THE DIGITAL ELECTRONIC SUBSYSTEM OF MARSIS

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1. INTRODUCTION

MARSIS (Mars Advanced Radar for Subsurface and Ionospheric Sounding) is one of the Instrument of the ESA Mars Express mission, to be launched in June 2003 with a Soyuz/Fregate. Its primary objective is to map the distribution of water, both liquid and solid, in the upper portions of the crust of Mars. Secondary objectives are subsurface geologic probing, surface characterisation and ionosphere sounding.

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.

Functionally and also from the responsibility point of view of each organisation involved in MARSIS, the instrument can be split into three subsystems:

- Antenna: ANT
- Radio Frequency Subsystem: RFS (TX+RX)
- Digital Electronics Subsystem: DES

MARSIS is an international co-operation between Italian Space Agency (ASI) and National Aeronautics and Space Administration (NASA). The experiment has an Italian Principal investigator (from Infocom Dept. of University of Rome "La Sapienza"), an U.S. Co-PI (from Jet Propulsion Laboratory), and Co-I's from Italy, the U.S. and other countries.
Italy is the lead for the experiment definition with the participation of the U.S.. In particular Alenia Spazio/Rome is the Prime Contractor of the industrial team and also supplier of part of the RF subsystem.
Laben (a company of Finmeccanica) is the supplier of the Digital Electronic Subsystem (DES), including its basic and application SW, as subcontractor of ALS.

The purpose of this paper is to describe the DES from HW and SW point of view, including the Test Equipment and the special simulator developed used for DES validation.

2. SCIENTIFIC OBJECTIVES

There's plenty of evidence that water once flowed freely on the surface of Mars, however most of it cannot be detected nowadays. Many planetologists, believe that a lot of water must still be on Mars, locked into frozen or liquid underground reservoirs and the recent MGS results support this view. MARSIS (Mars Advanced Radar for Subsurface and Ionospheric Sounding) will set out to map underground water and ice.

The MARSIS primary objective is therefore to map the distribution of water, both liquid and solid, in the upper portions of the crust of Mars. Detection of such reservoirs of water will address key issues in the hydrologic, geologic, climatic and possible biologic evolution of Mars, including:

- the current and past global inventory of water,
- mechanisms of transport and storage of water,
- the role of liquid water and ice in shaping the landscape of Mars,
- the stability of liquid water and ice at the surface as an indication of climatic conditions,
- the implications of the hydrologic history for the evolution of possible Martian ecosystems.

Three secondary objectives are defined for the MARSIS experiment:

- subsurface geologic probing
- surface characterisation
- ionosphere sounding

3. INSTRUMENT DESCRIPTION

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. MARSIS can be effectively operated at any altitude lower than 800 km. In standard operative mode the instrument will be able to transmit any of the following bands: 1.3-2.3 MHz (centred at 1.8 MHz), 2.5-3.5 MHz (centred at 3 MHz), 3.5-4.5 MHz (centred at 4 MHz,), 4.5-5.5 MHz (centred at 5 MHz,).

A HW tree of MARSIS is reported in Fig. 3-1.

