5.2.1.

Table 5.2.1. Receiver Bandpass Filters Requirements.

Center frequencies	1.8/3.0/4.0/5.0
3-dB Bandwidth	1.2/1.0/1.0/1.0
10-dB Bandwidth	1.5/1.3/1.3/1.3
Out of Band Rejection	40 dB at 1 MHz from center frequency
Ripple Requirement	1.0 dB in central 80% of 3 dB BW

The filter for Band 1 has a larger bandwidth to allow the frequency range 2.3 MHz to 2.5 MHz to be in the passband during the ionosphere-sounding mode.

5.3 Receiver Requirements

The receiver requirements stated in this section are for the RFS-RX section which excludes the front end amplifier in the Antenna Subsystem which is covered in Chapter 3.

The RFS-RX requirements for the ionosphere mode and the sounding mode are the same, except as noted in Table 5.3.1.

5.3.1 The RFS-RX requirements are shown in Table 5.3.1, Table 5.2.1 and 5.3.2.

Table 5.3.1 Receiver requirements.

Parameter	Units	Mode	Value	Accuracy *	Knowledge **
Frequency Range	MHz	Ionosphere	0.1 to 5.5	N/A	N/A
Input Power Range	dBm	Sounding	-128 to –36	N/A	N/A
Receiver Gain	dB	Sounding	50 dB nominal (TBC)	3	1
Receiver Gain Control	dB	Sounding	28 dB total in 4 dB steps	1	1
Baseband Offset Center Frequency	MHz	Sounding	0.7	0.05	0.05
Amplitude Transfer Function across Operating Band	dB peak to peak	Sounding	2 in central 80% of 3 dB BW	N/A	N/A
Phase Transfer Function across Operating Band	Deg deviation from quadratic	Sounding	30 over center 80% of 3 dB BW	N/A	1
Receiver Intermodulation Requirements	DB	Sounding	2^{nd} and 3^{rd} Harmonic 24 dB below ADC Maximum output	N/A	N/A
Receiver Relative Group Delay (difference between the 2 channels)	ns	Sounding	20	TBD	TBD
Noise Figure	dB	Sounding	<12 at nominal gain	N/A	N/A
Mixer Local Oscillator Frequency	MHz	Sounding	2.5/2.3/3.3/4.3	0.00001	0.00001
Mixer Local Oscillator Noise	dBc	Sounding	<-33	N/A	N/A

* Accuracy for full operating range as defined in Chapter 2 of MEX-MMT-SP-0007

** Knowledge after receiver temperature compensation

Table 5.3.2 Receiver Front-end Requirements.

Parameter	Requirement
Receiver RF Center Frequency Requirement	3 MHz
Receiver RF Front-end Filter Bandwidth Requirement	6 MHz
Receiver Protection Requirement	60 dB provided by T/R switch
Leakage Calibration Requirement	No calibration requirement

5.3.2 The receiver's high order amplitude and phase error requirements shall be consistent with the overall system sidelobe Requirements given in 2.2.11. The uncorrected sidelobes due to amplitude and phase deviations from the ideal shall not be greater than 6 dB below the system sidelobe requirements.

The amplitude of the ripple and phase deviation of the ripple across each of the bands must be in the following range:

Cycles across Spectrum	***Amplitude (percent)***	***Phase (degrees)***
2	*5.01*	*5.71*
3	*2.33*	*2.65*
4	*1.08*	*1.23*
5	*0.50*	*0.57*
6	*0.23*	*0.27*
7	*0.11*	*0.12*
8	*0.05*	*0.06*

It is acceptable to trade off errors in amplitude against phase errors.

5.3.3 The receiver subsystem third order intercept point shall be greater than +6 dBm.

5.3.4 The receiver recovery time from a –10 dBm 250 microsecond transmit event shall be less than 200 microseconds. Receiver recovery is defined as the point in time after the end of a transmit event where the excess noise contribution from the receiver in the 200 kHz to 1200 kHz spectral range is less than –110 dBW (-80 dBm) at the receiver input for any receiver gain.

5.3.5 Any transient signal due to the transmit event which is added to to the received signal shall not drive the receiver to its non-linear region.

5.3.6 The receiver front end shall not be damaged to an input signal at the antenna terminals of –10 dBm.

5.4 Analog to Digital Converter

5.4.1 The ADC *shall* provide an 8-bit logic output.

5.4.2 The ADC maximum input *shall* be <= +6 dBm.

5.4.3 The sampling frequency shall be 2.8 MHz.

5.4.4 The minimum dynamic range of the ADC shall be 33 dB.

5.4.5 The RFS *shall* provide 8-bit digital sample data to the DES for each of the 2 receiver channels for a total of 16 bits.

5.5 Interfaces

The detailed interfaces are described in the MARSIS Interface Control Document and the description contained therein shall take precedence. The principal interfaces are documented here for reference purposes only. The RFS receives the chirp waveforms and local oscillator frequency signals from the DES. The chirp waveforms are routed to the transmitter for amplification and the local oscillator frequency signals are routed to the receiver channel 1 and 2 mixers local oscillator inputs.

All RFS control signals originate from the DES. These control signals consist of but not be limited to the following types:

DCMOD signal(s) for controlling the transmitter bias.
TXRXCM signal for indicating whether transmit timing or receive timing is active.
FILTER_SEL signals for selecting the correct bandpass filter and thus correct frequency band for both receiver channels.
ATTEN_SEL signals for selecting the correct gain value for both receiver channels.

5.5.1 DC Power. The maximum DC power used by the RF Subsystem shall be 3 watts.

5.5.2 The RFS shall provide a transmit pulse of the appropriate amplitude and frequency to the dipole antenna at the correct time under control of the DES.

