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The Ground System of the SHAllow RADar (SHARAD) Experiment

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Abstract. A primary scope of Mars exploration is the research of underground water. Knowledge of water and ice quantity and distribution has enourmous impacts on our understanding on gelogic, hydrologic and climate evolution of Mars and of its origin. To this aim, high resolution observations of geophysical parameters can address these items expecially when conducted by means of penetrating radar systems orbiting around the planet, due to their intrinsic capabilities to detect underground water/ice. In this framework, SHARAD (SHAllow RADar) on-board NASA's Mars Reconnaissance Orbiter (MRO) assumes a key role within Mars exploration activities. SHARAD is a wideband radar sounder transmitting at a centre frequency of 20 MHz within 15-25 MHz spectral range. SHARAD has been launched on August '05 and will start its nominal observation phase from November '06. To guarantee its operations, commands and data analysis and processing, the SHARAD Ground Data System (GDS) has been designed and developped. SHARADA GDS is a ground system equipped with ad-hoc sw tools to allow instrument operations and data processing during the two-year mission duration. The present paper is focused on SHARAD GDS description of its architecture and of instrument planning, commanding and data processing sofwtare tools.

Key words. Space vehicles: instruments – Techniques: radar astronomy – Planets and satellites: individual: Mars

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1. SHARAD Instrument Overview

The SHAllow RADar (SHARAD) experiment (Seu et al. 2004) is a sub-surface sounding radar provided by the Italian Space Agency (ASI) as a facility instrument to NASA's 2005 Mars Reconnaissance Orbiter (MRO) (Graf et al. 2005). SHARAD is a wideband radar sounder transmitting at a centre frequency of 20 MHz. The bandwidth of the radar pulse is equal to 10 MHz.

The transmitted waveform is a chirp, a long pulse that is linearly modulated in frequency. The chirp allows a resolution that depends on the bandwidth of the pulse rather than on its duration, but requires processing of the received signal: with a bandwidth B, the approximate time resolution of the output pulse, after processing, is 1/B. The 10 MHz bandwidth of the transmitted pulse provides a theoretical range resolution of 15 m in free space propagation.

Horizontal resolution is 300-1000 m along-track, and is achieved by means of a conventional focused synthetic aperture processing, compensating for the spacecraft radial and tangential velocities and a possible average slope of the observed surface. Horizontal resolution across-track is 1500-8000 m, depending on spacecraft altitude and terrain roughness.

In Tab. 1, SHARAD main characteristics are summarized.

The primary objective of the SHARAD investigation is to map, in selected locales, dielectric interfaces to depths of up to one kilometer in the Martian subsurface and to interpret these interfaces in terms of the occurrence and distribution of expected materials, including rock, regolith, water, and ice.

SHARAD can be operated in different Operational (or Measurement) Modes. An operational mode corresponds to an action that the instrument may perform under the guidance of OST entries. Each OST entry specifies details for the transition to, and the execution of, a given Operational Mode. Telemetry is always generated during Operational Modes and monitoring is active. In case of other error or anomalies during Operational Modes processing, an automatic transition is performed to Safe/Idle State. Two main operational modes are envisaged, Subsurface Sounding (SS) Mode and Receive Only (RO) Mode.

Subsurface Sounding Mode is the main measurement mode for SHARAD. In this Mode the instrument shall perform scientific measurements by transmitting radar pulses and collecting, processing and formatting received echoes. Pulse repetition interval and duration are variable depending on parameters specified in each OST entry. A variable Science Data rate will be produced in this Mode depending on the specific processing parameters.

Receive Only Mode is used to perform passive measurements mainly during the on-orbit phase, but can also be used to check the performances of the instrument during the cruise phase (even with the antenna folded). No transmissions will be performed. A variable Science Data rate will be produced in this Mode depending on the specific processing parameters.

2. SHARAD GDS Description

The SHARAD Ground Data System (GDS) is the element of the Internet-distributed architecture defined for controlling and monitoring the instrument, and for receiving and processing the downlinked Science Data.

