A LOW FREQUENCY SAR FOR MARS OBSERVATION

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ABSTRACT

Radar imaging of Mars is very attractive. A radar observation at several incidence angles allows the relief to be extracted and the use of low radar frequency can provide information on the subsurface structure. A feasibility study of a Synthetic Aperture Radar able to observe the whole Mars planet has been conducted by ALCATEL ESPACE for the French Space Agency (CNES). The big challenge of such a planetary radar is to minimize mass and power consumption while including an efficient way to transmit the enormous SAR data from the observed planet to the Earth. The results presented hereafter show that this objective can be obtained by using first, a single antenna shared between the SAR and the payload telemetry, and secondly an on-board SAR processor.

Keywords: SAR, MARS, subsurface,imaging.

1. INTRODUCTION

Even if MARS can be observed with optical means, the radar observation can bring complementary valuable information. In particular, as demonstrated in very arid regions [1], subsurface sounding can be obtained if the radar frequency is low enough. On the other hand, surface roughness and relief can be derived from several measurements at different incidence angles [2].

ALCATEL ESPACE is in charge of a feasibility study funded by CNES in order to design a SAR for MARS observation. The objective of the study is quite clear: the radar has to be able to observe the whole surface of MARS at a minimum of two incidence angles, during a two years mission. As demonstrated by MAGELLAN experiment, it is obvious that mass, power consumption and data rate are the driving parameters for the design of such a planetary radar.

2. REQUIREMENTS

The requirements are determined in order to fulfill the scientific mission including subsurface sounding and relief extraction [2]. They include a radar frequency below 1 GHz, a swath width of 50 km, a spatial resolution below 100 m , a four look image, a dynamic range of 40 dB and a minimum of two incidence angles. The noise equivalent σ_0 is derived from MARS characteristics and is -30 dB for incidence angle above 20 deg and -22.5 dB for incidence angle below 20 deg. In addition a realistic 8 hours availability per day for the 34 m antenna of the Deep Space Network (DSN) is taken into account for the telemetry performance analysis. Finally we suppose a circular and heliosynchronous orbit with an altitude of 450 km.

3. INSTRUMENT DESIGN

The first parameter to be considered is the data rate. In a first step, an estimate of the raw SAR data taking into account required coverage, resolution and dynamic range can be calculated. If we now compute the necessary data rate, taking into account the Earth / Mars range, the existing technology for payload telemetry (in particular High Power Amplifier) and the DSN availability and performances, we find that a very large antenna must be used for the telemetry purposes. On the other hand, mainly due to the low radar frequency, the usual SAR system design procedure leads also to a very large antenna.

From these elements we drive the system study with a few basic principles. One of these ideas is to share the antenna between SAR and telemetry payloads. The mass advantage of such a solution is obvious. But this means that the antenna is used alternatively for radar and telemetry purposes. So the platform must be able to perform, for each of these phases, the adequate pointing.

Another idea is to reduce the raw data by on-board processing. In fact, it is clear that for realistic antenna length, the useful Doppler bandwidth needed to obtain the required azimuth resolution is considerably lower that the available one. So a Doppler prefiltering can be used without loss of information. For the range features, the required two minimum incidence angles with a constant range resolution leads to a chirp bandwidth that will change with the pointing. So for the high incidence, the chirp bandwidth is reduced and we can filter only the useful receive bandwidth for each incidence angle. Furthermore, data compression techniques like Block Floating Point Quantizer (BFPQ) can be used to reduce the number of bits of the data coding.

Unfortunately, these data rate reduction techniques are not sufficient to reach the coverage objective. So an on-board SAR processor is required. This processing performs range compression and azimuth compression including multi-look processing. For this purpose, we use a Range Doppler algorithm and this gives a data rate reduction in a ratio 10:1.

Finally, the global instrument is composed of three parts:

- a single deployable antenna
- a radar system
- a telemetry system.

These systems are described in detail hereafter. For each part and for the complete instrument, trade-off are performed between technological constraints and system performances. The main result is a radar frequency of 800 MHz and an X band telemetry.

4. ANTENNA DESIGN

The antenna includes a deployable reflector and a feeder. For the nominal solution, the deployable reflector is based on a technology developed by LOCKHEED (WRAP-RIB reflectors) [3]. It consists in a mesh attached to flexible radial ribs shaped to form a parabola. For stowage, ribs are wrapped around the central hub, and the deployment use only stored energy in the ribs. This technology ensures a very low mass for very large antennas. Furthermore the stowed configuration can be very small. The current design uses a circular reflector of 5 m diameter. The radar feeder includes eight slots, disposed in a rectangular array (4*2). Such a feeder allows pattern weighting. This design also limits multipactor risks. The telemetry and telecommand horn is located at the center of the radar feeder (reflector focus). It is a dual band one and a diplexer allows the separation of receive and transmit signals.

