Bistatic Space Borne Radar for Early Warning

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ABSTRACT

The Bistatic Radar architecture, with early warning capability, has been analyzed considering the Tactical Ballistic Missiles (TBM), cruise missile and aircraft, as preferred threats. This study is addressed to analyze the requirements and a proper design of a space borne Bistatic SAR (BSAR) with the relevant performance. The bistatic solution has been considered as a preferred one due to the good immunity to potential jammer present on the theatre area, allowing also a reduced value of peak transmitter power, permitting to utilize quite all the temporal interval for the signal transmission without interruption during the receiving phase. The BSAR technique permits to increase the resolution in order discriminate closely targets.

In addition this paper investigates the imaging of an isolated fast moving pointing object (MPO) and the clutter cancellation needed in presence of fixed terrain/sea background (feature expected in the realistic situation of an object moving over a terrain or over the ocean).

1. INTRODUCTION

In view of this growing potential threats to Europe this study is addressed to analyze the system architecture and the radar characteristics that can give an early warning capability for a suitable immediate defense reaction.

In particular this study addresses the problem of requirements description and design of a space borne bistatic SAR. The transmitter will be on board one o more geo-stationary or HEO satellites while the receiver only on board the LEO satellite constellation. In this solution the LEO satellite constellation will be simpler and lighter due to the absence of the transmitter on board each LEO satellite. The drawbacks, on this solution, are the range between the transmitter and the illuminated target, the lower reliability in case of a transmitter failure. The BSAR requires synchronization between the transmitter satellite and the

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receivers on board the LEO satellite constellation. Therefore a direct communication link between the transmitter and the receiver is necessary in order to measure the frequency and the phase of the received signal referred to the transmitted signal. The imaging of an isolated moving point like object and the clutter cancellation technique are analyzed considering the realistic situation of a target moving over a terrain or over an ocean area.

2. SYSTEM REQUIREMENTS

The wide area coverage has an extension of about 2200 km ∗ 9400 km. Within this area coverage are defined the theatre regions (*access area*) that will have an extension of about 1500 km ∗ 1500 km. An 'a priori' knowledge of which theatre area has to be covered will permit to concentrate the surveillance of the satellite constellation only on this specific area. After detection and track extraction of a threat within the theatre area the system must be capable to maintain the track of the detected target as well to maintain the surveillance task on the assigned crisis area. The system availability required is 80 % with a reconfiguration capability (for a new crisis area) within 24 hours.

The threats to be detected and engaged are:

- TBM;
- Cruise missile;
- Aircraft.

The missile and aircraft threats have been defined in terms of radar parameters, in order to select the best radar solution for the satisfaction of the requirements as follows:

- Target RCS 0.2 m^2. The Radar Cross Section will fluctuate according to Swerling case 1;
- Altitude within 50 Km- 400 Km for TBM, 200 m- 400 m for cruise missile and 200 m-10 Km for aircraft;
- Maximum range for TBM 3500 km. Time of flight for TBM 1÷15 minutes.Average absolute velocity for TBM ≤ 2.5 km/sec.;
- Delivery to ground based radar of the target position within a basket of 1° ∗ 1° ∗ 1 km. For tracking requirements (plot association, track formation) the resolution will be within 1 km;
- Presence of jamming on board and on ground enemy radar;
- Ground/Sea clutter level to be considered.

Two configurations have been preliminary considered and envisaged as potential candidates for a design base:

- Transmitter on board geo-stationary satellite and receiver only on board the satellite constellation;
- Transmitter and receiver on board each satellite on the constellation.

As stated in the introduction the first solution (bistatic) has been selected as a preferred one considering that also if the second solution has the advantage to be more reliable (e.g. if one TX fails the mission is not completely jeopardized) there is a drawback in terms of cost due to the transmitter on board each satellite. The constraint on the system configuration (radar and satellite constellation) is the minimization of the number of satellite (for a realistic and feasible design). They should be as low as possible (e.g. less than 100 satellites should be a goal) for the reduction of cost, maximization of utilization with affordable management and maintenance. This constraint, considering the theatre area of 1500 km ∗ 1500 km (very wide swath capability), has suggested the utilization of the following techniques:

- Use of large antennas;
- Beam forming and phased array;
- SCANSAR.