From a network point of view, SHARAD GDS exchanges data fromt/to JPL/NASA and ASI sites. Information on S/C orientation and trajectory and on MRO payloads activities as well as S/C and instrument telemetries, are retrieved from MRO ground data system (GDS) sited at JPL, while planning and commanding files are sent to MRO GDS. On the other hand, processed data files are delivered to the ASI Data Center (ASDC) of the Italian Space Agency. Relationship between the entities directly involved with the SHARAD GDS is performed entirely via the Internet public network. All communications are performed via file exchanges and/or via E-mail messages.

From a functional point of view SHARAD GDS has to fulfil the following main activities:

- *Planning and commanding*, aimed at flight instrument operation definition taking into account S/C constraint (in terms of bit rate, data volume, power budget) orbital information and Mars surface characteristic. This functionality will be provided by Planning Tool and Commanding Tool.

Table 1. SHARAD main characteristics

Parameter	Value
Vertical resolution	15 m
Horizontal resolution	300-100 m along ground track, 1500-8000 m across ground track
Depth of penetration	100's of meters, up to $\approx$ 1 km
Antenna efficiency	> 10 %
Center frequency	20 MHz
Radiated peak power	10 W
Pulse length	85 μs
Pulse bandwidth	10 MHz
Pulse repetition frequency	335, 350, 387.6, 670, 700, 775 Hz

- *Instrument checking*, devoted to verify the health status of the instrument; from a engineering point of view (Monitoring Tool), and from instrument performance point of view (Quick Look Tool).
- *Data processing*, devoted to a scientific product generation. Namely, two levels of processing and PDS generation are envisaged.
- *Archiving*, devoted to data storing and extraction into/from GDS Repository.
- *External entities data exchange*, aimed at data retrieving and submission from/to external entities.
- *Supervision*, aimed at GDS status check, either HW and SW, and mission status check.

Starting from the functional activities and following a top-down approach, the GDS architecture has been design in order to be composed of the following main subsystems:

- *Data Archive Subsystem*, composed by the necessary resources, procedures, events and sw to execute mission data archiving, browsing, and administration tasks.
- *I/O Manager Subsystem*, composed by the necessary resource, procedures, events and sw to execute data/file retrieving/submission from/to external entities management.
- *Mission Operation Subsystems*, composed by the uplink/downlink subsystems, processing subsystems and supervisor subsystems.

The uplink/downlink subsystems consist of all resources, procedures and events about uplink/downlink phase are managed by these S/Ss and by the following dedicated sw tools::

- Planning tool (PLN)
- Commanding tool (CMD)
- Monitoring and L1A tool (MON)

The processing subsystems consist of all resources, procedures and events about monitoring,to process scientific and engineering instrument data are managed by these S/Ss and by the following dedicated sw tools:

- Quick-Look tool (QLK)
- Processing "Level1B" tool (L1B)
- Processing "Level2" tool (L2P)

The supervisor subsystems consist of all the information about mission status and SGS status are collected and visualized by these S/Ss, and particularly by the following dedicated tools

- System supervisor (SSP)
- Mission supervisor (MSP)

The SHARAD GDS architecture is depicted in Fig. 1. The architecture builds a distributed application in order to match all user requirements and operate according to external and internal interfaces constraints.