An implementation study, "Fig 1", on a cubic platform (2 m* 2 m*3 m) is done and leads to an easy accommodation in ARIANE 5 launcher fairing.

An alternative antenna based on a rigid elliptical parabolic dish with a horn feeder is possible. For this solution slight changes in radar and telemetry parameters and performances occur.

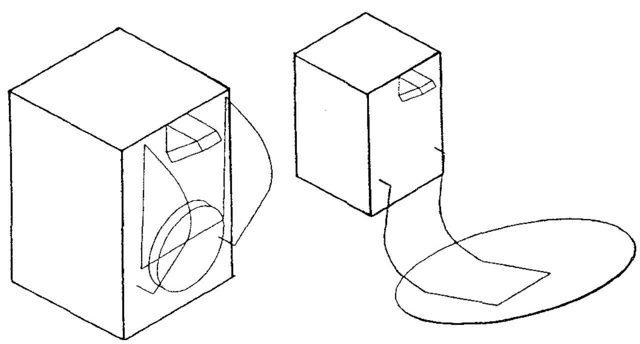

Figure 1: Stowed and deployed antenna configuration

5. RADAR DESIGN

The radar functional architecture is shown on "Fig 2". The radar includes three main subsystems:

- the digital electronic subsystem,
- the radiofrequency (RF) subsystem,
- the transmit receive subsystem.

For the nominal mode the chirp is generated in the digital chirp generator with adequate bandwidth and duration. The signal is upconverted in the RF subsystem, amplified by five HPA's and dispatched to the antenna. Due to the design of the antenna feeder and for beam shaping purposes, one of the HPA is used for the first feeders row, while others are used each for one of the feeders of the second row. Note that a 6 for 5 redundancy scheme is used for reliability purposes. The total needed RF peak power is less than 400 W, which is easy to obtain with Solid State Power Amplifier.

The received signal is first amplified by the Low Noise Amplifier and down converted to intermediate frequency in the RF subsystem. Then In-phase (I) and Quadrature (Q) components are directly generated by numerical means. The Doppler and range prefiltering is applied in order to keep only the useful information.

At this stage we can either transmit raw data or process the data. In the first case, the raw data are compressed by the BFPQ, formated and sent to the telemetry system for storage. In the alternative case we temporary store the data in a solid state memory. The non-real-time SAR processor is then used to focus the signal and obtain processed SAR data which are sent to the telemetry system for storage. The processor architecture is based on a standard DSP chip and an ASIC (Application Specific Integrated Circuit). The elementary operations (multiplication, addition...) are performed by the DSP chip while all the FFT operations are performed in the ASIC. This architecture allows a flexible and relatively fast processing. For example a standard image is defined as 280 km by 50 km which corresponds to an observation of 100 seconds. For such an image, the raw data after prefiltering represent around 1.5 Gbits, the processing time is about 15 minutes and we finally obtain around 150 Mbits of processed data. So the data rate reduction given by SAR processing is significant with an acceptable delay.

6. TELEMETRY SYSTEM

The functional architecture of the telemetry system is described below. Note that the design includes complete redundancy in order to have a very good reliability. The three main subsystems are:

- the TTC (Telemetry Tracking and Command) and ICU (Instrument Control Unit) subsystem,
- the data processing and storage subsystem,
- the Relay subsystem

The ICU is based on an on-board computer which manages the telemetry and radar systems. The TTC unit performs all the communications. It contains two X band transponders, two TWTA (Traveling Wave Tube Amplifier) and a RF distribution unit. The telemetry signal is nominally connected to the high gain antenna (shared between radar and telemetry). Command signals are usually received by the omnidirectionnal low gain antenna. The Relay subsystem is designed in order to achieve communications with beacons or rovers on the Mars surface. The data processing includes the coding for errors corrections. The storage memory uses the solid state technology (Dynamic RAM). The unit can store up to 10 Gbits of raw or processed data.

7. PERFORMANCES ANALYSIS

The main performance estimates from this instrument design are summarized in table 1. All the results are compliant with the requirements.

