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A BISTATIC ALTIMETRY MISSION FOR OCEAN TOPOGRAPHY MAPPING

C. Zelli*, M. Martin-Neira+, G. Alberti*, F. Impagnatiello*, M. Matteoni****

*Alenia Aerospazio, Space Division, Remote Sensing Engineering, Via Saccomuro 24, 00131 Rome - Italy, e-mail: c.zelli@roma.alespazio.it

**Alenia Aerospazio, Space Division, Advanced Studies, Corso Marche 41, 10146 Turin – Italy, e-mail: mmatteon@to.alespazio.it

***Consortium for Research on Advanced Remote Sensing System (CO.RI.S.T.A.), P.le Tecchio 80, 80125, Naples - Italy, e-mail alberti@unina.it

+European Space Agency, XRI Department, Keplerlaan 1, 2200 Ag Noordwijk - The Netherlands; e-mail: mneira@estec.esa.nl

ABSTRACT

Through a feasibility study funded by the European Space Agency (ESA), the authors analysed the possibility of using the innovative concepts of bistatic altimetry to enhance the spatial sampling of topography measurements over the oceans.

Purpose of this paper is thus to review the major results of the mission design, focusing on the spacecraft configuration, mission analysis and the descripition of the mono-bistatic altimeter payload which represents the real innovative feature of the study carried out.

NOMENCLATURE

h	satellite altitude
θ	bistatic angle value
P_p	transmitted peak power
$G(x,y)$	generic antenna pattern gain
R_T	distance transmitter-target
R_R	distance target-receiver
λ	wavelength
σ	target's radar cross section
kT_0B_nF	noise power
k	Boltzman constant
F	receiver noise figure
T_0	system noise temperature
B_n	system noiseidth
L_a	total atmospheric losses (Tx + Rx)
L_{RF}	total radio-frequency losses (Tx + Rx)
$\overline{\sigma^0_{eq}}$	equivalent mean backscattering coefficient
B	baseline length
r	radar vertical resolution (related to radar pulse characteristics)
$(\vartheta_x, \vartheta_y)$	antenna to bistatic point direction
$(\overline{\vartheta_x}, \overline{\vartheta_y})$	antenna pointing angles
$(\vartheta_{3x}, \vartheta_{3y})$	antenna apertures (-3dB)
η_{tot}	total antenna efficiency
τ	transmitted pulse length
E	transmitted energy
SNR	Signal to Noise Ratio
(D_x, D_y)	antenna dimensions
Δh	maximum orbit variation

INTRODUCTION

Topography has been identified by ESA as a candidate explorer mission in the 2000-2010 period^1.

Ice topography has been successfully studied by several space missions, but more accurate measurements are required in order to allow derivation of ice thickness which is an essential parameter for climate and hydrology investigations.

Concerning land topography, several techniques have been used, but results lack of homogeneity and, in most cases, of accuracy.

Ocean topography is mainly used to monitor the ocean circulation which influences mechanical energy, mass and heat exchanges between ocean and atmosphere and, therefore, the world climate at seasonal and long-term time scales.

Several missions (Seasat-1, ERS-1, ERS-2, Topex-Poseidon) have extensively measured the ocean surface and future missions (ENVISAT-1, Topex-Poseidon Follow-On) will guarantee data continuity. However, the mission requirements for an ocean topography mission dedicated to the mesoscale, global circulation and high latitude observation demand for short revisit times (10 days as worst case for high latitude) and quite dense spatial sampling (30 km).

Since a trade-off exists between the achievable spatial and temporal samplings, a single-satellite mission does not meet both requirements. A constellation of nadir-looking altimeters allows to meet the mission requirements by means of existing sensor technology, but the large number of required satellites[2] (8 or 10 depending on the exact coverage and sampling requirements) would result in a cost demanding mission. During the years, many efforts have been then concentrated in the definition of various measurement concepts[3,4,5] based on multi beam off nadir altimetry techniques to overcome the limited spatial sampling capabilities of nadir looking altimeters. In this light, very recently, an innovative technique based on the application of bistatic measurements to constellation of satellite altimeters has been proposed[6]. Such a method, once applied to constellation of altimeters, represents a real shortcoming in the reduction of the number of satellites otherwise required using nadir looking altimeters with the key advantage of keeping to a reasonable level the amount of added complexity in the instrument design.

In this framework, the authors have carried out under ESA contract a feasibility study for the design of such a bistatic altimetry mission dedicated to ocean topography mapping. On the basis of the science requirements, the constellation parameters have been defined in terms of orbit and number of satellites.