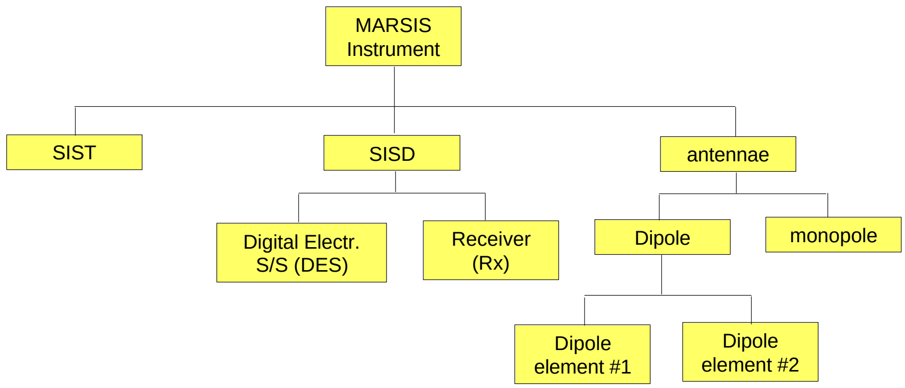

Fig. 3-1 MARSIS HW Tree

The Instrument allows a vertical resolution of 50-100 m in the subsurface, depending on the E.M. wave propagation speed in the crust. The typical spatial resolution will be 5÷9 Km x 10 Km in the along track and cross track directions respectively. In standard operative mode up to four echo profiles will be produced at intervals of ~ 1÷2 seconds (depending on the orbit altitude), resulting in a spatial sampling rate of ~ 5÷8 Km. The acquired profiles will be stored for download at a rate < 80 Kbit/sec. The possibility of downlinking raw data for small region of particular interest is also offered. Ground processing will extract from the downlinked profiles significant information on the surface topography and composition, as well as on the location and possibly the dielectric properties of subsurface discontinuities.

A simple *ionosphere sounding* mode is also foreseen to generate ionosphere plasma frequency profiles with a vertical resolution of 15 Km and a spatial sampling step of ~20 Km.

4. SYSTEM DESCRIPTION

A block diagram of the system is given in Fig. 4-1.

The Antenna Subsystem contains two separate antennas. The main antenna is a dipole with 20 meters per element and is dedicated to both the transmission of the signals and their reception. The other or secondary antenna, is a 5 meter monopole and is used only for reception.

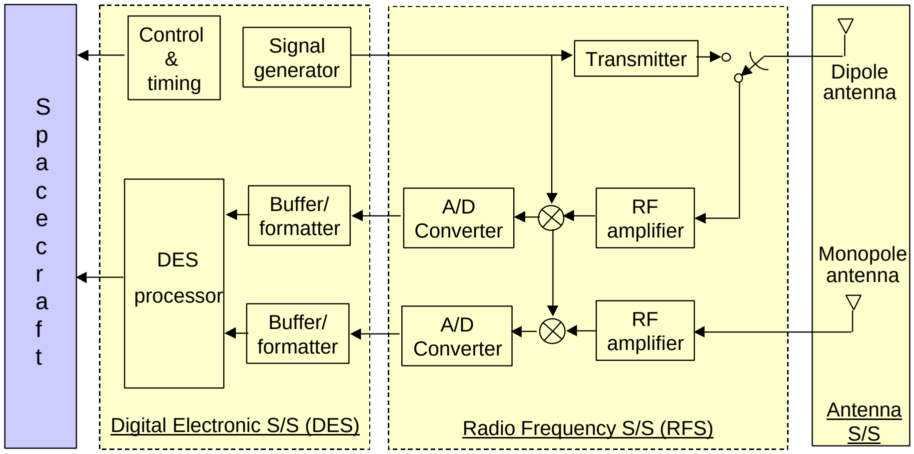

Fig. 4-1 MARSIS System Description

The Radio Frequency Subsystem (RFS) contains all the radio frequency parts of the instrument. During operations, the RFS is under the control of the DES. The RFS consists of a power amplifier, a transmission/reception switch and two receivers to collect echoes from each of the antennas. The output of both receivers is converted to digital form for processing by the DES. A dedicated power converter provides the regulated voltages for the electronics.

5. DIGITAL ELECTRONIC SUBSYSTEM

The DES, which has been developed by Laben, contains all the logic for the instrument and the interfaces with the S/C. A reference oscillator provides the coherence required by the instrument.

A sounder frequency generator generates the transmission waveforms as well as the reference local oscillator frequencies for the RFS. The DES processes the echoes in two separate channels corresponding to each antenna.

The Sounder Timer and Controller, which has the additional task of generating the timing for the entire instrument, supervises the control of the instrument and the interface with the S/C. A dedicated power converter board provides the regulated voltages for the electronics of DES and of the RX.

The DES is a triple-processor system based on programmable DSPs. The selected DSP is ATMEL TSC21020F.

A block diagram of DES is reported in Fig. 5-1.

