TOPSAT Radar System

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ABSTRACT

A good knowledge of the shape of the Earth's surface is needed for a wide variety of the earth and environmental sciences as well as for engineers, land -use planners and the military.

Recent studies have investigated the requirements and have reviewed available topographic maps and Digital Elevation Model (DEM).

The results of such a study have shown the insufficiency of the present topographic cartography, both in terms of quality and in terms of coverage.

To overcome such a deficiency, several study programs are currently undergoing for defining a space-borne system able to collect data to derive the DEM information for the whole globe.

The aim of this paper is to describe the system proposed by Alenia Spazio and JPL in order to produce a DEM which meets, in terms of coverage and height accuracy, the requirements set by the scientific community.

INTRODUCTION

The most important applications which claim for a more accurate DEM are in the area of geology and geophysics, polar and ice sciences, hydrology and ecosystem studies.

Common to the all the above disciplines is a need for topographic data which comply to the following requirements:

- very high resolution topographic data with horizontal resolution in the order of tens of meters (approximately the one of most of the currently operating space based imaging systems) and vertical precision in the order of several meters or better;
- a global Earth coverage;
- temporal consistency of the derived DEM which implies that the above coverage shall be obtained in a time frame of maximum 1 year.

Existing data and existing or planned data acquisition systems fall far short of these requirements, and on the other side it stands to reason that they can be met only by space based sensors.

Different parallel studies have identified the Side Looking Radar Interferometer with Aperture Synthesis (SAR) as the most promising technique to obtain high resolution, global topographic data.

In such a contest, in 1990 University of Naples, JPL and Alenia Spazio carried out a joint study on a global land/ice Topographic Mission based on the Interferometric Synthetic Aperture Radar Altimeter technique.

JPL analyzed a system constituted by a single spacecraft carrying two horizontally separated antennas operating in Ka band.

The approach followed by University of Naples and Alenia Spazio was based on a system of two spacecraft tethered in vertical configuration each carrying an antenna operating in L-band.

Afterwards JPL kept on the study on a Global Topographic Mission and proposed a twin satellite system where two conventional spacecraft work together as a L band Interferometric SAR antenna system.

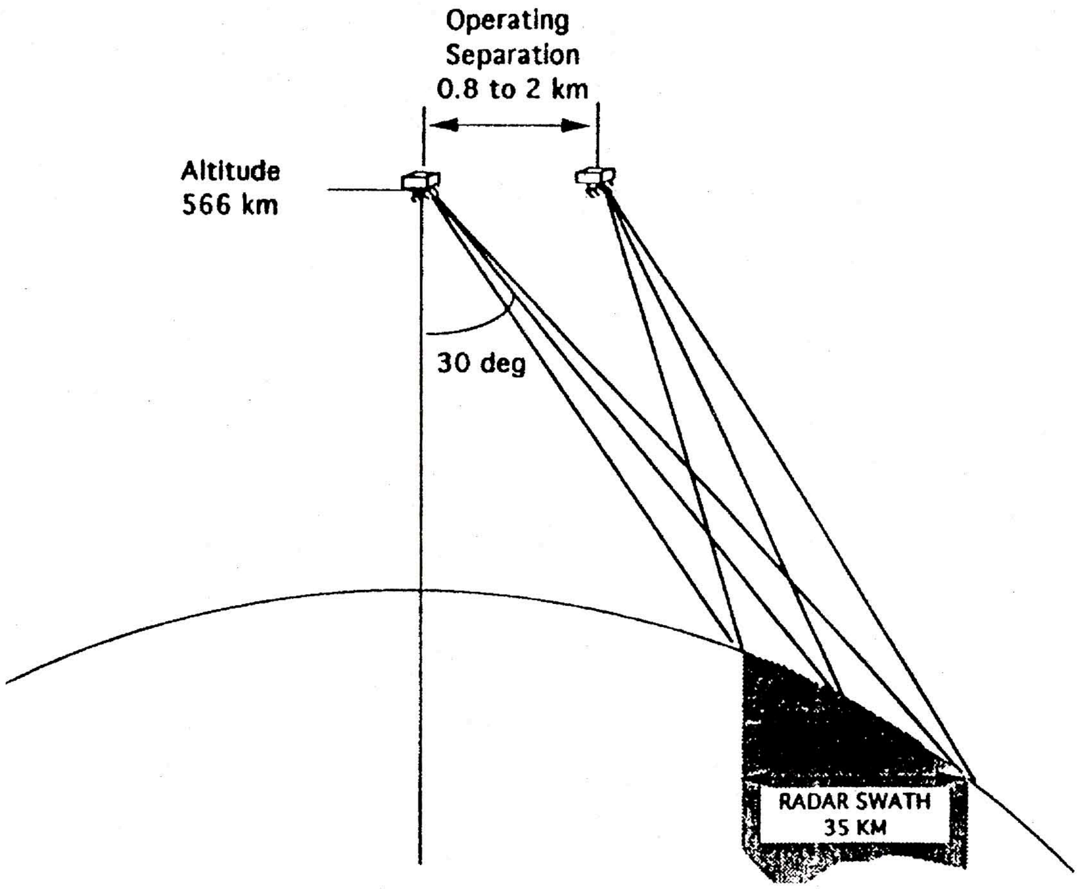
Besides different aspects of orbital mechanics relevant to the spacecraft, main system parameters and performances are comparable for tethered and twin satellite systems.