The instrument, aimed to perform mono and bistatic measurements simultaneously, has been designed according to the guidelines identified for the selection of the main sensor parameters (i.e. antennas pointing angles, antennas aperture, transmitted energy, pulse length, transmission timing). The system parameter figures have been determined to minimise the overall system complexity and cost. In particular, antenna chararacteristics (a multi aperture fixed beam configuration has been selected), transmitted peak power and radar pulse length are tailored to guarantee a satisfactory level of Signal to Noise Ratio for the bistatic operations along the whole orbit.

BASIC CONCEPTS OF BISTATIC MEASUREMENTS

In a straightforward way, a bistatic radar system is defined when antennas for reception and transmission are physically separated[7]. In this case, the location of the target (T) depends on the distance between the transmitting and receiving antennas (S1 and S2), called baseline, and the measured propagation path.

The targets for which the sum of distances from the transmitting and receiving antennas is constant, can not be resolved in distance by the bistatic system. These point targets identify in the three-dimensional space an ellipsoid and its intersection with a generic plane determines ellipsoidal isorange contours.

Referring to a single pair of satellite radar altimeters, the point tangent to the Earth surface for which the sum of the distances from the two satellites is minimal is called *bistatic point* and it is characterised by a *bistatic angle* from the nadir direction.

As it happens in the monostatic case, the area delimited by two consecutive isorange contours is constant over the swath and it is approximately given by:

$$\Delta S_{bi} \approx \frac{2 \cdot \pi \cdot h \cdot r}{\cos^2 \theta} \qquad (1)$$

From the qualitative point of view the situation is depicted in figure 1: a series of ellipses around the point of reflection is obtained which simplifies in the well-known pulse limited nadir looking geometry when the transmitter and the receiver match in the same point.

The fact that the isorange lines are assimilated to ellipses over the observed surfaces, leads to an echo model[8] which, at a first glance, has some similarities with the well-known Brown model[9] of the monostatic nadir-looking geometry. This is a main advantage respect to off-nadir altimetry: the off-nadir observation geometry causes, in fact, broadening of the echo leading edge which, in turn, reflects in reduced sensitivity to sea surface roughness and worsening of topography estimation algorithms performance.

Figure 1 - Sketch of bistatic isorange contours over a spherical surface

The Signal to Noise Ratio (SNR), driving item of any electronic system under design, for a generic bistatic radar system can be written as:

$$SNR_{bi} \approx C\overline{\sigma^0_{eq}} \frac{G(S1,T)G(S2,T)}{R_T^2 R_R^2} \Delta S_{bi} \qquad (2)$$

with:

$$C = \frac{P_p \lambda^2}{(4\pi)^3 k T_0 B_n F L_{RF} L_a} \qquad (3)$$

where an equivalent mean backscattering coefficient can be introduced by averaging over the integration area an equivalent backscattering coefficient which includes the mechanisms of the bistatic scattering. Due to the small bistatic angles involved (<10 deg.) and by considering gently undulating surfaces with large radius of curvature compared with the incidence wavelength, in the Kirchhoff approximation[10] a very slight variation from the value used in the monostatic case is expected.

By considering equal Gaussian antenna patterns for the altimeter systems and by applying the approximations related to the small angles involved, the following final expression for the bistatic Signal to Noise Ratio can be assumed:

$$SNR_{bi} = K_{SNR} \frac{E}{\vartheta_{3x}^2 \vartheta_{3y}^2} \frac{1}{h\left(4h^2 + B^2\right)} \exp\left[-2\log 2 \frac{\tan^2\left(\vartheta_x - \overline{\vartheta_x}\right)}{\tan^2\left(\frac{\vartheta_{3x}}{2}\right)}\right] \qquad (4)$$

$$\exp\left[-2\log 2 \frac{\tan^2\left(\vartheta_y - \overline{\vartheta_y}\right)}{\tan^2\left(\frac{\vartheta_{3y}}{2}\right)}\right]$$

where

$$K_{SNR} = \frac{2 \cdot r \cdot \lambda^2}{k \cdot T_o \cdot F \cdot L_{RF} \cdot L_a} \cdot \overline{\sigma_{eq}^o} \cdot \eta_{tot}^2 \qquad (5)$$

In the analyses, the following reference values have been used:

$h = 707$ Km	$\lambda = 2.2$ cm	$\eta_{tot} = 0.5$
$\overline{\sigma_{eq}^0} = 6$ dB	$F = 4$ dB	$L_{RF} = 4$ dB
$L_a = 2$ dB	$T = 290$ K	$r = 0.46875$ m

COSTELLATION AND ORBITAL CONSIDERATIONS

Various satellite constellations have been considered with different orbit solutions, either based on Sun Synchronous options or not.