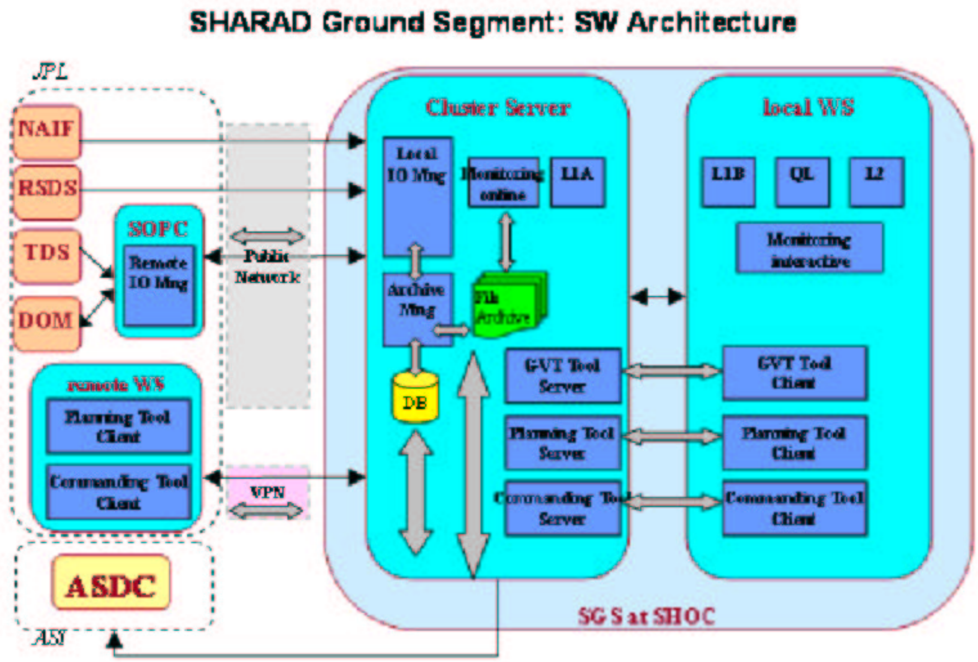

Fig. 1. SHARAD Ground Data System architecture

2.1. Planning Tool

The GDS Planning Tool is a software that analyze the feasibility of scientific requests for SHARAD instrument operations, optimize the radar utilization for scientific purposes, and consequently define the mission plan for the SHARAD instrument.

This tool is used to plan and schedule SHARAD operations all along the mission. Planning Tool main function is to generate a Payload Target File (PTF) in which are sequentially reported all instrument proposed operation modes.

SHARAD activities are planned taking into account spacecraft position and trajectory, other MRO payloads activities and on-board resources, Mars surface characteristics and scientific targets (Fig. 2).

PTF is compared with other instruments request and then, after some iteration if necessary for conflicts solving, it is integrated with all instrument requests to form the Integrated Payload Target File (IPTF).

Finally Payload Operations Support (POST) produces conflict-free IPTF to be used in the weekly planning.

The Planning Tool makes use of Graphical Use Interfaces (GUIs) to show s/c tracks, targets position and Mars surface characteristics, as well as planned timelines. On the basis of specific user needs, the Planning Tool allows also manual modification to be done.

The tool generates as output the timeline file. This plan is submitted to MRO GDS at JPL and, when approved, the MRO GDS uplinks to the spacecraft the binary file that contains the plans of all MRO payloads.

Planning Tool has been designed following a Client/Server architecture in which client side implements basically the graphical user interface services managing the interaction between user and the rest of S/S and system, while the Server side implements all services dedicated to extract and process data.

Client/Server architecture makes Planning functionalities accessible from remote sites through VPN connections reducing computational overload on the client and data flow through the network.

2.2. Commanding Tool

Once the payload observation plan has been approved, the uplink phase is characterized by the generation of command sequences to be executed by SHARAD. Commands are constituted either by single radar operational modes and radar parameters necessary to execute its onboard processing (Seu et al. 2004). In fact, the Commanding Tool generates two different kinds of files: one for operational modes (Operational Sequence Table files), where the approved timeline is traslated into instrument commands sequences, and one for parameters (Parameters Table files). To generate Parameters Table files, the tool basically estimates polynomial coefficients of sixth and seventh order polynomials approximating Mars surface topography and terrain slope trends over the area to be flown to allow radar to estimate its distance from Mars surface.

These commands files are submitted to MRO GDS that checks and uplinks them to S/C. Commanding Tool uses GUI interfaces to show results and allow users to manually modify commanding sequences and instrument parameters.

As for Planning Tool, Commanding Tool has been designed following a Client/Server architecture in which client side implements basically the graphical user interface services managing the interaction between user and the rest of S/S and system, while the Server side implements all services dedicated to extract and process data.

2.3. Monitoring/L1A Tool

After commands uplink, SHARAD begins data acquisition. Collected data are sent to the spacecraft and then transmitted to ground as telemetry files. The Telemetry files are collected from MRO GDS that makes them available to the GDS.

Two kinds of TM are foreseen: housekeeping (HK) TM, subdivided in S/C HK and SHARAD HK, and scientific TM. The HK TM contains information about instrument status, in terms of voltages, currents and other engineering parameters. The scientific TM are characterized by scientific contents related to the signals transmitted/received by SHARAD. During this phase (named Downlink phase), GDS performs a set of check on TM data. A first check is related to the instrument health assessment: critical engineering parameters are monitored and their incorrect behavior (for example, voltage values out of range) is highlighted.