Moreover we can notice that:

- The reason for the selection of the bistatic SCANSAR solution is a good trade-off between number of satellites needed and the LEO constellation lightness including solar arrays due to the transmitter absence. It has to be considered that a sophistication for the transmitters on HEO is, in any case, unavoidable. In addition the bistatic geometry permits to utilize all the temporal interval for the transmitter without interruption during the receiving phase. It is possible to utilize CW signal (coded) with lower peak power and higher radiometric performance;
- The Signal to Noise ratio (SNR) is a critical parameter, considering the satellites geometry (range) and the limited value of the radar cross section of the targets. In addition the SNR is strongly correlated with the power density on the target and therefore to the swath dimension (TX and RX antennas gain);
- The theatre area (swath size) is too much extended to be covered with a reasonable number of satellites;
- The resolution requirements, for the target spatial identification, are in good agreement with the beam dimension during acquisition and also during tracking, due to the improvement factor, related to the implementation of the Synthetic Aperture concept (SAR), taking into account the integration of a certain number of pulses (defined by the time needed to generate the synthetic antenna referred to the p.r.f.).

In order to arrive to a feasible solution, few constraints have been assumed, considering the present and future (next 10 years) state of the art technology:

- The maximum available transmitter power can not be greater than 75 KW for practical reasons;
- The antenna dimension has been limited to 15 m $*$ 15 m (limited to these values by mechanical problems);
- A frequency utilization within the L band (1÷2 GHz) has been selected as a good trade-off between loss and components availability (antenna and transmitter).

3. BISTATIC GEOMETRY

In order to analyze the constraint related to the **Range resolution** a particular bistatic intercept geometry is shown in figure 1.