The most reliable solution both in terms of cost and complexity suitable to meet the topography mission requirements, is represented by a double pair of monostatic / bistatic radar altimeters in Sun Synchronous Orbit. Bistatic operations is limited to the acquisition of one bistatic measurement beneath each pair of satellites ; each satellite pair operates independently of the other. The major orbital parameters are reported in table 1.

Within the satellite pair, the satellites are closed and slightly spaced out in Ω (right Ascension Node) of about 1 deg and in mean anomaly of about 0.16 deg to avoid collision risk at poles crossing. On the other hand the two satellite pairs are spaced out in Ω of about 90 deg. to guarantee optimum revisit time homogeneity.

Looking to the single satellite pair and fixing an orbiting right-handed reference frame in the centre of mass of a satellite (y axis perpendicular to the orbital plane and z axis along the local vertical towards Earth's centre) the variations of the baseline components along the orbit can be evaluated.

The component along the y axis, the largest one (up to ~ 110 km), is due to the difference in the ascending node and it changes sign passing over the poles since the satellites switch their mutual position. The component along the x axis (few Km) is due to the time lag introduced between the two satellites for safety reasons, while the z component is caused by the orbital geometry and it is surely negligible.

The strong variability of the baseline along the orbit entails significant changes of the relative position of the bistatic point with respect to the two satellites.

Semi-major axis	7085.6996 [km]
Inclination (mean)	98.218390 [deg]
Eccentricity (mean)	0.00106689
Argument of perigee	90 [deg]
RAAN	270 [deg]
Mean Anomaly	90 [deg]
Revolutions in a cycle	131
Repetition cycle	9 [day]
Mean Motion (J2 corrected)	14.564 [rev/day]
Subcycle period	2 [day]
Revolution period	98.931327 [min]
RAAN rate	0.985599 [deg/day]
Perigee height	700.0000 [Km]
Apogee height	715.1193 [Km]
Equator Cross Separation	305.916 [Km]
RAAN difference	0.916029 [deg]
Anomaly difference	0.1617 [deg]

Table 1 - Main orbital parameters of the chosen bistatic constellation

For further evaluation of SNR, it is preferable to express the position of the bistatic point by means of two angles measured in the elevation plane (yz) and in the azimuth plane (xz). Figure 2 shows, for each satellite of the bistatic pair (upper and lower solid line), these azimuth and elevation angles which can be viewed as the steering angles needed to align the antenna broadside with the line of sight of the bistatic point. The satellites positions for which the baseline length is less than 30 km are not plotted since the bistatic measurements are considered to be not significant.

Of course, the most significant angle is the steering angle in the elevation plane since it is mainly caused by the variation of the y component of the baseline, while the other one is due to the variation of the x component.

As expected, due to the symmetric position of the bistatic point, the steering angles needed for one satellite are opposite to those required for the other one.

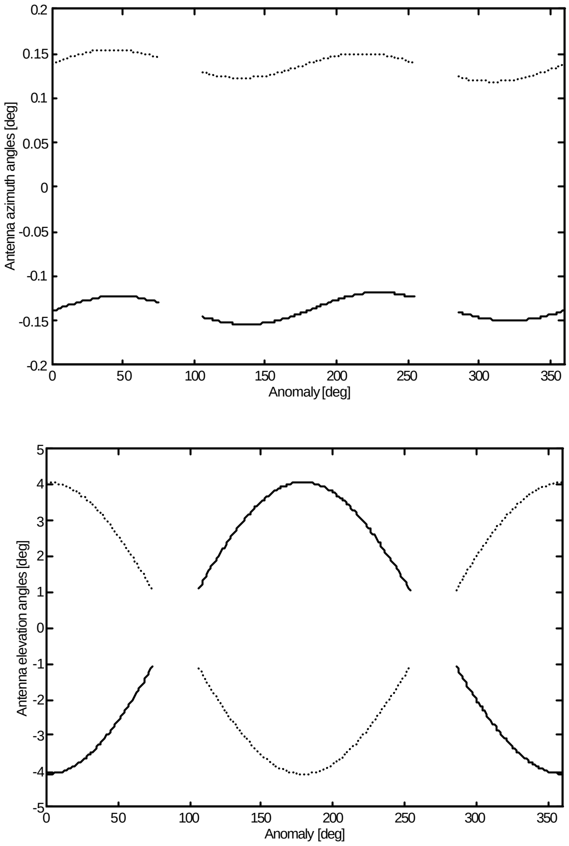

Figure 2 - Position of the bistatic point measured by means of the two antennas steering angles

SYSTEM DESIGN

The general goal consists in determining the main system parameters, such as the transmitted peak power, the pulse length and repetition frequency, the antenna pointing and aperture angles, suitable for a small satellite mission.