Other checks regard the syntactic and semantic integrity of TM files, in term of corrupted or missing packets, and the coherence between commands really executed and commands generated during uplink phase. Then, the tool packs them into PDS Level 1A (L1A) data files (Hughes et al. 2004). Level 1A data consist of the instrument telemetry correlated with the auxiliary information needed to locate observations in space and time and to process data further.

2.4. Quick Look Tool

The Quick Look Tool is a GDS software specifically designed to perform SHARAD instrument performance analysis and an overall instrument monitoring. The tool can process L1A data products either when the instrument is operated in Receive-Only operative mode and in Sub-Surface operative mode. In case of Receive-Only operative mode, the Quick Look Tool evaluates power spectral density of the signal in order to give noise level estimation. In case of Sub-Surface operative mode, the tool performs a quick range compression processing and evaluates echo SNR. Monitoring SNR parameter, in fact, gives an idea on instrument current performance wrt the expected one.

Processed data can be visualised and plotted to allow data verification and comparison.

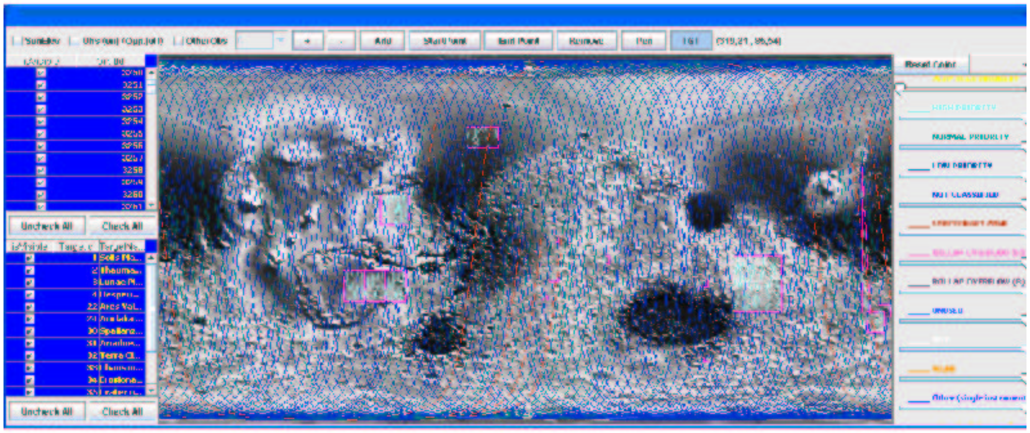

Fig. 2. Planning Tool GUI - MRO spacecraft ground tracks and targets

2.5. Level 1B Tool

The Level 1B Tool is the GDS sofwtare devoted to basically accomplish Range and Doppler processing in order to produce radargrams of Mars sub-surface. It generates as output PDS Level 1B data files.

SHARAD is quite different from a classic SAR, because Doppler bandwidth and centroid are stricly dependent on surface scattering. In particular Doppler bandwidth is a direct conseguence of surface roughness, while surface slope affects tightly Doppler centroid. This has lead to design the tool in order to perform an accurate Doppler parameters estimation (centroid and bandwidth) before starting processing chain. Moreover, realignment of each range line before Doppler parameters estimation and range Doppler processing has been faced to remove very high variability of receiving window position. The Chirp Scaling Algorithm has been adopted to perform data processing. Depending on Doppler bandwidth of the received signal, this algorithm can provide a maximum full resolution of 300 meters by compesating range migration effects.

Since a 55dB in signal dynamic is requested, each source of distortion (Mars ionosphere, on board noise) is compensated by the tool.

2.6. Level 2 Tool

The Level 2 Tool is devoted to calibrate L1B products and to provide additional informations to scientists. Image calibration is performed by means of radar equation using instrument parameters data either measured on ground test and \or during commissioning/calibration phase. User can select multi looking option in order to obtain a degradated resolution image that exibhits improved signal to clutter ratio. Tool is able to interface with MOLA topographic products in order to retrieve statistical parameters needed for simulating surface expected returns. This provides useful information to scientists to correctly interpretate real scientific data.

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