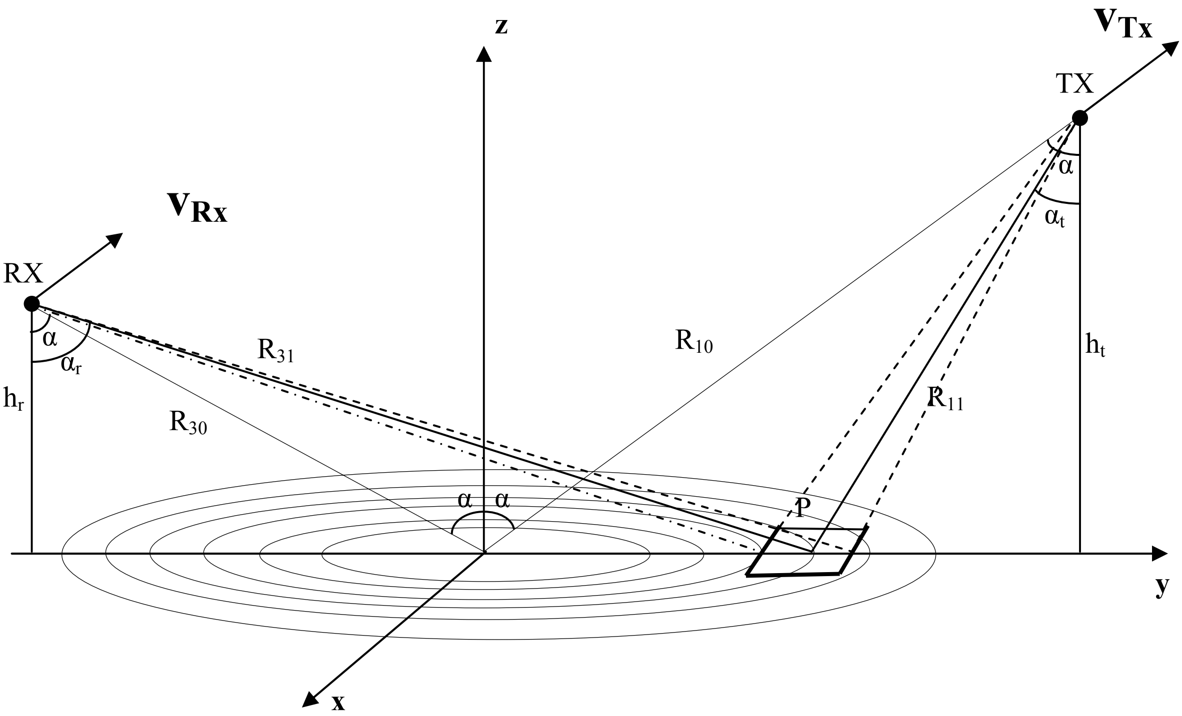

Figure 1

The satellite trajectories must be compensated in order to perform the synthetic aperture. The relation that considers the value of R_{30} in figure 1 must be modified when considering the radial component of the velocity. In order to choose the right centre of the swath, along the y axis, we can define the bistatic ellipse as the collection of points P so that the sum $TP + PR$ is constant (where TP is the transmitter-point distance and PR is the point-receiver distance). If we consider two consecutive ellipses which cross the y axis in P1 and P2 respectively the difference $\delta = (TP_2 + P_2R) - (TP_1 + P_1R)$ represents the bistatic range cell resolution in the slant plane. This distance, considered in the ground plane (x, y plane), is the distance between the two consecutive ellipses. Therefore, if P_1 is placed in $(0,y_1,0)$, P_2 will be in $(0,y_1+R_D,0)$ where R_D is the range resolution. Moreover δ is connected to the transmitted chirp bandwidth B by the relation $\delta = \frac{c}{B}$. We can calculate, after having imposed the range resolution R_D, the chirp bandwidth B as a function of the coordinate y_1 for the center of the swath.

The figure 2 shows that, if we impose, for example, a range resolution of 500 m and a swath centered in y=700 Km, we need a chirp bandwidth of about 1.2 MHz.

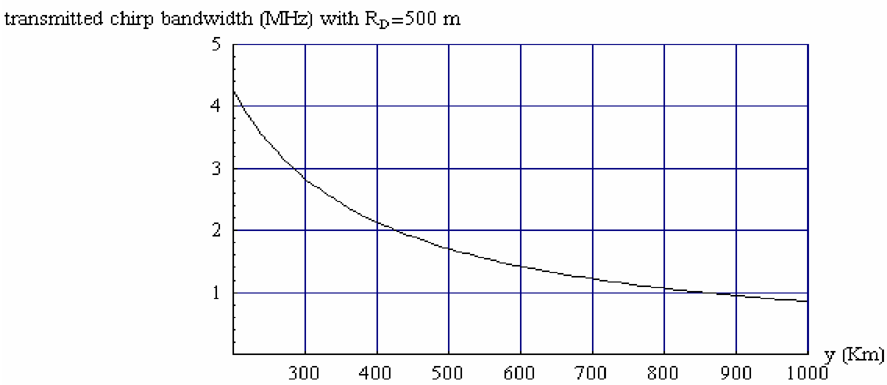

Figure 2

In order to evaluate the Doppler chirp we can write the frequency slope as [23]:

$$\frac{df}{dt} = \frac{B_A}{T_A} \qquad \rightarrow \qquad T_A = \frac{\lambda}{L_r}\frac{PR|_0}{V_{RX}} \tag{1}$$

where:

$$PR|_0 = PR|_{\substack{t=0\\x=0}} = \sqrt{[h_r tg\alpha + y]^2 + h_r^2} \cong \frac{h_r}{\cos\alpha} + \frac{y^2\cos^3\alpha}{2h_r} + y\sin\alpha \tag{2}$$

The azimuth resolution is equal to:

$$R_{AZ} = \frac{V_{RX}}{B_A} \cong \frac{V_{RX}}{V_{RT}} L_r \tag{3}$$

and the integration gain is given by:

$$T_A = \frac{\lambda}{L_r V_{RX}} \frac{h_r}{\cos\alpha_{Pr}} \quad \rightarrow \quad B_A T_A \quad \frac{\lambda}{L_r^2} \frac{V_{RT}}{V_{RX}} \frac{h_r}{\cos\alpha_{Pr}} \tag{4}$$

where α_r is shown in figure 1.

In order to avoid aliasing problem it is necessary that:

$$p.r.f. > B_A = \frac{df}{dt} T_A \cong \frac{V_{RT}}{L_r} \tag{5}$$

We can notice that the last approximations can be accepted in case of slow target motion.

4. TARGET ENGAGEMENT

The **acquisition phase** is a continuous process (multiple target detection requirement) while the tracking process will start, after the detection, for each target.