To this end, for limiting the system power requirement, it is preferable to fix a satisfactory level of SNR (10 dB) and thus determine the antenna characteristics in order to minimise the required transmitted energy per pulse along the orbit.

In particular, the values of antenna apertures can be optimised with respect to the energy to be transmitted by solving, regardless the subscript x and y and by considering small angles, the following equation:

$$\frac{\vartheta_3}{2} \approx \left|\tan\left(\vartheta - \overline{\vartheta}\right)\right|\sqrt{2\log 2} \qquad (6)$$

Of course, if the SNR level threshold should be maintained along the whole orbit, the worst case of the (6) should be considered, in correspondence with the maximum expected steering angle.

If systems with single beams wide enough in the across track direction (y axis) to cover the variability of the bistatic point along the orbit because of baseline changes are considered, the previous optimisation procedure does not lead to suitable design values. In fact, the required level of SNR can only be maintained along the whole orbit either by transmitting a high energy value per pulse or by using very large antenna in the along-track direction (x axis) to compensate the antenna gain decrease demanded by the assumption of a wide antenna beam along the y axis. For example, the performed analysis gives:

θ_{3y} [deg]	9.7			
θ_{3x} [deg]	0.2	0.35	0.5	1
E [mJ]	2	5	10	40
B [Km]	115			
G [dB]	39.2	36.7	35.2	32.2
D_y [m]	0.11			
D_x [m]	5.56	3.18	2.22	1.11
SNR [dB]	10.7	9.8	9.7	9.7

To make a comparison, it is worth to remind that the RA-2 system[11,12] for the ENVISAT platform, transmits an energy of 1 mJ per pulse by using a circular antenna 1.2 meters wide.

A great improvement can be achieved, instead, if two beams, devoted only to bistatic measurements, are added in the baseline antenna subsystem design. Such beams shall be pointed off-side (rightward and leftward) the spacecraft, roughly along the across track direction, and should be sufficiently wide to compensate for the baseline variation along the orbit; they should be used alternatively on the ascending and descending part of the orbit, since the satellites of the constellation change their mutual positions passing over the poles.

Their precise pointing angles in the elevation and azimuth planes can be determined as the mean between the maximum and the minimum values of the steering angles in the corresponding plane of figure 2, obtaining the following values:

$\overline{\vartheta_x}$ [deg]	0.136
$\overline{\vartheta_y}$ [deg]	2.573

The optimisation procedure of the antenna apertures entails a value of 3.55 degrees in the elevation plane, while, in the azimuth plane, a value of 1.3 degrees has been assumed. In this way, a transmitted energy of 7.5 mJ results sufficient to ensure a minimum SNR of 10 dB along the whole orbit for the bistatic measurement.

Following such a design approach, the antenna subsystem of the monostatic / bistatic altimeter shall be characterised by a central circular beam devoted only to monostatic nadir looking measurements (an onset parabolic circular reflector can be used), and two side elliptical beams devoted to the bistatic measurements which can be implemented as planar apertures (slot waveguides).

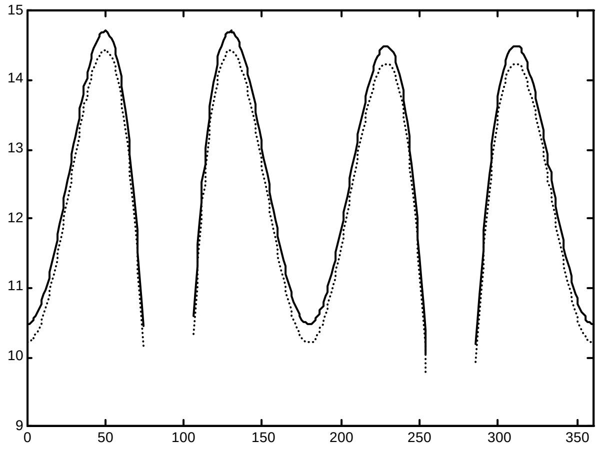

Figure 3 – Bistatic SNR [dB] as a function of the mean anomaly along the orbit.

In addition, the opposite pointing angles in the azimuth plane of the two planar arrays can be avoided by accepting very small degradation in the final performances; the simulation in figure 3 confirms that the decrease in SNR level is very small along the whole orbit, reaching a maximum value of just 0.25 dB.

Synchronisation between monostatic and bistatic operation in the satellite pair shall take place according to the timing proposed in figure 4.
Bistatic and monostatic operation are alternate in time : M_1 and M_2 represent the monostatic echoes received by the altimeter pair (the ambiguity rank is neglected for the purpose of illustration), while B_{12} (B_{21}) is the bistatic echo received by the second (first) satellite in correspondence to a pulse transmitted by the first (second) one.

