BISTATIC MAPPING RADAR BISAR

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***Abstract*- Synthetic Aperture Radar (*SAR*) is a system of active prints that are loaded in a sensor, able to carry out the cartography of natural scenes with a better resolution. SAR's supplies images based on the waves reflected by the earth surface. This technique is very useful since it doesn't depend on the weather condition. In addition, it reveals properties of the earth's surface that do not appear on classical optical images. Indeed, radar waves may describe drifted ices in aquatic surfaces ; they can penetrate under vegetation and even slightly into the basement. However, the main problem with this approach is the interpretation of the radar image that is different from usual graphics.**

When the radar is composed of a simple antenna, we speak about a monostatic configuration. The antenna works in alternative it will function as a transmitter and then switch to a receiver.

The radar can be designed to operate with two separate antenna to perform the transmit and the receive functions, and this may be called bistatic radar

The bistatic system has particular features coming from the separation between the transmitter and the receiver. In this configuration, the transmitter illuminates the scene with beam pointed to its centre. The diffused signal is then picked up by the receiver.

Technological progressions enabled to place the receiver and the transmitter aboard satellites, ships, planes or other carrier. The delocalisation of both the transmitter and receiver makes it possible to improve the capacity of detection and identification of the radar, and thus to increase the detection capacity of a furtive target.

This paper presents the potential scientific objective of the BIstatic Synthetic Aperture Radar (*BISAR*). First, it begins by an extension of modelling, proposed by literature such us monostatic scalar radar model and vertical model (*that take in account the polarisation wave in the transmitter and the receiver*) are presented. Then, the next part will be devoted to the development of two bistatic methods that are an extension of monostatic approaches. Namely, method of coherent summation and method of adapted filtering.

I. INTRODUCTION

When we want to operate above the cloud cover or night, it is necessary to give up the optical techniques for the benefit of radars with short wavelength, which make it possible to establish stereotypes monochromic photographic or with contrast reinforced by use of artificial colors corresponding to different rates of reflection, as it is about constructions, about class of water, about forests or about farmlands.

Radars use electromagnetic emissions of which the wavelength must be sufficiently large so that it is not very sensitive to the clouds and the fog, and sufficiently small to be able to be concentrated and directed by metal reflectors, or to cross the ionosphere

Synthetic Aperture Radars are airborne systems how present very high resolution, capable of making the cartography of the natural scenes with a better resolution.

When the radar consists of a single antenna to execute the functions of transmission and reception, it is then about a Monostatic configuration [1]. The antenna is divided at time between the functions of transmission and reception "Fig. 1".

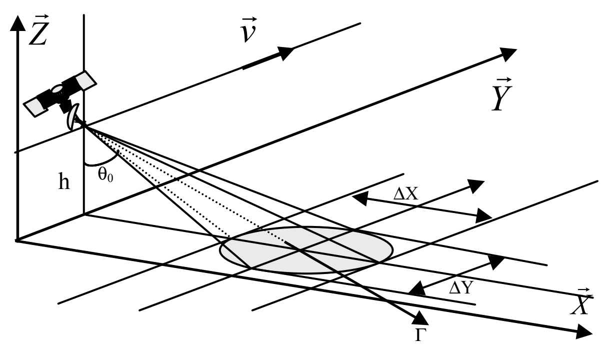

Fig. 1. Geometrical configuration of a monostatic SAR

The SAR can be built in order to operate with two separate antennas so as to carry out the functions of transmission and reception and he is called BIstatic SAR or BISAR [2]. A radar system is said in bistatic configuration, "Fig. 2", when the transmitter and the receiver stations are placed in two different places situated at a large distance.

A direct communication link between the transmitter and the receiver is necessary to measure the phase of the received signal relative to that of transmitted signal.

Radar images of the earth surface can be produced with a BISAR. With two images of the same area viewed from different angles, it is possible to derive three-dimensional stereo images. For the same resolution, the amount of integration time and transmitter power is less than those required for a monostatic SAR [3].

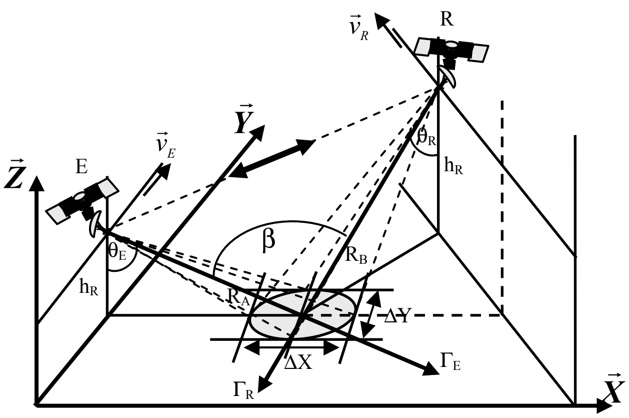

Fig. 2. Geometrical configuration of a bistatic SAR

II. MODELLING FOR BISAR IMAGING

Figure 3 illustrates the general geometry of a bistatic connection between a moving transmitter, a moving target and a moving receiver, where speeds are respectively noted $\vec{v}_E(t)$, $\vec{v}_C(t)$, and $\vec{v}_R(t)$.