The signal to noise ratio for bistatic radar, after compression gain, can be written as:

$$SNR = \frac{P_p}{4\pi\lambda^2} A_t A_r \cdot \frac{\sigma \cdot \tau}{R_t^{\ 2} \cdot R_r^{\ 2} \cdot KTFL} \quad (6)$$

where:

A_t, A_r are the transmitter and receiver antenna area, λ is the wavelength of the transmitted frequency, R_t, R_r are the range transmitter-target and receiver-target, σ is the target radar cross section, KTBF is the noise power and L is the system loss.

In order to obtain at least an SNR value of 12 dB, by the previous equation, we can calculate the pulse duration as shown in table 1.

Table 1

	f = 2 GHz		
Parameter	Value	dB	Note
Pp	75 kWatt	-48.7	
λ2	(0.15)2	-16.5	Wavelength
K	1.38·10-23	-228.6	Boltzman constant
T	300°K	24.7	Temperature °K
At•Ar	(15•15)2 m4	-47	Transmitter antenna area
F·L	2	3	Noise figure and loss
4π	12.56	11	
Σ	0.2 m2	6.98	Bistatic radar cross section
Rr2=(hr/cosαr)2	(1830)2 Km2	125.2	Rr = hr/cosαr
Rt2=(ht/cosαt)2	(4315)2 Km2	132.7	Rt = ht/cosαt
SNR		12	
T	3 ms	25	
r>vT τ	> 7.5 m		Range resolution

It has to be considered that this ground resolution is enough for the detection (the requirement is a basket of 1°•1°•1 km).

The IF (improvement factor) for the clutter canceller has to reduce the clutter below the noise level and, at least, a double canceller is needed. An alternative solution is to limit the scanning to a surfaces that are positioned at a suitable height with reference to the ground surfaces.

Concerning the **Tracking** phase, we can notice that an advantage to use the SAR is the possibility to detect closely target within the required basket.

It is straightforward to conclude that the SAR technique produces a better on ground resolution and therefore reduces the needed clutter cancellation (improvement factor).

The CSR (Clutter to Signal Ratio) considering a locally homogeneous terrain is equal to:

$$CSR = \frac{\sigma^0 \cdot \delta_r \cdot \delta_{az}}{\sigma} \tag{7}$$

where δ_r and δ_{az} are respectively the range and azimuth resolution on the ground while σ0 (assumed equal to 0.01 for typical scenario) and σ are respectively the on ground backscattering coefficient and the target cross section.

Assuming the possibility to reach a value of CSR equal to -20 dB, by having a range and azimuth δr and δaz ,we can find out the necessary Improvement Factor(IF), as shown in Fig. 3.

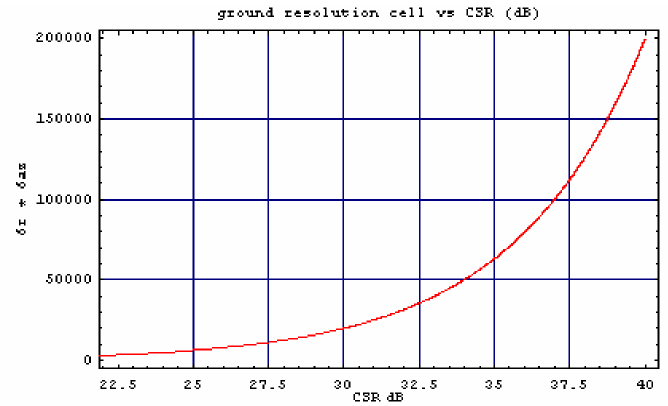

Figure 3

It is evident, by the figure, the resolution required in order to obtain a feasible IF. The design of the system is performed in order to initialize the tracking only on the detected targets during the acquisition phase. In this way the system is operating simultaneously a continuous search and a tracking.

The tracking process can be improved by the utilization of the SCANSAR technique. In this way it is possible to track the target, also in presence of an heavy fading, once an estimation of the target trajectory has been obtained by the detection process.