JPL and Alenia Spazio are currently planning a Global Topographic Mission called TOPSAT based on the twin satellite system which will determine the earth's land surface to an accuracy of better then of 5 m on a 30 m horizontal resolution.

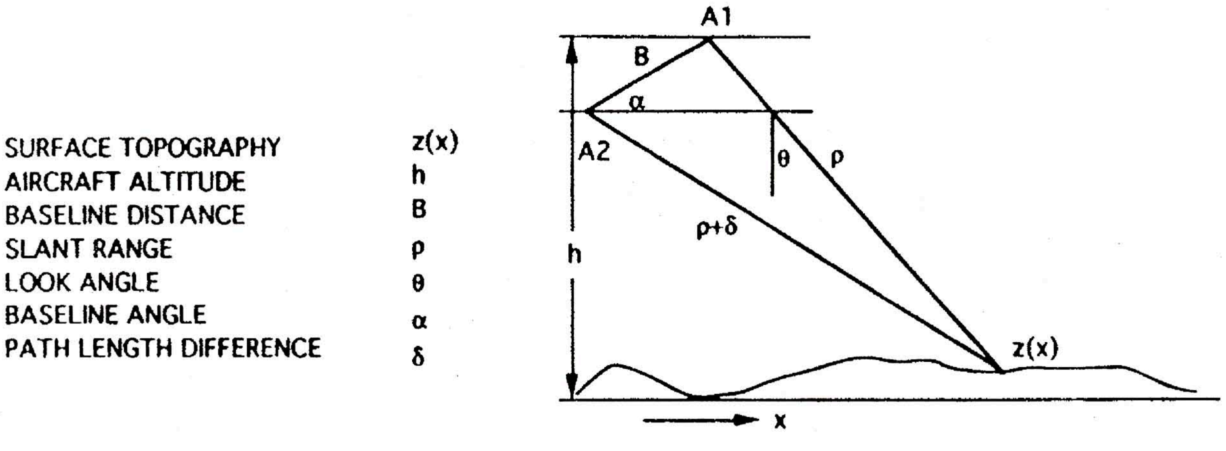
In the following the twin satellite approach will be explained and the main SAR system parameters will be illustrated.

1. SYSTEM GEOMETRY

The geometry of the "Twin satellite" concept is shown in picture 1.



a) View from behind velocity vector



b) Geometry and parameter definition

Fig. 1 - Dual Spacecraft Concept.

Two conventional spacecraft work together as L band interferometric synthetic aperture radar antenna system.

One antenna transmits a signal that is received by both antennas.

The two satellites have to remain in proximity to each other (less than 1100 meters in the lag orbit direction) so that the radar beams can be overlapped while maintaining the radar footprint along the velocity vector normal

The baseline distance (the distance between the two satellites measured perpendicularly to the velocity vector) will range from 800 to 2000 meter (800 at 65° latitude and 2000 at the equator).

Mapping of region from 70° to 83° will be accomplished by the Laser Altimeter.