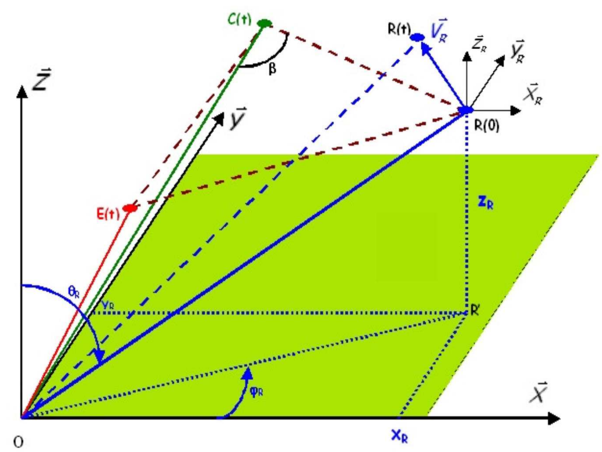

Fig. 3. Geometry of a bistatic connection

Each entity of the connection is located either by its cartesian coordinates or by its spherical coordinates.

The instantaneous positions of the transmitter, the target and the receiver are defined in a fixed reference mark of centre *O*.

The delay between the moments of emission and reception of the wave emitted at one moment t is equal to the travel time $\Delta t_{ER}(t)$ of the wave between the transmitter, the target and the receiver.

By supposing that the incidental wave is reflected instantaneously, the travel time transmitter-receiver will be the sum of the travel times transmitter-target and target-receiver [4].

$$\Delta t_{ER}(t) = \Delta t_{EC}(t) + \Delta t_{CR}(t) \tag{2.1}$$

$\Delta t_{EC}(t)$ is the duration of propagation of the signal between the transmitter and the target; it is given by (2.2).

$$\Delta t_{EC}(t) = \frac{\overrightarrow{E_tC_t}.\overrightarrow{V_C}(t) + \sqrt{\left\|\overrightarrow{E_tC_t}.\overrightarrow{V_C}(t)\right\|^2 + \left\|\overrightarrow{E_tC_t}\right\|^2\left(c^2 - \left\|\overrightarrow{V_C}(t)\right\|^2\right)}}{c^2 - \left\|\overrightarrow{V_C}(t)\right\|^2} \tag{2.2}$$

Where

$\overrightarrow{E_tC_t}$ is the vector which connects the transmitter and the target at the moment t,

$\overrightarrow{V_C}(t)$ is the speed of the target,

c represent the celerity.

$\Delta t_{CR}(t)$ is the duration of propagation of the signal between the target and the receiver; it is given by (2.3).

$$\Delta t_{CR}(t) = \frac{\overrightarrow{C_{t_C}R_{t_C}}.\overrightarrow{V_r}(t) + \sqrt{\left\|\overrightarrow{C_{t_C}R_{t_C}}.\overrightarrow{V_r}(t)\right\|^2 + \left\|\overrightarrow{C_{t_C}R_{t_C}}\right\|^2\left(c^2 - \left\|\overrightarrow{V_r}(t)\right\|^2\right)}}{c^2 - \left\|\overrightarrow{V_r}(t)\right\|^2} \tag{2.3}$$

t_C is the moment when the wave emitted at the moment t reaches the target,

$\overrightarrow{C_{t_C}R_{t_C}}$ is the vector which connects the target and the receiver at the moment t_C,

$\overrightarrow{V_r}(t)$ is the speed of the receiver.

If the communication between the transmitter and the receiver can be done by the direct way, then the duration of direct propagation of the signal between the transmitter and the receiver is given by (2.4).

$$\Delta t_{ER}(t) = \frac{\overrightarrow{E_tR_t}.\overrightarrow{V_r}(t) + \sqrt{\left\|\overrightarrow{E_tR_t}.\overrightarrow{V_r}(t)\right\|^2 + \left\|\overrightarrow{E_tR_t}\right\|^2\left(c^2 - \left\|\overrightarrow{V_r}(t)\right\|^2\right)}}{c^2 - \left\|\overrightarrow{V_r}(t)\right\|^2} \tag{2.4}$$

$\overrightarrow{E_tR_t}$ is the vector which connects the transmitter and the receiver at the moment t,

It is supposed that the transmitter, the target and the receiver are stationary during a phase of transmission-reception.