Moreover by geometric manipulations we obtain [23]:

$$L_r > \frac{V_{RT} S_R^{\ 2} \cos^3 \alpha}{\gamma 2Hc} \quad \Leftrightarrow S_R^{\ 2} = y_{\max}^2 - y_{\min}^2 \Leftrightarrow \Delta_R = y_{\max} - y_{\min} \tag{8}$$

$$\Delta_R = \frac{\lambda}{b_r} \frac{h_r}{\cos^2 \alpha} \quad \Rightarrow \quad b_r = \lambda \frac{h_r}{\Delta_R \cos^2 \alpha} \tag{9}$$

By the equation (8) appears that swath dimension S_R and resolution Δ_R are strictly related and in order to increase the dimension of the swath a large dimension of physical antenna is required; the limitation on swath dimension is a major problem considering the required large dimension of the coverage area. The dimension of the real antenna imposes constraints on swath dimension and its maximum permissible dimensions longitudinal (cross track) and transversal (along track) must satisfy the eq.s (8) and (9). In order to cover an access area of 1500*1500 Km^2 the SCANSAR technique divides the whole area in a number of sub-swaths N_r*N_c. The constraint that the access area A_q will be completely covered during the satellite trajectory is defined by:

$$A_q = (1500)^2\,Km^2 \rightarrow T_A N_r N_c \leq 1500\,Km / V_{RX} = 200\,\sec \tag{10}$$

where N_r and N_c are the number of vertical and horizontal sub-swaths necessary to cover the access area (see Fig.4) and T_A is the acquisition time necessary to obtain a SAR image of one sub-swath.

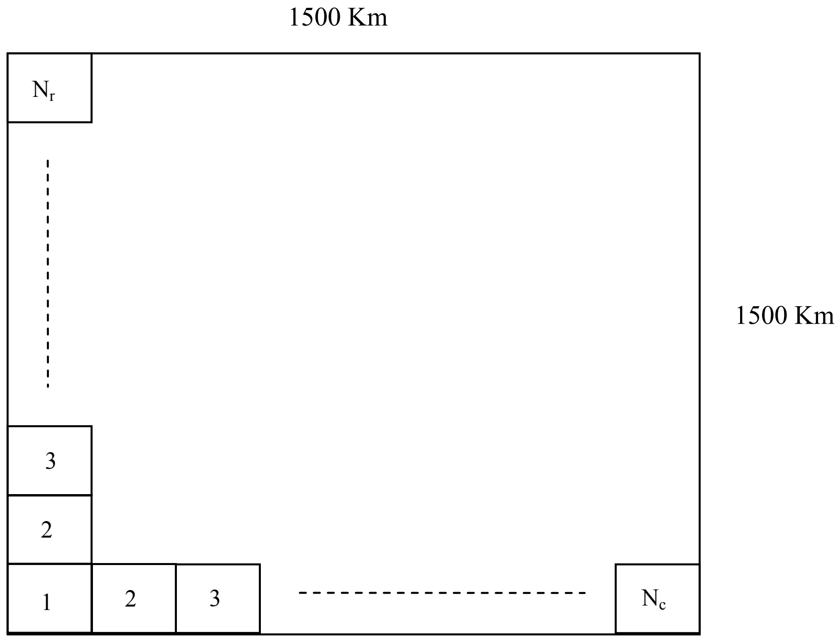

Figure 4

To evaluate T_A we have to consider that the maximum time available in order to avoid the target migration outside the SAR resolution cell, within two pulse repetition interval (minimum condition necessary to perform a suitable clutter cancellation), is equal to:

$$T_a = \frac{R_{AZ}}{2v_T} \tag{11}$$

where v_T is the target velocity. T_a is the maximum time available to obtain the SAR image. The SAR resolution is given by:

$$R_{AZ} = \frac{V_{RX}}{B_A} = \frac{V_{RX}}{V_{RT}} L_r \tag{12}$$

where V_{RX} is the receiver velocity and B_A is the Doppler chirp bandwidth defined by equation (5).

The time necessary to obtain the SAR synthetic aperture is equal to:

$$T_A = \frac{\lambda}{L_r} \frac{h_r}{\cos \alpha_{Pr}} \frac{1}{V_{RX}} \tag{13}$$

Imposing $T_a = T_A$ we obtain the real antenna dimension:

$$\frac{R_{AZ}}{2v_T} = \frac{V_{RX}}{2v_T V_{RT}} L_r = \frac{\lambda}{L_r} \frac{h_r}{cos\alpha_{Pr}} \frac{1}{V_{RX}} \rightarrow L_r^2 = \frac{\lambda}{V_{RX}{}^2} \frac{h_r}{cos\alpha_{Pr}} V_{RT} 2v_T \quad (430)^2\, m^2 \rightarrow L_r \quad 430m \tag{14}$$

where V_{RT} is the LEO satellite velocity equal to 7.6 Km/s.