The selection of the radar system parameters has been based on an orbit altitude of 566 Km, an off-nadir angle of 30 degrees and on the user requirements to have a swath width that allows a complete global coverage in less than 6 months.

A low orbit has been selected to improve height measurement , error contribution due to interferometric phase uncertainty, baseline length uncertainty and baseline attitude uncertainty linearly increase with the slant range distance hence with the satellite orbit.

Influence of the off-nadir angle on the height measurement accuracy is pretty pour in the range of off nadir angle used for SAR (20-60 degrees).

The off nadir angle choose is based on resolution requirements, SNR, layover and shadowing minimization. The selected value 30 degrees came out from a trade off among the above requirements.

RADAR DESIGN

The L-Band (f = 1.275 Ghz, λ = 0.24 cm) has been selected since it's the most suitable one for such a system, resulting from a trade-off for height estimate accuracy, height ambiguity minimization and the need for a 90% (at least) overlapping of the two antenna footprints.

Pictures 2 and 3 illustrate the trade-off between the first two points.

Height accuracy claims for a short wavelength whilst height ambiguity minimization claims for a long wavelength.

In the range of the chosen baselines (800 m - 2000 m) the C-band has a very poor ambiguity resolution (less than

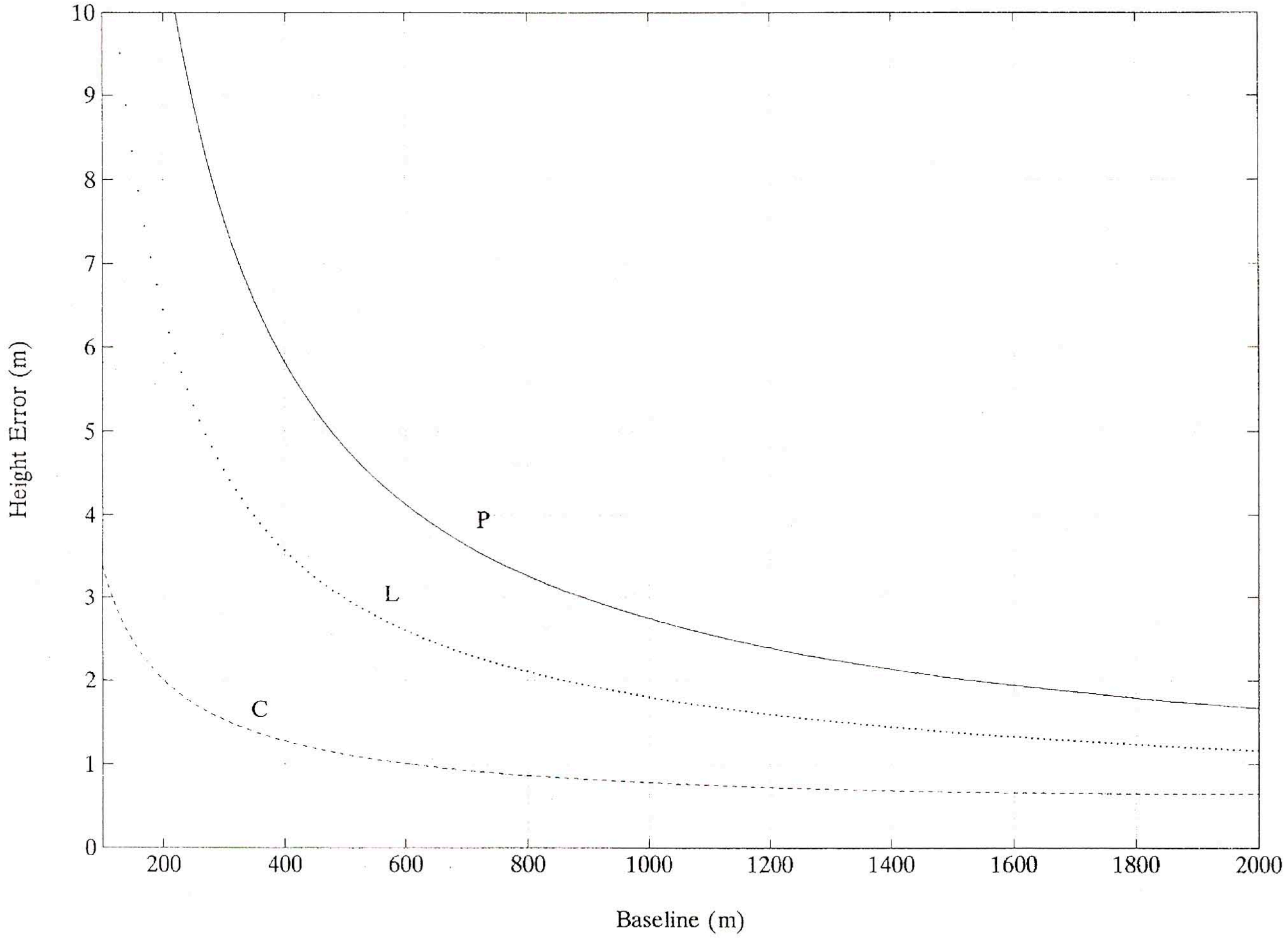


Fig. 2 - Height error for P, L and C band.