The alternate use of each altimeter of the satellite pair either as transmitter or as receiver in the bistatic operation allows to remove any residual bias in the measurements caused by relative shifts in the timing of the two instruments. What is important, instead, is the absolute synchronisation between the satellites timing sequences. This can be accomplished using the Pulse per Second signal available from GPS receiver[13] as reference synchronisation signal for timing generation inside the instruments.

PAYLOAD DEFINITION

The functional block diagram of the proposed monostatic / bistatic altimeter is reported in figure 5. It is a double frequency (Ku and S) altimeter with a slightly more complex antenna system if compared to the classic conventional altimeter scheme of the RA2 [11,12].
The S band has been included in the design to allow built in correction of ionospheric bias through combination of the Ku and S band measurements on ground[14].

A simple two channel - 24 and 37 Ghz- radiometer like the one of ENVISAT[15](not shown in figure 5) can also be included in the science payload configuration as auxiliary instrument to the altimeter for the tropospheric correction of the range measurements.

The up-down conversion frequencies in the altimeter system are all generated through the frequency of a reference oscillator locked to the common time reference given by the pulse per second signal of the GPS.

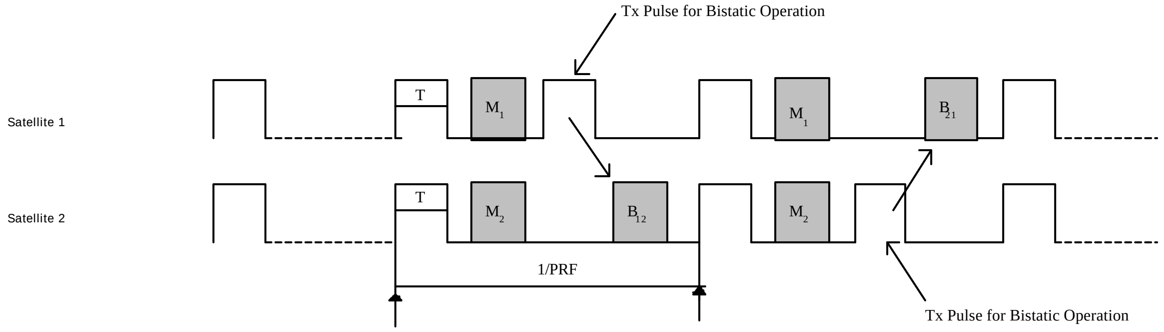

Figure 4 - System timing

The antenna subsystem is characterised by a parabolic reflector 1.2 m diameter with coaxial Ku/S band feed for nadir-looking operation as monostatic altimeter and by two rectangular radiating panels for the bistatic operation.

Only one of the two panel works at a time: i.e. the left one of the first satellite and the right one of the second satellite during the ascending pass while the right one of the first satellite and the left one of the second satellite during the descending pass of the orbit. The S band channel of the altimeter is of course operated only in the monostatic nadir looking geometry. The key system design parameters are reported in table 2. The resultant SNR for both monostatic and bistatic operation is:

SNR = 23.8 dB for nadir looking Ku band operation at 320 Mhz chirp bandwidth

SNR = 13.4 dB for nadir looking S band operation at 160 Mhz chirp bandwidth

SNR = 10 - 15 dB for bistatic Ku band operation at 320 Mhz chirp bandwidth.