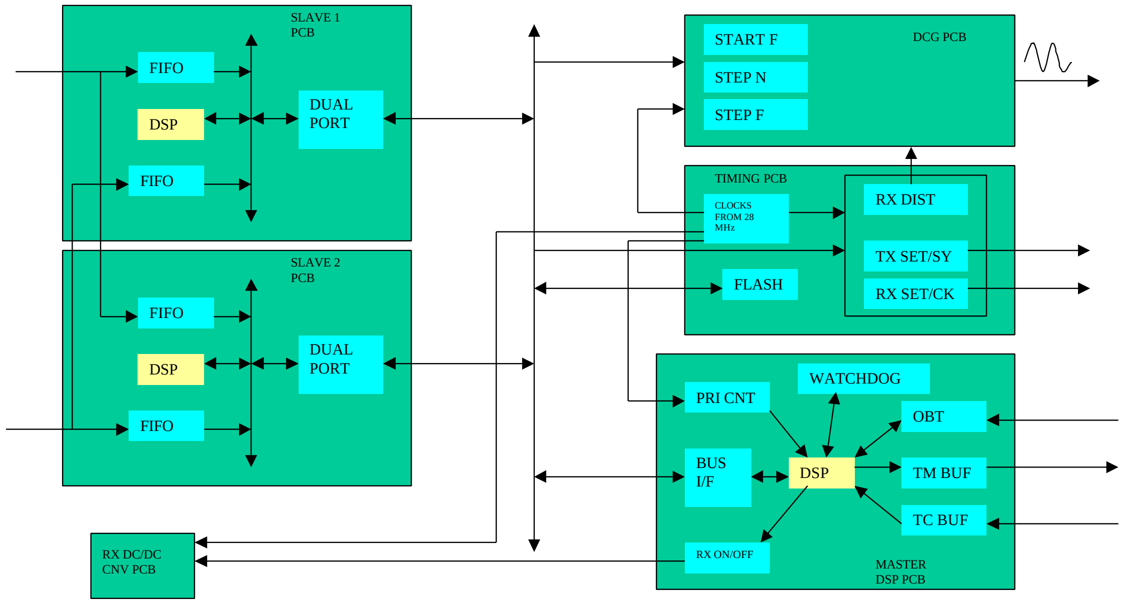

Fig. 5-1 DES Block Diagram

5.1 DES HW

The DES is physically organised in 4 mechanical "trays", which are piled up to form the whole unit. One of these trays is the DCG (Digital Chirp Generator) developed by ALS whilst the remaining three trays have been developed by Laben.
The Receiver (RX) is an assembly mounted inside the spacecraft instrument bay on two mechanical slices and in physical contact with the DES. DES and RX together have to be considered as a unique box, that from the S/C point of view is called SISD.

The mass of DES is about 4 Kg and the dimensions 203 x 216 x 155 mm^3 (L x W x H).
The power consumption depends on the selected operational mode: typically is between 32 and 36 W and can reach 43 W in the worst case.

As shown in Fig. 5.1, DES has two front end processing boards called "slave DSPs", physically connected to the channels associated to the two antennas of the payload (*D* stands for dipole and *M* stands for Monopole). It is possible to switch data from one slave to the other one in some operative modes.
The third DSP board ("master DSP") manages telemetry, telecommand, on-board time and orbital position. Moreover it controls the mode transitions, the programming of the "chirp"/LO generation and other HW resources such as timing sequences, RX settings and transmitter settings.
The DSPs run at 20 MHz clock and are therefore capable of up to 20 millions of instruction per second. Since some instructions exercise up to 3 floating point units, a peak power of 60 MFLOP per DSP is achievable during the execution of particular routines.

The three DSP boards are almost identical and have been designed by Laben, along with the DC/DC converters board.
Two FPGAs have been specifically designed for MARSIS:

- FPGA#1, dedicated to the master DSP board, includes HW resources for time synchronisation, PRI counting, TM/TC buffering, DCG interfacing and interrupt management, as well as for system bus control

- FPGA#2, for the timing PCB, is the main radar sequencer, but includes also facility for FLASH memory access.

The following memory banks are associated to each DSP: 128k of 48 bit EEPROM, 512k of 48 bit program SRAM, 512k of 32 bit data SRAM. For each DSP, the EEPROM bank contains all the code, which, during bootstrap, is copied in the corresponding 48 bit RAM where it usually runs. The 32 bit RAM banks are data memories used at runtime.

Fig. 5.1-2 shows the PCB layout of one the threee DSPs.