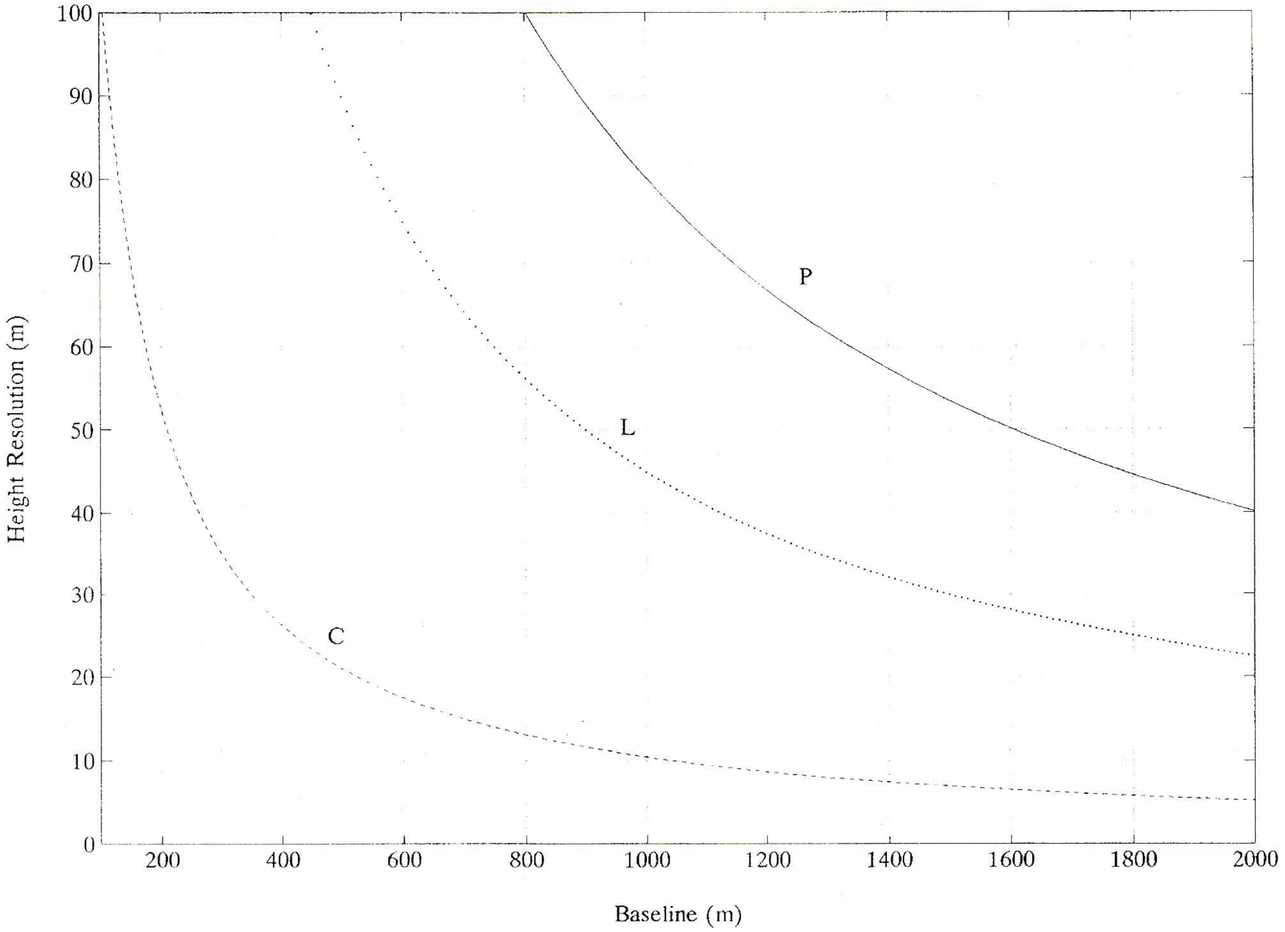


Fig. 3 - Height ambiguity range for P, L and C band.

10 m) while the P band presents an unsatisfactory height accuracy (2m - 3m).

The L-band still having a good height accuracy (better than 2 m) allows a maximum height jump between two contiguous pixels ranges from a maximum of 55 to a minimum of 20 meters.

In addition the L Band allows a 90% overlapping of the two antennas footprints with a safe lag separation (about 1300 m).

The cross track resolution is obtained by the chirp bandwidth resolution projected on ground and the swath width is the cross-track beam footprint size. In addition the along track resolution is obtained by focused processing.

For this particular system design a spatial resolution of 30 m x 30 m, a cross track swath width of 35 km an a total of 10 looks (5 in azimuth an 2 in ranges) can be achieved, assuming a chirp bandwidth of 20 MHz and antenna of 9 m x 3.5 m dimensions.

The 9 m antenna length would allow a nominal resolution of 4.5 m. Actual azimuth resolution is 6 m, got by processing a suitable azimuth bandwidth.

That yields a 2 dB noise reduction.

The selection criteria for PRF are Doppler Azimuth band sampling, interleave mode operation and range and azimuth ambiguity minimization .Satisfying the requirements above leads to the choose of a PRF of 1944 Hz and the relevant ambiguity diagram is depicted in picture 4.

Table 1 summarizes the antenna characteristics.

Table 1 - Antenna requirements.

Along-track antenna size (L)	9 m
Along-track beamwidth $(\theta_A\ 3dB - 1way) = \frac{\lambda}{L}$	1.5°
Cross-track antenna size (W)	3.5 m
Cross-track beamwidth $(O_E\ 3dB - 1way) = \frac{\lambda}{W}$	3.9°
Antenna gain $= 4\pi \, . \, A_{antenna} \, . \, 0.5/\lambda^2$	
Antenna directivity $= 4\pi \, . \, A_{antenna}/\lambda^2$	
Antenna losses	3 dB
Polarization	VV