This states that it's impossible to perform an usual SAR processing which use the whole synthetic aperture. So we have to use a synthetic sub-aperture which is a fraction (equal to1/NL) of the maximum permitted synthetic aperture length and follows that:

$$R_{AZ} = \frac{V_{RX}}{B_A} N_L = \frac{V_{RX}}{V_{RT}} L_r N_L \tag{15}$$

$$\frac{T_A}{N_L} = \frac{\lambda}{L_r N_L} \frac{h_r}{cos\,\alpha_{Pr}} \frac{1}{V_{RX}} \tag{16}$$

The equation (13), considering the equation (16) becomes:

$$T_a = \frac{T_A}{N_L} \rightarrow (L_r N_L)^2 = \frac{\lambda}{V_{RX}{}^2} \frac{h_r}{cos\,\alpha_{Pr}} V_{RT}\, 2v_T = (430)^2\, m^2 \rightarrow L_r N_L = 430\, m \tag{17}$$

In this way the number of sub-aperture N_L in which the synthetic antenna is divided can be chosen so that we can obtain a feasible antenna dimension L_r.

Therefore the maximum permissible value of the azimuth resolution is:

$$R_{AZ} = \frac{V_{RX}}{V_{RT}} L_r N_L \cong 425\, m \tag{18}$$

In this case the synthetic sub-aperture is equal to:

$$L_s = \frac{\lambda}{L_r N_L} \frac{h_r}{cos\,\alpha_{Pr}} \quad 640\, m \tag{19}$$

With the assumption in (17) the value of T_a becomes:

$$T_a = \frac{T_A}{N_L} = \frac{R_{AZ}}{2v_T} = 0.085\, s \tag{20}$$

The number of sub-swaths is given by:

$$T_a N_r N_c \leq 200 \sec \;\rightarrow\; N_r N_c \leq \frac{200 \sec}{T_a} \cong 2353 \tag{21}$$

The transmitter swath must be greater than receiver swath for practical reasons and to verify this condition, as an example, the maximum possible value for antenna dimension are:

$$A_t = 15 \quad 15 = 225 m^2 \rightarrow S_p^t = \frac{\lambda^2 h_t{}^2}{A_t \cos^3 \alpha_{Pt}} \quad 2000\ Km^2 \tag{22}$$

In order to satisfy the above constraint $A_r = L_r b_r \leq 120\,m^2$, we can choose, in order to obtain a approximately square swath, L_r=11 m, b_r=11 m, then N_L is:

$$L_r N_L = 430\,m \rightarrow N_L \cong 39 \tag{23}$$

So we can consider only 1/39 of the whole synthetic aperture. With this value we obtain the stated resolution of 425 m.

The azimuth compression gain is defined as the number of pulses integrated in the acquisition time $T_a = \frac{T_A}{N_L}$ and then it can be written as $p.r.f. \cdot T_a$.

The clutter requirements imposes to maintain the swath as small as possible.

The time required to cover the access area is 200 sec, and potential targets launched during the acquisition and tracking time can not be detected unless several LEO are utilized. In order to overcome this problem, if a preliminary information, on possible launch sites, is available, the acquisition and tracking can be focused only on these sites. In this case the coverage percentage can be increased and simultaneously will also increase the probability to discover simultaneous threats, differently located, in the access are.

5. CLUTTER EVALUATION

If we accept to detect the threat at a certain altitude we can consider that the transmitter and the receiver are not pointed on the ground but at a particular height. Therefore the swaths on the ground are not in the same location and then the influence of the clutter could be reduced (if the two swaths are not overlapped, the clutter will be absent, at least in the main lobe) (see Fig.5).