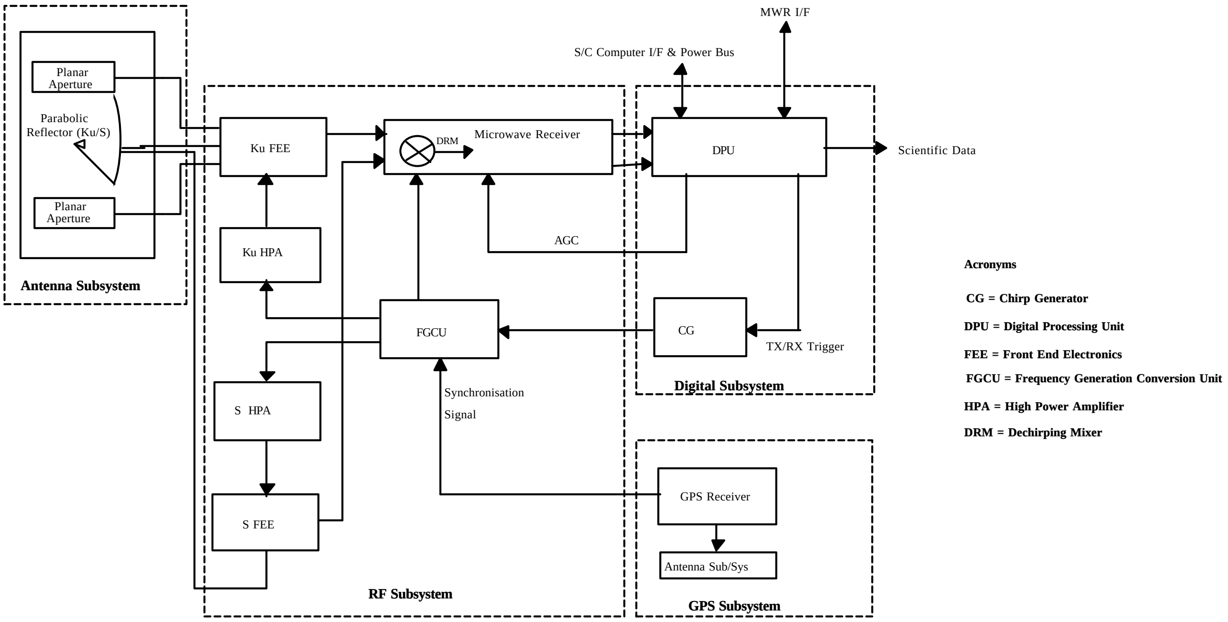

Figure 5 - Radar Altimeter Functional Block Diagram

Operative Frequency	13.575 Ghz and 3.2 Ghz
Antenna Characteristics **1.2 m parabolic reflector Ku/S** **1.2 x 0.3 m 2 rectangular apertures**	1.3° - Nadir Looking 3.55° x 1.3° +/-2.57° off-nadir orientation
Tx Peak Power	95 W Ku band - 60 W S band
Tx Pulse Length	80 µs Ku band - 40 µs S band
Pulse Repetition Frequency	890 Hz - Ambiguity rank: 4
Chirp Bandwidths	320 - 80 - 20 Mhz (or 10 Mhz) Ku band 160 Mhz S band
Receiver Noise Figure	4 dB Ku band - 3 dB S band
RF Losses	4 dB Ku band - 3 dB S band
FFT Size	128 points
IF Bandwidth	1.6 Mhz
Atmospheric Losses	2 dB Ku band - 1 dB S band
Instrument Data Rate	approx. 100 Kbit/s

Table 2 Radar Altimeter System Parameters

The SNR figure for the Ku monostatic operation is well oversized respect to typical needs of conventional nadir looking altimetry (suitable reference figure is in fact 10 - 15 dB) but this is due to the tailoring of the Tx peak power level for the bistatic operation.

A classic pulse transmission timing like the one reported in figure 5 is assumed for the system with Monostatic / Bistatic measurements limited to +/- 70 deg latitude.

Outside this range only monostatic operation is envisaged with the same timing scheme except for the fact that the additional Tx pulses needed for the bistatic operation are blanked.

S band pulses for every Ku monostatic pulse are to be included in the timing.

Instrument hardware recalls that typical of any other conventional altimeteric system (pulse compression is accomplished through the well known dechirping technique) except for the peculiarity of time synchronisation to a common reference and of a double tracker processor to handle both monostatic and bistatic echo measurements at a time.

A key point in the on-board tracking philosophy definition is represented by the tracking initialisation strategy. In a monostatic system the tracking phase is preceeded by an acquisition phase for a preliminary definition of the echo position within the expected receiving interval established by the orbit range of variability.

Typically, an unmodulated pulse of coarse resolution (hundreds of meters) is used for this task and operation with chirped pulses is only accomplished after successful determination of the radar - surface distance position.
In a bistatic system such an operation is much more complex since a direct communication link between the transmitter and receiver would be required to program the radar pulse characteristics to be used by the transmitter according to the decisions taken by the receiver.
To avoid such a level of complexity the most straightforward solution is represented by the use of a predefined resolution switching sequence, making use of the nadir-looking tracking information for the initialisation of the tracking. The tracker shall be designed to automatically perform acquisition and tracking with resolution adaptivity for the normal monostatic nadir-looking operation, instead.

Due to the coarse initialization of the receiving window position, both transmitter and receiver shall start the bistatic operation at low resolution (typically a 10 or 20 Mhz chirp bandwidth would be required) for a predefined number of pulses; then, a switch to a higher resolution (as the one provided by an 80 Mhz chirp bandwidth) shall be automatically performed by both systems and mantained for a predefined duration before finally passing to the highest resolution (320 Mhz chirp). A suitable strategy should also be defined to avoid loss of tracking condition during bistatic operation. To this purpose an automatic programmable degradation of the resolution by both the transmitter and receiver could be used.