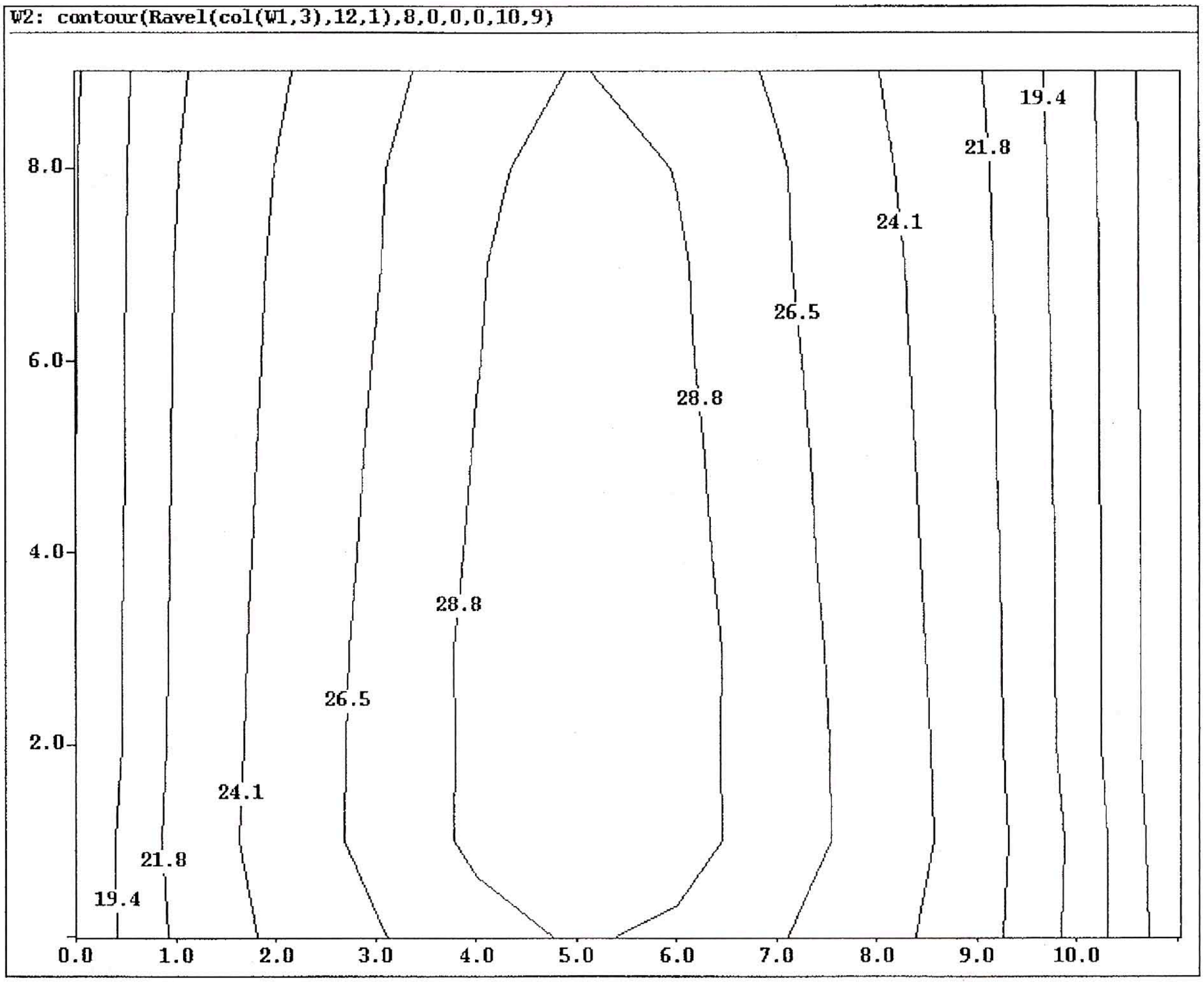


Fig. 4 - Signal to ambiguities ratio in the swath.

Assuming a σ_o = -20 dB and a peak power of about 1.5 kW the Signal to Noise Ratio (SNR) is calculated to be better then 14 dB leading to a radiometric resolution of 1.26 dB. The system peak data rate, taking into account a sampling window of 153 μ sec, 4+4 bit on each channel, a range sampling frequency of 22 MHz and a PRF of 1944 Hz, turns out to be 52 Mbps for each radar system.

SYSTEM PERFORMANCE

The major error sources on the height measurement are:
- Interferometric phase noise
- Baseline length measurement error
- Baseline attitude uncertainty.

These error terms can be expressed as:

$$\sigma_h = \frac{\rho}{B}\frac{\lambda}{2B}\frac{\sin\vartheta}{\cos(\vartheta-\alpha)}\sigma_\Phi \qquad (1)$$

$$\sigma_h = \frac{\rho}{B}\sigma_B \tan(\vartheta-\alpha)\sin\vartheta \qquad (2)$$

$$\sigma_h = \rho\,\sigma_\alpha \sin\vartheta \qquad (3)$$

The phase noise (σ_Φ) is a function of the interferometric image correlation coefficient γ which depends on geometric configuration parameters and on SNR.
For a large number of looks (greater then 5) it can be expressed (after Rodriguez) as:

$$\sigma_h = \frac{1}{\sqrt{2N}}\sqrt{\frac{1-\gamma^2}{\gamma}} \qquad (4)$$

from which a phase noise of about 6 degrees can be estimated to which corresponds an height error of 1.58 meters.

From the Eqs. (2) and (3) the knowledge on the system attitude and baseline separation must be accurate to 0.0003° and 3 mm respectively in order to obtain the required height accuracy andthis is can be obtained by differential GPS data.

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