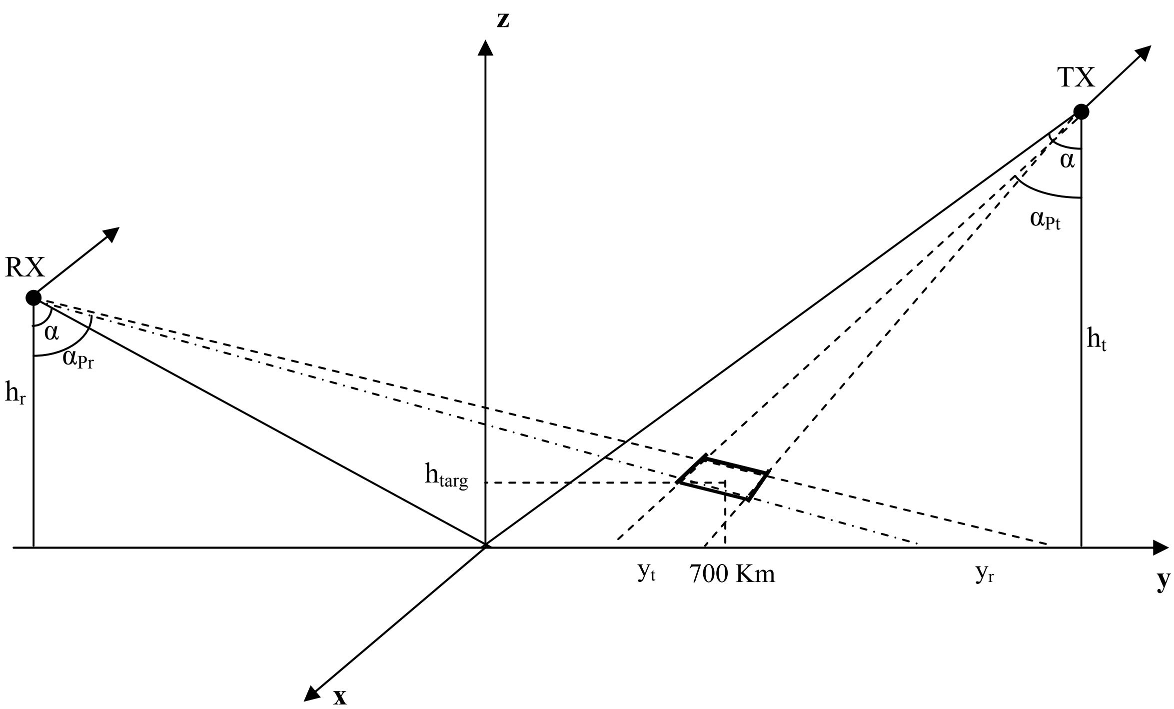

Figure 5

In order to avoid the clutter in the main lobe of the receiver we have to point the antennas at a higher altitude.

It has to be highlighted that to avoid the constraint that the target will be detected only at very high height we can reduce the receiver swath increasing the receiver antenna area up to 225 m^2 (presently has been fixed at 120m^2). This constrains can only be removed if we reduce the access area.

When utilizing clutter canceller the Moving Point Object (MPO) detection and velocity estimation can be performed either incoherently, with a single SAR aperture, or coherently, with two or more apertures [20].

If the receiver antenna is partitioned in two apertures along track direction, coherent processing can be used to find moving objects and estimate their velocities.

The fundamental principle is that each aperture (phase centre) observes the scene from the same point in space at a different time. Features whose range location has shifted from one scene to the next are moving-target candidates. SAR data from each aperture are focused to a complex image and the image content is common except for scene changes over time τ. For land scenes "fixed" elements are stationary over time τ and their images will be very nearly identical.

Moving objects will be displaced between the two scenes, and these displacements can be measured as phase shifts: **Displaced Phase Centre Antenna (DPCA)**.

The SAR DPCA analysis is made by the correlation between the complex sample sets of the first aperture image, S_1, and the second aperture image, S_2, to yield:

$$J = S_1 - S_2 = |S| \cdot \left(e^{j\phi_1} - e^{j\phi_2}\right)$$

$$J = 2|S_1| \sin\left(\frac{\phi_1 - \phi_2}{2}\right) e^{j\left(\frac{\phi_1 + \phi_2}{2} + \frac{\pi}{2}\right)} \tag{23}$$

The magnitude of the subtracted DPCA signals is a sinusoidal function, whose argument is directly proportional to the speed v_{targ} of the scene elements. Transfer function of the DPCA canceller is given by **[22]**:

$$|H(f,\theta)|^2 = \left[1 + \tan^2\left(\frac{\eta}{2}\right)\right] \cdot \left[2 \cdot \sin\left(\pi \frac{f - f_d'}{f_r}\right)^2\right] \tag{24}$$

The performance of the moving target indication with DPCA are shown in [22].