5.5.3 The channel one of the RFS shall receive echos from the dipole antenna for amplification, eventual down-conversion and sampling.

Proper frequency band selection is under control of the DES.

5.5.4 Channel two of the RFS shall receive echo returns from the monopole antenna for eventual down-conversion and sampling.

5.5.5 The maximum mass of the RF subsystem shall be TBD Kilograms.

The RFS mechanical interface requirements are provided in Chapter 8 of the MARSIS PID-B (ID-MAR-0002-INF).

The RFS thermal interface requirements are provided in Chapter 9 of the MARSIS PID-B (ID-MAR-0002-INF).

Chapter 6 – Ground Data Processing

6.1 Description

The processing of the sounding data acquired by the MARSIS subsurface sounder is performed on board the MARS Express spacecraft because of the limited downlink rate available. The MARSIS ground segment will be located at the Mars Express Science Operations Center (MESOC). MARSIS ground operations has five main tasks to support MARSIS operation while in orbit around Mars. These are:

1. Analysis of limited raw data sent from MARSIS to the operations center for updating processing parameters on board the spacecraft. This is data acquired in the calibration mode.
2. Monitoring the status of the experiment.
3. Quick look analysis of processed data and
4. Detailed processing including quantitative and spatial analysis of received data and clutter correction of data acquired with the clutter cancellation channel. This is also known as Primary and Secondary Data Products.
5. Generation of Mosaicked Global Data Products.

6.2 Calibration Data Processing

During the on-orbit checkout phase of the operations and for a limited duration during each orbital data pass, data is acquired by the MARSIS experiment is a raw form, bypassing the data processor. Data acquired in this form is known as calibration mode data. A description of this mode is in Requirement 2.1.8.

6.3 Experiment Status Monitoring

Prior to the analysis of processed data, it is planned to monitor the health of the instrument by analyzing the housekeeping source packets. The purpose of this analysis is to provide the state of the instrument prior to data analysis. Included in this analysis is determination of instrument temperatures, gain states for any calibration requirements.

6.4 Quick Look Analysis Processing

The quick look processing capability will provide for rapid scientific analysis of data acquired during a single orbit data pass. The following tools shall be provided for this capability:

1 A vertical profile of return echo strength vs time for each channel
2 Mapping of surface reflectivity, roughness and altitude for each channel

3 Spectrogram plots of ionospheric echo strengths and time delay vs. frequency.

Within each tool, the following capability shall be provided:

1 Zoom capabilities for detailed examination of data.
2 Superimposing of data from any channel with a time delay selection for ionospheric delay correction.
3 Export capability of any data set for analysis by other tool sets.
4 Print out capability of any data set.

6.5 Data Product Generation

The principal data products generated by the MARSIS Ground Data Processor shall be the Primary and Secondary Data Products. The Primary Data Product shall consist of a sequence of echo profile sets from a single orbital pass of the MARSIS instrument for each of the channels acquired during that orbital pass. This data product will have attached ancilliary spacecraft data such as spacecraft ephemerides, local time of day obtained from data headers as well as processed information showing the location of each footprint on the surface of Mars. This data set will be in digital format to allow further processing.

The secondary data products shall have an identical format as the Primary Data Product but will have surface clutter removed from the data set. This data product will be limited to one per frequency acquired from the orbital pass since the clutter cancellation channel data will have been used to remove surface clutter.

6.6 Mosaicked Global Data Products

The generation of mapped global data products will be possible in the later stages of the MARSIS Ground Data Processing Operations.

Chapter 7 - Mission Operations

7.1 Description

Chapter 8 – Test Requirements

8.1 Description

This section describes the top level test requirements for the MARSIS instrument and provides a matrix for testing or verification of the principal parameters of the sounder instrument. Due to the nature of the sounder, it is not possible to test for all the parameters directly. Verification of performance parameters may be done by:

I – Inspection
A – Analysis
T – Test

At the module, sub-assembly, system or integration levels.

Index

Appendix A – Acronymns

The following is a list of acronymns used in this document:

A/D	Analog to Digital (convertion)
ADC	Analog to Digital Converter
AGC	Automatic Gain Control
ANC	
ANS	
ANT	Antenna
AS	Antenna Subsystem
BW	Bandwidth
CF	Center Frequency
CW	Constant Wave
dB	Decibel
DC	Direct Current
DES	Digital Electronics Subsystem
DFT	Direct Fourier Transform
DMS	
ESA	European Space Agency
FFT	Fast Fourier Transform
HW	Hardware
INFOCOM	
I/Q	In Phase/Quadrature
IFFT	Inverse Fast Fourier Transform
KHz	KiloHertz
LCL	Latching Current Limiter
LO	Local Oscillator
MARSIS	Mars Surface and Ionospheric Sounder
MDE	
MESOC	Mars Express Science Operations Center
MHz	Megahertz
MMS	Matra Marconi Space
N/A	Not Applicable
NCO	Numerically Controlled Oscillator
NPM	Noise Power Measurement
OBT	On Board Time
OP	Operate mode
OST	Operations Sequence Table
PID-A	Payload Interface Document – A
PID-B	Payload Interface Document - B
PRI	Pulse Repetition Interval
PT	Parameter Table
PW	Pulse width
RF	Radio Frequency

RFS	Radio Frequency Subsystem
RMS	Root Mean Square
RSS	Root of Sum of the Squares
RX	Receiver section
S/C	Spacecraft
SS	Subsurface Sounding (Mode)
SSRA	Subsurface Sounding Radar/Altimeter
STALO	Stable Local Oscillator
STC	Sounder Timer and Controller
TCSGS	Timer, Control and Signals Generation Section
TM	Telemetry
TOF	Time of Flight
TTMT	Time-Tagged Macrocommand Table
TX	Transmitter Section