Instrument calibration shall be accomplished as in any other altimetric system through the measurement of instrument point target response, IF filter shape and main oscillator frequency. A key point is represented by the necessity, at least from a theoretical point of view, to measure the joint Tx -Rx point target response of the bistatic system. This would be the only chance for monitoring and correction of errors caused by differential phase ripples and differential chirp slopes between the Tx and Rx hardware that pertains to two physically distinct hardwares. Being such a possibility absolutely to be verified (i.e. active trasponders should be located on the bistatic reflection point in between the two satellites involved in the measurement) slightly higher residual calibration errors are expected to affect the bistatic range measurements with respect to the conventional monostatic nadir-looking measurements.

MISSION DEFINITION

The spacecraft configuration and subsystems have been designed to allow the maximum flexibility in term of launch approach and satellite costellation configuration.
With the present satellite design single, double or quadruple launchs are allowed.
The selected launchers could be, for example, COSMOS for the single launch, EUROCKOT and LLV 2 for the double launch and ARIANE 4 or CYCLONE for the quadruple launch.

The considered reference mass for any spacecraft is of 400 Kg, therefore for the double launch (in stacked configuration) 800 Kg must be injected into the operational orbit; for a quadruple launch at least 2000 Kg (including the adaptors masses as SPELDA for Ariane 4) must be launched.

Mission performance analysis and trade-off have shown that a sun-synschronous orbit with an altitude of 707.5 Km can be considered as the best solution to fulfil the topography mission requirements.

A so-called "double-pairs" satellite constellation configuration has been selected: the two satellites composing each satellites pair are close and slightly separated in Ω and mean anomaly. The bistatic altimetry

working mode is performed between the two satellites belonging to the same pair.
In order to allow the design of four identical spacecrafts selection of two similar Sun Synchronous Orbits (SSO) spaced out in Local Time Ascending Node of 90 deg. has been preferred. The first couple could be in a 9 am / 9 pm SSO while the second couple could be in a 3 am / 3 pm SSO.

Spacecraft configuration

The Spacecraft configuration has been designed taking into account of the following criteria:

- full compatibility with a single, double (on a small launcher) and quadruple launch (on a medium capability launcher)
- minimisation of the spacecraft dimensions and weight
- minimisation of deployment mechanisms (for antennas feeds and reflectors) in order to increase the intrinsic system reliability
- a total spacecraft mass compatible with the launcher capability for the selected orbits

Of course, in order to minimise the overall mission cost the four bistatic spacecraft must be identical.
The designed spacecraft with a payload based on a traditional reflector is shown in figures 6 and 7 respectively for the double launch (within EUROCKOT fairing) and the flight configuration.

The spacecraft has been designed following a traditional approach; no new development equipment is baselined at present.

Structure

The structure can be considered as a critical subsystem because of the need to perform a double launch with two spacecrafts in a stacked configuration. The central thrust tube (which must withstand the main launch loads) must be dimensioned (honeycomb structure with Carbon Fiber Reinforced Plastic - CFRP - skins) considering the selected launchers launch loads requirements.

Thermal Control Subsystem (TCS)

No particularly demanding thermal requirements (absolute temperature, thermal gradient and thermal stability) and no severe mission operative conditions are foreseen for the satellite, the TCS should not be a critical subsystem.
A TCS design, based on passive techniques (i.e. paints, heaters, radiators, etc.), should be suitable to guarantee the spacecraft internal thermal environment and temperature.

Attitude Determination and Control Subsystem (ADCS)

A pointing error requirement of 0.07 deg (2 σ) has been assumed about pitch and roll for the nadir-looking altimeter working mode.
Considering the rather demanding attitude pointing requirement the ADCS can be baselined on the following equipment:

- two (for redundancy reason) medium-accuracy star sensors
- three coarse sun sensors for the initial attitude acquisition and for sun direction tracking accuracy of about 0.5 - 1 deg)
- magnetometer for the Earth magnetic field orientation detection
- four reaction wheels for a fine attitude actuation
- three magnetic torquers to dump the wheel accumulated angular momentum

Figure 6 - Double launch configuration within EUROCKOT fairing

Figure 7 - Spacecraft flight configuration

The star sensors can provide a full three-axis attitude determination; the accuracy about the sensor Line Of Sight (LOS) is obviously lower than that about LOS perpendicular direction but is anyway compatible with the requirements (pointing req. about star sensor LOS = 0.3 deg - 2σ).

The four reaction wheels can provide torques for a very accurate attitude control while the magnetic torquers have the task to unload the wheels accumulated momenta.

