SHARAD and SORA: two radar sounders, a unified experience

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Academic year 2007/2008
Summary

- SHARAD overview
- SORA overview
- Two radar sounders, a unified experience
- The need for SAR radar data processing and possible algorithms
- How can we choose?
- The choice for SHARAD: a guideline for SORA
- The first steps in SORA data processing
- Future objectives
- Publications
SHAllow RADar: scientific objectives

- Map in selected locales water and ice distribution in the first 2 kilometers of the Mars subsurface
- Map the thickness, extension and continuity in the North and South polar deposits
- Map the thickness, extension and continuity of the sedimental layers
- Map the distribution of subsurface channels
- Determine the subsurface electromagnetic properties
- Identify on Mars planet regions suitable for the “follow the water” strategy
SHAllow RADad SHARAD

- Is one of the six scientific instruments on board of NASA’s 2005 Mars Reconnaissance Orbiter mission
- Is a nadir-looking, pulse limited radar operating both as SAR and altimeter.

### DESIGN PARAMETERS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrier</td>
<td>$f_0 = 20$ MHz</td>
</tr>
<tr>
<td>Band</td>
<td>$B = 10$ MHz</td>
</tr>
<tr>
<td>Chirp Tx duration</td>
<td>$T = 85$ μs</td>
</tr>
<tr>
<td>Nominal PRF</td>
<td>PRF = 700 Hz</td>
</tr>
<tr>
<td>Nominal PRI</td>
<td>PRI = 1428 μs</td>
</tr>
<tr>
<td>Wavelength</td>
<td>$\lambda = 15$ m</td>
</tr>
<tr>
<td>Azimuthal resolution</td>
<td>$300$ m – $1$ Km</td>
</tr>
<tr>
<td>Range resolution</td>
<td>$3$ Km – $7$ Km</td>
</tr>
<tr>
<td>Vertical resolution</td>
<td>~$15$ m</td>
</tr>
<tr>
<td>Penetration</td>
<td>~$0.1$ Km – $2$ Km</td>
</tr>
<tr>
<td>Radial velocity</td>
<td>$30$ m/s</td>
</tr>
<tr>
<td>Tangential velocity</td>
<td>$3$ Km/s</td>
</tr>
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</table>
SOunding RAdar: scientific objectives

- Provide valuable information on ice thickness, sub-ice lakes, layers discontinuity lithological and compositional changes, layer geometries, physical properties

- Perform a test campaign to operate the radar in Martian Analogue environments in order to provide a set of reference measurement to be used to eliminate possible ambiguities in Mars data analysis.
SOunding RAdar SORA

- SORA is an ASI’s experiment which consists of a stratospheric balloon flying at about 35 km above the Arctic sea level, carrying a gondola with a subsurface radar on-board

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<tr>
<td>Range resolution</td>
</tr>
<tr>
<td>Vertical resolution</td>
</tr>
<tr>
<td>Balloon velocity</td>
</tr>
<tr>
<td>Flight altitude</td>
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</tbody>
</table>

- The balloon will be launched from Svalbard where the facility of the Italian base will be used
- The cruise will last about a week
- Simulations of the balloon trajectory show a circular shape with a landing area within 100 km from the launch pad
- Data of great scientific interest will be acquired by the on-board payload
SHARAD vs SORA

Similarities

- Hw (except antenna)
- Observation geometry
  - Nadir looking
- Transmitted chirp
  - 10 MHz Band
- Vertical resolution

Differences

- Environment (geology, atmosphere)
- Carrier frequency
- SHARAD has on-board processing (presumming)
- SHARAD transmits both data and telemetries, SORA only telemetries
SORA payload

- **RF transceiver assemblies**
  Is the module mainly devoted to signal generation and reception: is composed by a Chirp generator, Transmitter, Duplexer, Receiver. This unit will interface the payload antenna via the duplexer. The antenna system, takes into account trade-off analysis among dimension, weight and instrument performances, and instrument working frequency and wide bandwidth.

- **Digital subsystems and on board computer.**
  This module provides clock and timing to synchronize all instrument subsystems functionalities and provide RF signals to the different modules. It includes a computer to run the on-board software and store data.