6. CONCLUSIONS

The satisfaction of the main requirements can be obtained with a Bistatic configuration utilizing the phase array technology. The use of BSAR permits to increase the resolution and discriminate closely targets. The preliminary study shows that the bistatic solution is a good trade off for the feasibility of the system. The availability of the satellites on the theatre is a function of the number of satellite within the LEO and HEO/GEO constellation. The transmitted power needs to be very high, for the given SNR (low target RCS), and its value can be obtained by summing the power of more than one HEO satellite. The orbit selection, when operating with BSAR must be selected accurately in order to intercept the target according to the necessary geometry.

REFERENCES

[1] G. Picardi et alii "Bistatic Model of Ocean Scattering " IEEE Tr. Antennas Propag. Vol. 46 n.1Oct.98

[2] A. Ciaffone et alii " Application of the Paris concept to the GPS Signals " T.R. n.1 -3.1.95

[3] A.K.Fung and H.J.Eom , "Coherent Scattering of a Spherical Wave from an Irregular Surface IEEE Tr. Antennas Propagat. Vol. AP-31, pp. 68-72, Jan. 1983

[4] B.Levine, "Fondaments Theoriques de la Radiotechnique Statistique." Moscow, Russia:MIR,1984

[5] "Topography Observing System Study," Studi Tecnologie Sistemi, Rome, Italy Tech.Rep.TR/ STS/001/97, Alenia Spazio Contract TLR/ALS/AR/19/96.

[6] M.A.Srokosz, "On the Joint Distribution of Surface elevation and slope for a non-linear random sea with application to radar altimetry," J. Geophysical Research, Vol.91, pp.995- 1005, Jan.1986.

[7] G.S.Brown, "The Average Impuls Response of a rough Surface and its Application," IEEE Tr. Antennas Propagat., Vol.AP-25, pp.67-74, Jan.1977.

[8] E.Rodriguez, "Altimetry for non-Gaussian Oceans: Eight Biases and Estimation of Parameters," J.Geophys. Res., Vol.93, pp.14.107-14.-120, Nov.1988.

[9] D.E. Barrich and B.J.Lipa, "Analysis and Interpretation of Altimeter sea Echo," Adv. Geophys.,Vol.27, pp.60-99,1985.

[10] G.Picardi et alii "Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS)," T.R. n. MRS-001/004/99, Oct.99.

[11] V.U.Zavorotny and A.G.Voronovich "Scattering of GPS Signals from the Ocean with Wind Remote Sensing Application" IEEE Tr.

[12] M.Migliaccio, M.Sarti On the electromagnetic Scattering from Wind-Roughened Water Surface 0-7803—6362-0/00/§10.00 © 2000 IEEE

[13] G.Bogo et alii "Doppler Beam Sharpening in Bistatic altimeter" Infocom Tr.04 - 005-2000

[14] M.Martin Neira "A passive reflectometry and interferometry system (PARIS): application to ocean altimetry" ESA J. Vol.17 pp.331-355, 1993

[15] Picardi et. al. : "Estimation or surface slope and reflectivity base on processing or radar altimeter data", IEEE National Radar Conference, Wakefield -Boston (Ma), AprиI 20-22, 1993

[16] H. Cramer: "Mathematical Methods of Statistics", Princeton University Press, 1958

[17] F.W. Ulaby, R.K. Moore, A.K. Fung: "Microwave Remote Sensing -Active and Passive" vol.II, Artech House Microwave Library 1986

[18] L.Petrone, G.Picardi, E.Rocca, R.Seu, P.T.Melacci – Multilook techniques and simulation software applied to the DBS Bistatic Altimeters - Oppscat2 – WP400 Mid-Term Report Infocom T.R. 001-005-002B.

[19] Willis N.J., Bistatic Radar, Artech House, 1991

[20] Livingstone et alii, An airborne SAR experiment to support RADARSAT-2 ground moving target indication (GMTI), Can. J. Remote Sensing, Vol. 28, No. 6 , 2002

[21] Picardi G. et alii, Bistatic Model of Ocean Scattering , IEEE Tr. Antennas Propag., Vol. 46 No.1, Oct. 98

[22] Wang H., Mainlobe clutter cancellation by DPCA for space-based radars, IEEE, 1991

[23] Picardi G., Masdea A, SBREW with Bistatic solution, STS, Technical Report February 2005.