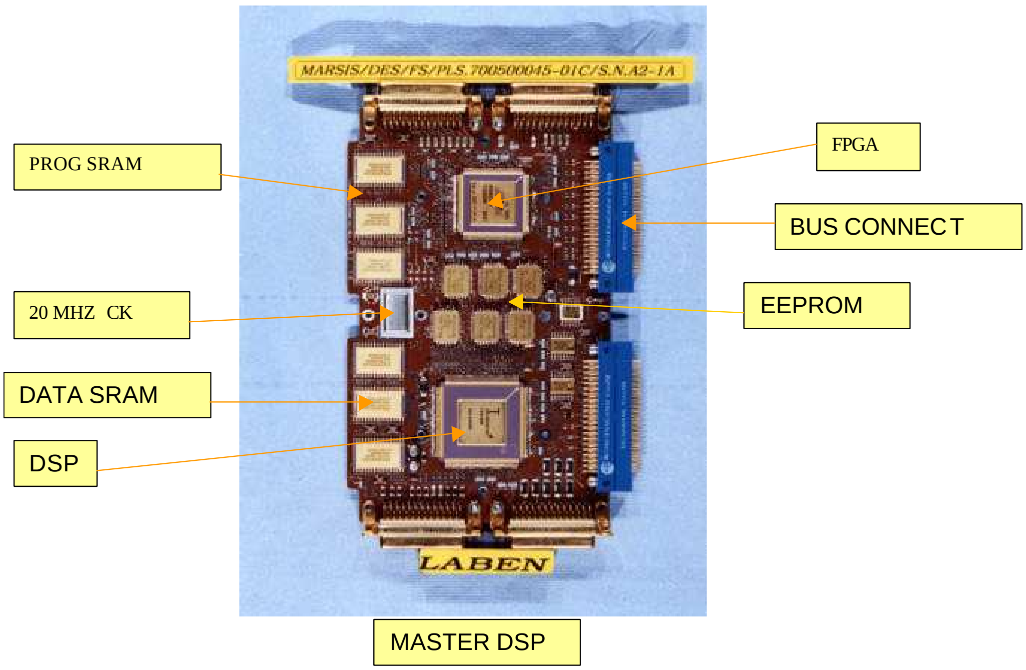

Fig. 5.1-2 DSP board layout

5.2 MARSIS on board SW

The MARSIS DES science SW complexity reflects the MARSIS instrument versatility: 4 bands, 5 sub-surface operative modes, 3 real time signal reconstruction methods, 3 raw data acquisition modes, can be combined in any way by the user through the Operation Sequence Table. There are, moreover, several hundreds of processing tuning parameters and automatic gain and range (i.e. satellite/planet distance) controls. These are executed in real time on the basis of the received data, known the transmitted signal and the orbital position.

The general processing structure is shown in figure 5.2-1.

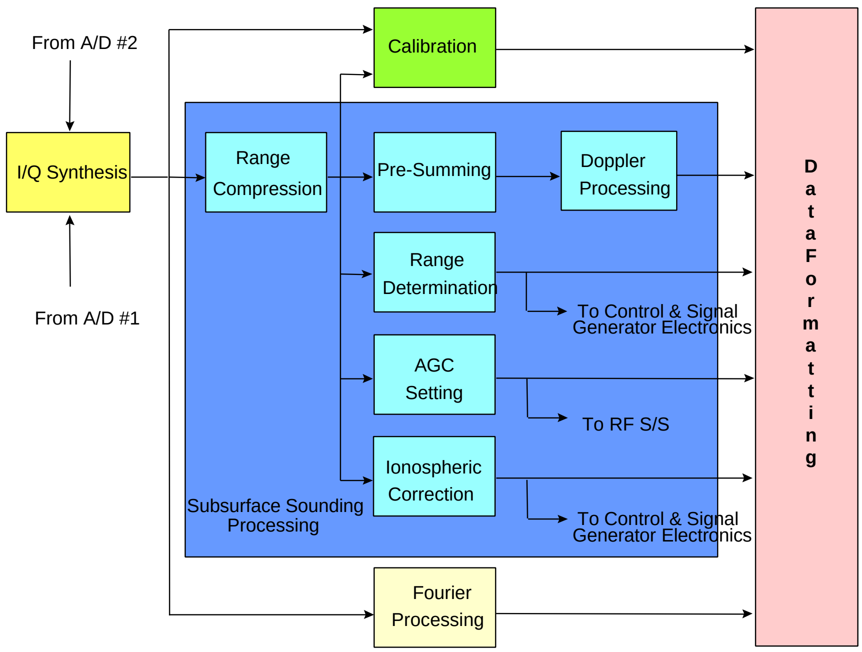

Fig. 5.2-1 High Level Processing functions Decomposition

As a general requirement, the DES shall be able to provide a suite of processing functions suitable to meet the science needs of the MARSIS experiment. Specific processing functions shall be available and selected according to the chosen operational mode. In particular, following a general data pre-processing for the I/Q data synthesis and raw data collection, different processing schemes will apply for:

- Subsurface Sounding Mode
- Active Ionospheric Sounding Mode
- Calibration Mode

In addition one background parallel task allows for Orbit and Velocity Determination during the flyby phase for any of the Operational Modes identified.

As said above, one DSP acts as master processor: it has the “time and status awareness” and orders the actions of the other two DSPs, named "slave" DSPs, by means of interrupts and command words. The MASTER DSP has the whole control of the DES, its main tasks being:

- TC execution
- TM building,
- Memory management (patch and dump),
- HW programming
- "slave DSP" science processing commanding and controlling
- FLASH memory management
- Automatic gain control based on estimated altitude
- Periodic check and reporting of the system status

The slave DSPs are essentially "number crunching" devices and execute in real time sequences of several functions typical of SAR digital signal processing, e.g. DFFT, digital filters, and complex vector multiplication. The SLAVE DSPs receive input data directly from the ADCs and transmit the processed outputs to the MASTER DSP by means of dual port RAM memory banks.

The MASTER DSP program has been coded mostly in ANSI "C" language and the o.s. *VIRTUOSO* has been adopted to schedule all the SW tasks, while the slave DSPs programs have been coded in simple assembly language to expedite their computational tasks. The resulting master DSP source code is about 25k lines long, while the slave DSP are 10k lines each. The source codes result in 125 k instructions for the master DSP, and 98 k instructions for both slave DSPs.

During scientific operations the DES cannot receive TCs and must therefore perform completely autonomously. It transmits to the DMS TM packets resulting from processing of every acquired raw data burst. The bare transmission of raw data is also foreseen. However, due to the large data amount, these may be packetised and stored in dedicated FLASH memory banks (16 Mbyte deep) and moved to the DMS off line only at the end of scientific operations.

Only the master DSP exchanges TC/TM with the S/C DMS. All the DES scientific operations are commanded to the master DSP in the form of Operation Sequence Tables (OSTs), loaded via TC once per orbit before starting the scientific subsurface sounding.

5.3 Test Equipment and Simulator

Along with a dedicated Test Equipment, a MATLAB simulation model has been developed to validate the whole scientific processing code. The simulator receives off-line the same inputs received by DES and is able to reproduce the entire expected scientific telemetry in all the various MARSIS instrument operation conditions. Simulator and DES outputs can then be compared and possible discrepancies analysed.

6 CONCLUSIONS

This paper has presented an overview of MARSIS, one of the scientific instruments on board the European probe Mars Express directed to Mars, whose primary objective is to map the distribution of water, both liquid and solid, in the upper portions of the crust of the planet.

In particular the Digital Electronic Subsystem (DES) of MARSIS, developed by Laben, has been described both from HW and SW point of view. The computational core of DES is based on a triplet of digital signal processors (TSC21020) that assures the necessary processing power to cope with the given stringent operational requirements.

It is planned to re-use most of the DES HW and SW in the forthcoming mission SHARAD (<u>Sh</u>allow <u>Rad</u>ar) on board the Mars Re-connaissance Orbiter. SHARAD, which is funded by the National Space Agency (ASI), is also aimed at investigating the Martian subsurface in the next few years (2005/2006) with better performance than MARSIS.

REFERENCES

1. MARSIS: Subsurface Sounding Radar/Altimeter, ESA Mars Express page (http://sci.esa.int/content/doc/9b/21915_.htm)
2. MARSIS home page of University "La Sapienza", Rome/Italy (http://www.marsis.com/)
3. "MARSIS Design Description, Science Analysis and Performance", RPT-MAR-0004-INF
4. "MARSIS On Board Processing Algorithms", TNO-MAR-0037-ALS
5. "DES HW Architectural Design", TL 16433
6. "DES - Software Architectural Design", TL17713