Propulsion Subsystem

A traditional hydrazine system (working in a blow-down mode) is baselined in order to perform the following tasks :

- launcher injection errors correction
- orbit maintenance
- satellites constellation configuration generation
- satellites constellation configuration maintenance
- satellite removal from the constellation in case of satellite failure

The total required hydrazine mass is then of about 29.6 Kg (including 20 % of margin).

The hydrazine propulsion system will be then mainly composed by a tank (capacity of about 30 litres) and four thrusters with a 5 N thrust.

The propulsion system is arranged in two branches with two thrusters each; in nominal condition all the four thrusters are working but in case of a thruster failure the ΔV manoeuvres can be anyway performed with only two thrusters.

Electrical Power Subsystem (EPS)

The total required power, in operative conditions, is of about 335 Watt.

The EPS architecture will be based on an unregulated 28 V bus and it will composed of:

- two deployable solar arrays with a total surface of 5 m^2 (GaAS cells technology)
- Two NiCd batteries; with 866 Ah capacity
- a Power Control and Distribution Unit

The required total power consumption is not particularly high but nevertheless the unfavourable satellite Solar Aspect Angle imposes a high cosine loss degradation factor (about 65 %). This justifies use of GaAs cells technology to avoid a very large solar arraysas baseline design.

On Board Data Handling Subsystem (OBDH)

The OBDH will be based on a central architecture approach. An ESA standard OBDH bus has been baselined.

The OBDH central processor has to perform both OBDH and ADCS tasks.

Telemetry Tracking and Command Subsystem (TT&C)

The TT&C system can be based on the use of only one medium latitude Ground Station (e.g. Fucino) and the following hardware:

- a X-band trasponder to dump only the scientific data contained in the mass memory (maximum Telemetry rate of 6.1 Mbps)
- a S-band trasponder (not necessarily coherent) for Telecommands and House Keeping Telemetries

It must be pointed out that the selection of a medium latitude Ground Station imposes the use of a high capacity on-board mass memory because of the long “blind” time between two following contacts (maximum required memory capacity of 4.5 Gbits).

Mass and Power Budgets

In line with the baseline design proposed we have:

	Mass (Kg)	Power (W))
TOTAL ADCS & OBDH	43.6	57.2
TOTAL PROPULSION SYST	36.2	2.2
TOTAL EPS	97.1	22.0
TOTAL TT&C	18.9	7.9
STRUCTURE & MECHANISMS	36.0	
THERMAL CONTROL	6.0	16.5
HARNESS	14.4	16.5
TOTAL PAYLOAD	105.1	182.6
S/C TOTAL	356.1	304.9
SYSTEM MARGIN (%)	10.0	10.0
OVERALL RESULTS	391.7	335.3

CONCLUSIONS

A potential technique for improving spatial and temporal sampling in reduced revisit times of ocean topography measurements from space has been presented in this paper.

The novel measurement approach foresees use of satellite constellations of radar altimeters able to provide nadir-looking monostatic measurements as well as bistatic measurements between satellites, that is the real innovative aspect of the mission. The technique allows to reduce the number of satellites otherwise needed by a constellation of conventional nadir-looking altimeters reaching the same spatial / temporal sampling and revisit time requirements.

Quite simple constellations have however been considered (i.e. two independent pairs of satellites) in order to reduce the complexity of the payload which would otherwise reflect in a complexity of the overall flight system. A key point in the design is in fact represented by the amount of Tx peak power and antenna configuration to accomplish the bistatic measurements.

Taking into account, instead, the simple constellation configuration selected, a quite simple system can be designed, based on a nadir looking parabolic reflector for combined monostatic Ku / S measurements and two rectangular antenna apertures with predefined off-nadir angle to accomplish bistatic measurements along the orbit.

Absolute time synchronisation of the altimeters involved in the bistatic measurements is a new additional need with respect to constellations of conventional monostatic pulse limited systems. The Pulse per Second signal available from space qualified GPS systems can be used to this purpose as common external reference source.

The spacecraft platform can be designed following a traditional approach; no new-development equipment is baselined at present and compatibility with small/cheap launchers with single/double or quadruple launch is possible. This provides a really high flexibility from the mission planning and launcher selection point of view.

Telemetry and telecommands system can be based on ESA standard S band and X band (limited to science data) channels. Only one ground station (i.e. Fucino) can be used but alternative options with Kiruna, Svalbard, Fairbanks have been investigated for the Ground Segment design.

In the end, the measurement concept, however, looks quite attractive and further work should be devoted in the future to:

- precise definition of algorithms suitable to extract the geophysical informations (i.e. mean sea level height) from the bistatic range measurements.
- detailed electrical subsystem definition (including calibration methodology) to clearly assess the intrument contribution, principally for the bistatic condition, to the overall measurement performance budget.

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