In this paper, we chose a configuration for which the transmitter and the receiver move in parallel to mapping the scene, "Fig. 4". The scene consists of a whole of elementary contributors.

It is supposed that the two entities are separate in site by a distance equal to X_0 and in azimuth by a distance equal to Y_0.

The illuminated zone with -3dB by the transmitting radar is defined by the apertures angles to semi-power θ_{Ea} and θ_{Ed} of the lobe of the antenna and by the angle of orientation of the beam of the transmitting antenna compared to the vertical θ_{E0}.

The aperture to -3 dB of the lobe of the transmitting antenna is defined by:

$$\theta_{Ea} = \frac{\lambda_0}{L_E} \tag{2.5}$$

$$\theta_{Ed} = \frac{\lambda_0}{H_E} \tag{2.6}$$

L_E is the length of the transmitting antenna,

H_E is the width of the transmitting antenna,

λ_0 is the wavelength.

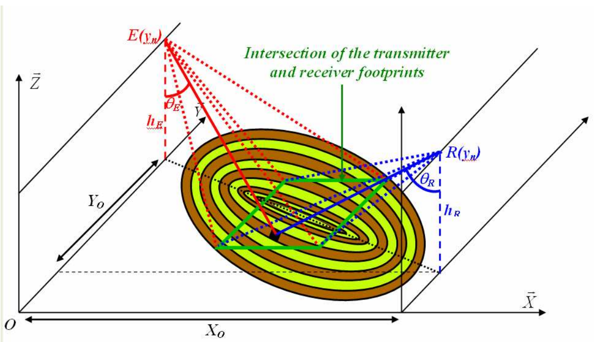

Fig . 4. Configuration for bistaic mapping

The transmitting radar is located at a height h_E, laterally moving compared to the scene to image at a speed $\vec{v}_E$, along the azimuth axis *Y*, "Fig. 4".

In the reference mark $O\left(\vec{i},\vec{j},\vec{k}\right)$, coordinates of the transmitting radar are $E\begin{pmatrix}0\\ y^E\\ h_E\end{pmatrix}$

The coordinates of a point of the zone illuminated by the transmitting radar check (2.7) and (2.8).

$$h_E \tan\left(\theta_{E0}\right) - \frac{\Delta X_E}{2} \le x \le h_E \tan\left(\theta_{E0}\right) + \frac{\Delta X_E}{2} \tag{2.7}$$

$$y^E - \frac{\Delta Y_E}{2} \le y \le y^E + \frac{\Delta Y_E}{2} \tag{2.8}$$

Where

$$\Delta X_E = \frac{h_E \lambda_0}{H_E \cos^2(\theta_{E0})} \tag{2.9}$$

$$\Delta Y_E = \frac{h_E \lambda_0}{L_E \cos(\theta_{E0})} \tag{2.10}$$

The illuminated zone with -3dB by the receiving radar is defined by the apertures angles to semi-power θ_{Ra} and θ_{Rd} of the lobe of the antenna and by the angle of orientation of the beam of the transmitting antenna compared to the vertical reference θ_{R0}.

The aperture at -3 dB of the lobe of the receiving antenna is defined by:

$$\theta_{Ra} = \frac{\lambda_0}{L_R} \tag{2.11}$$

$$\theta_{Rd} = \frac{\lambda_0}{H_R} \tag{2.12}$$

L_R is the length of the receiving antenna,

H_R is the width of the receiving antenna,

The receiving radar is located at a height h_R, laterally moving compared to the scene to image at a speed $\vec{v}_R$, along the azimuth axis *Y* "Fig. 4".

Coordinates of the receiving radar are $R\begin{pmatrix}X_0\\ y^R\\ h_R\end{pmatrix}$

The zone illuminated by the receiving radar is defined by (2.13) and (2.14).