- **Power supply manager**
  The power supply is provided by the gondola balloon. Therefore there is a power supply manager module devoted to distribute the power among the radar components.

- **Telecommand and Telemetry subsystem**
  This module is devoted to control and command radar operation and data telemetry either manually and/or via data-link. Specific software has been developed to control the system, set radar operative parameters and configuration.
From digital numbers to radargrams

Sharad Payload

Mars North Pole
SAR data processing

Processing algorithms:
- Omega-K algorithm (ωKA)
- SPECtral ANalysis algorithm (SPECAN)
- Chirp Scaling Algorithm (CSA)

Objective: reconstruct the scene

Algorithms common operations:
- Range and azimuth FFT e IFFT;
- Range and azimuth compression;
- Total and/or partial RCM correction;
- Phase compensation.

Add specific corrections (e.g. vehicle motion)
SHARAD processing chain evolution

- **Data deformatting**: each bit sequence is assigned to the corresponding field;

- **Monitoring**: S/C scientific (e.g. S/C height) and engineering (e.g. temperature, electric current, Tx power) telemetries monitoring;

- **Processing (L1A, L1B)**: space/time collocation of the received, **raw data processing**;

- **Visualization and scientific analysis of the processing output**.
A processing for SORA radar data

The data processing for SORA scientific data will be necessary as soon as the data will be retrieved from the Arctic sea.

In order to choose in advance the type and the steps needed to carry out the radar data scientific analysis, two complementary paths could be followed:

- Perform an analysis of the most common processing algorithms found in the vast body of literature at our disposal
- Refer to the experience of SHARAD data processing, taking advantage of the SHARAD-like characteristics of SORA radar
Exact $\omega$KA (1987)

- $H_p: V_r$ (effective radar velocity) is range invariant
- Transformation domain: $\omega - K$
- Basic operations
  - **Reference Function Multiply**: is a bidimensional frequency domain filtering which realizes the bulk focusing. RF is computed in the centre of the swath and multiplication for this function produces a phase compensation in the swath centre.
  - **Stolt Interpolation**: is a mapping, a change of variable in $f_\eta$ domain and realizes the differential focusing, that is target focalization in points which are not in the swath centre. Interpolation implements differential RCMC, SRC e azimuth compression.
SPECAN (1979)

- Hp: linear frequency modulated signals
- Domain: temporal bidimensional
- Basic operations
  - Linear RCMC
  - Azimuth compression in 2 steps
    - **deramping**: conversion of a linear frequency modulated signal into a sinusoid with frequency proportional to signal position
    - **FFT**: signal compression using a spectral analysis of its frequencies and target registration in its correct position
  - Descalloping
  - Deskewing and stitching

```
Radar Signal Data
  ↓
Range Compression
  ↓
  Linear RCMC
  ↓
  Deramp, weighting, FFT
  ↓
Descalloping
  ↓
Multi-looking
  ↓
Phase Compensation
  ↓
Deskewing and stitching
  ↓
SAR Image
```
CSA (1992)

- Hp: the signal must be a chirp in range and the scaling function must avoid aliasing
- Domains: Range-Doppler, bidimensional frequency, bidimensional time
- Basic operations
  - 2 FFT (range and azimuth)
  - 2 IFFT (range and azimuth)
  - 3 phase corrections (multiplication for exponential functions)
- Total RCM in 2 steps
  - Differential RCMC
  - RCMC bulk
- Scaling functions applied in different domains
### Algorithms in comparison to:

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| ωKA       | - Exact processing  
- Exact SRC  
- Its approximation is computationally efficient  
- This algorithm works also on compressed data, even if compressed on board of the S/C. | - Computationally not very efficient  
- Barely suitable for large swaths (V_r not constant)  
- Exact algorithm needs interpolation  
- Doesn’t compensate fast Doppler centroid variations  
- Generates big array (weighting)  
- It does not take into account V_r variations in range  
- Only the target in the centre of the swath is correctly focused. Approximate version shows more problems in focalizing target far from the swath centre (residual RCMC)  
- A weighting function has to be used to reduce sidelobes level  
- Stolt mapping produces a shift in the range spectrum  
- In approximate version RCM is not completely corrected and a residual angle QPE exists |
| SPECAN    | - Is used for azimuth processing  
- Is computationally efficient  
- The memory allocation is reduced  
- Both processing single look and multilook: a reduced number of looks are allowed, and this processing is sort of raw but fast  
- Fast matched filtering (1 FFT costs)  
- 20 % Overlapping looks improves output image | - Scarcely efficient for range processing  
- It applies to FM linear signal with reduced non linearities  
- The more the resolution, the less the efficiency  
- It correct only linear RCM  
- Deskewing needed  
- In multilook, the more the looks, the less the efficiency  
- Radiometric frequency and phase corrections needed. |
| CSA       | - No temporal interpolation needed  
- RCMC using phase functions  
- Accurate azimuth matched filtering  
- Range compression is not the first step  
- Hybrid algorithm (2 domains used) | - No need for separate range compression  
- Short range matched filtering needed  
- No fast variations of Doppler centroid  
- Matched filter arrays are rather big  
- SRC has to be constant with range and V_r.  
- Phase corrections can be non linear functions.  
- RCMC in 2 steps to avoid problems with centre frequency and signal band  
- Applying scaling function shifts the signal band |
SHARAD: how did we make the choice?

- The choice generally depends on the project specifics
- The choice for SHARAD was based on:
  - **Error terms (accuracy)**
    - QPE in azimuthal matched filtering
    - QPE in secondary range compression
    - Residual RCM
  - **Computational charge (efficiency)**
    - FFT e IFFT
    - Phase multiply
    - Interpolation
  - **Qualitative analysis**
- **SHARAD processing uses CSA:**
  - RCMC accurate
  - Focalization of both point target and extended areas
  - QPE minimization through appropriate phase functions
  - Need for block processing (minimizes processing time)
  - CSA was onerous but easy to implement
SORA observation geometry

- SORA is a nadir looking pulse limited radar

- Its Synthetic Aperture Ls had been chosen to be the pulse limited diameter

\[ r = \sqrt{(R_0 + \delta)^2 - R_0^2} \approx \sqrt{2R_0\delta} \approx 2048m \]

\[ A = 2\pi R_0\delta \approx 3.3km^2 \]

- The observation geometry is

\[ \delta = 15m \]

\[ R_0 = H = 35000m \]

\[ r_{pl} \]
Can we really do on SORA an advanced along track processing to increase the resolution?

Range chirp

But what happens in the azimuth direction?
What the next steps look like? (1/3)

1. SORA data processing algorithm definition

- Should we consider all the CSA steps?
- Analyze the received data
- Apply the algorithm to SORA data
2. Scientific analysis

- **Dual Band processing**
  The dual band processing consists of splitting the band of a radar signal in two sub-bands and applying a processing algorithm to these two sub-bands, each centered in a specific carrier frequency. The availability of two different carrier frequencies allows different penetration capabilities of a fixed area and, then, improves the sub-surfaces detection analysis of the received radar data.

- **Data inversion**
  The inversion process allows the dielectric constant of the subsurface material to be estimated once the dielectric constant of the surface is known. In addition, if impurities are present, it is possible to estimate the dielectric constant of any inclusions as well as the percentage amount of material in the inclusions relative to the host material. The data inversion method is based on the analysis of the surface to subsurface power ratio and the relative time delay estimated through radar echoes.
What the next steps look like? (3/3)

3. Compare Earth (SORA) and Mars (SHARAD) results
Publications

- **Science 2007**
  - Accumulation and erosion of Mars south polar layered deposits from subsurface radar sounding

- **ASI Conference 2007**
  - Understanding the three-dimensional stratification of Mars Polar Layered Terrains seen by SHARAD using terrestrial analogies

- **AGU 2007**
  - SHARAD radar stratigraphy of the martian north pole
  - A study of the subsurface structure of a region of the Martian SPLD by means of SHARAD high resolution radar data
  - Incoherent simulator for Mars surface applied to the analysis of SHARAD data

- **IEEE Radar conference 2008**
  - Incoherent simulator for SHARAD experiment
  - SHARAD, a shallow radar sounder to investigate the red planet