Two, and potentially three, radar pointings can be used. This leads to incidence angle (center of the swath) of 16 deg, 45 deg, and potentially 33 deg. So relief extraction can be achieved by stereoscopic means. With the 3 incidences' observation and taking into account the shape of the backscatter strength it will also be possible to estimate the surface roughness. This information can be useful if the radar mission is coupled with a rover mission, because this could be of interest for the choice of the rover evolution zones. With the addition of a calibration scheme (internal

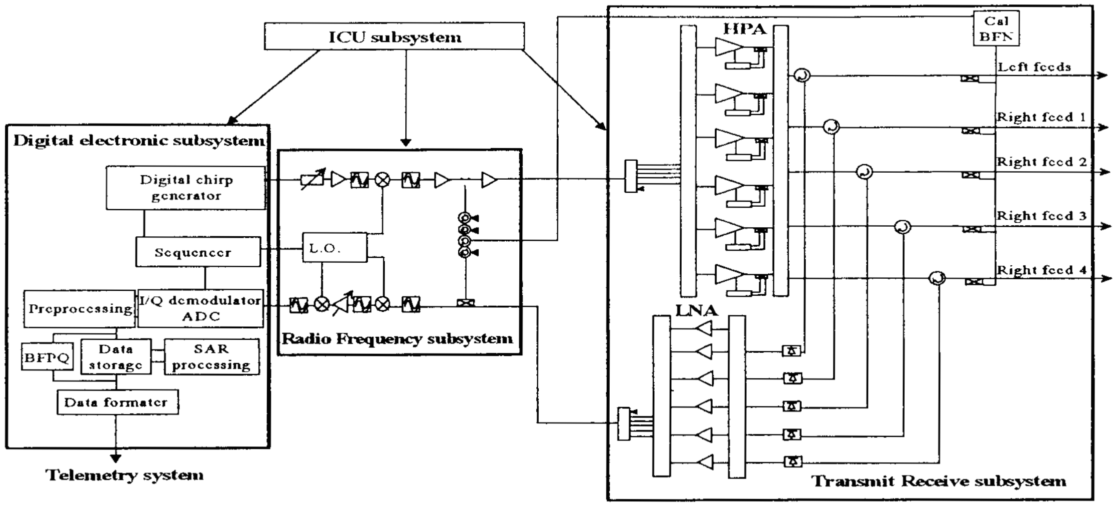

Figure 2: Radar block diagram

and external) the radiometric accuracy is around 1.6 dB and the radiometric stability is better than 1 dB. Such values are compatible with the applications.

The radar frequency of 800 MHz is low enough to penetrate several meters of the believed very dry dust that covers most of the Mars surface. So, subsurface information could effectively be extracted.

Table 1: Main instrument performances

Radar frequency	800 MHz	
Swath width	50 km	
Range resolution	38 m	
Azimuth resolution	32 m	For 4 looks
Incidence angle	16 / 45 / 33 deg	
Dynamic range	40 dB	
Noise equivalent σ_0	-22.5 / -30 dB	For 16 / 45 deg
Radiometric accuracy	1.6 dB	Stability 1 dB
Ambiguity ratio	25 dB	Range or Doppler
Telemetry frequency	X band	
Data rate	82 kbit/s	At max range
Mars covering rate	260 %	2 years mission
Reliability	0.96	2 years mission

The other important performance is the Mars coverage rate. This performance is obtained first by the design of the antenna and the telemetry system. But this performance is mainly due to the on-board SAR processing. Note that the data rate indicated in table 1 is the value at maximum Earth to Mars range. The design allows a data rate variable by steps. Note also that in the operational sequencing, priority is given to the telemetry. This means that if Earth is visible, and DSN available, the instrument is in the telemetry mode. Observation mode, and processing mode share the remaining time. So the objective of whole planet observation at two incidences (200 %) is achieved. Finally in case of failure of the processing unit, a degraded mission can be realized because we keep the possibility of transmitting raw data.

Table 2 gives the estimated instrument budgets. These budgets include the redundancy. The unit power consumption is a peak value but the total power consumption is a worst case averaged on a day. The effective value depends on the duration of each mode.

Table 2: Instrument Budget

System	Mass (kg)	Power consumption (W)
Radar	32 kg	180 W peak
Telemetry	40 kg	165 W peak
Antenna	71 kg	/
TOTAL	143 kg	136 W average

8. CONCLUSION

The designed dual incidence low frequency MARS RADAR is compliant with requirements derived from subsurface sounding, relief extraction and whole planet surface mapping.

The objective of complete observation of mars surface at two incidence angles is achieved thanks to the on-board SAR processing. In addition, due to the single shared antenna, and the use of advanced digital equipments (data storage, demodulation, processing) this design leads to a low mass and low power consumption concept.

Some developments including antenna, HPA, data processing, are necessary, but no major critical point is identified.

In addition the current design can be easily updated to a slightly different mission, including observation of another planet.

REFERENCES

[1] J.F McCauley & all "Subsurface valleys and Geoarcheology of eastern Sahara revealed by Shuttle radar", Science, 218, pp 1014-1019, 1982.

[2] A. Lifermann, E. Thouvenot, "Definition of a L-Band SAR for a Mars rover mission", Proc Symp on radars and lidars in Earth and planetary sciences, pp 59-63, Sept 1991.

[3] E. Kovalcik, "Space-based radar structures", in Space-based Radar Handbook, L.J.Cantafio Ed, Artech House, 1989, pp.637-675.