$$X_0 - h_R \tan\left(\theta_{R0}\right) - \frac{\Delta X_R}{2} \le x \le X_0 - h_R \tan\left(\theta_{R0}\right) + \frac{\Delta X_R}{2} \tag{2.13}$$

$$y^R - \frac{\Delta Y_R}{2} \le y \le y^R + \frac{\Delta Y_R}{2} \tag{2.14}$$

Where

$$\Delta X_R = \frac{h_R \lambda_0}{H_R \cos^2(\theta_{R0})} \tag{2.15}$$

$$\Delta Y_R = \frac{h_R \lambda_0}{L_R \cos(\theta_{R0})} \tag{2.16}$$

Thus, for the configuration suggested, "Fig. 4", the coordinates of a point of the intersection of the two prints of the transmitter and receiver check (2.17) and (2.18)

$$X_0 - h_R \tan\left(\theta_{R0}\right) - \frac{\Delta X_R}{2} \le x_M \le h_E \tan\left(\theta_{E0}\right) + \frac{\Delta X_E}{2} \tag{2.17}$$

$$y^E - \frac{\Delta Y_E}{2} \le y_M \le y^R + \frac{\Delta Y_R}{2} \tag{2.18}$$

III. TRANSMITTED ELECTROMAGNETIC FIELD

The choice of the transmitted signal has a great influence on the detection capability and on the resolving power of the radar. In this way, the pulse compression techniques usage yields good resolution both in distance and Doppler frequency [5] [6]. These techniques are based on a bandwidth widening. This is accomplished by modulating the transmitted pulse either in phase or in frequency, and yields a finer-range resolution than can be achieved with a conventional radar systems using an unmodulated pulse. Pulse compression technique is realized in the program by adopting the chirp technique[7]. Then, the frequency of transmitted pulse is linearly swept from $f_0 - \frac{\Delta f}{2}$ to $f_0 + \frac{\Delta f}{2}$. The time variation of the frequency is given by (3.1) as a function of the carrier frequency f_0, the transmitted bandwidth Δf , and the pulse duration T_i [8].

$$f(t) = f_0 + \frac{\Delta f}{T_i}\left(t - \frac{T_i}{2}\right) \quad (3.1)$$

The temporal expression of the transmitted signal is given by (3.2).

$$S_e(t) = \sum_{n=0}^{\infty} \mathrm{Re}\,ct_T(t - nT_r)e^{j2\pi(t-nT_r)f_0} e^{j2\pi(t-nT_r)\frac{\Delta f}{2T_i}[t-(n+\alpha)T_r]} \quad (3.2)$$

Where

f_0 is the central frequency,

T_i is the duration of the impulse,

T_r is the pulse repetition period,

$\alpha = \frac{T_i}{T_r}$ is the cyclic report of the pulse train,

Δf is the bandwidth emitted.

the transmitted waveform is drawn in "Fig. 5" considering a rectangular pulse shape.

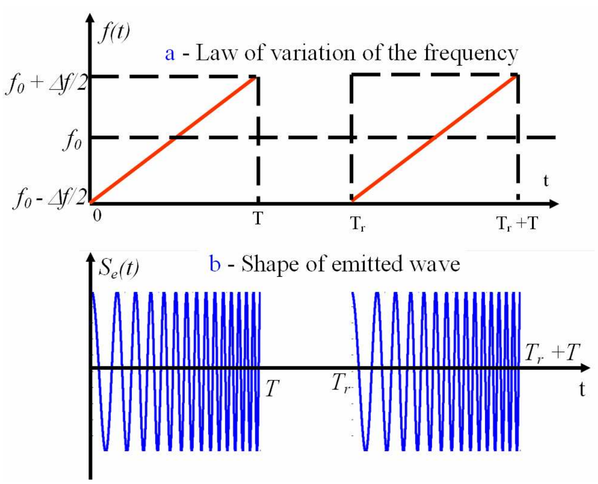

Fig. 5. Time variation of the transmitted signal waveform

IV–EXPRESSION OF THE RECEIVED SIGNAL

BIstatic Synthetic Aperture Radar *(BISAR)* is an active print system For which the transmitting antenna and receiving antenna embarked on separate sensors operating in the field of the microwaves. During its movement "Fig. 4", the transmitting antenna emits towards the ground, with a slope given with regard to the vertical line, a train of pulses in a cadence called Pulses Repetition frequency (*PRF*). Every pulse affects a point of the ground after a time of propagation $\Delta t_{EC}(t)$. The bistatic received antenna receives a signal from all the present reflectors in the common lobe of the transmitted antenna and received antenna.

The bloc diagram of the computation of the receiving signal and reconstruction of images is illustrated in "Fig. 6".

The BISAR is thus a system of prints which allows to have radar images of high resolution.

BISAR supply precise images of vast zones with a better precision. They allow to have images of the surface of the earth and to establish the cartography of the precipitation, mesure their intensity to foresee the evolution of the debit of rivers by a network of radars.

BISAR offer an improved potentiality of surface classification, three-dimensional observation, and the opportunity of advanced scientific experiments in the field of bistatic scattering[9].

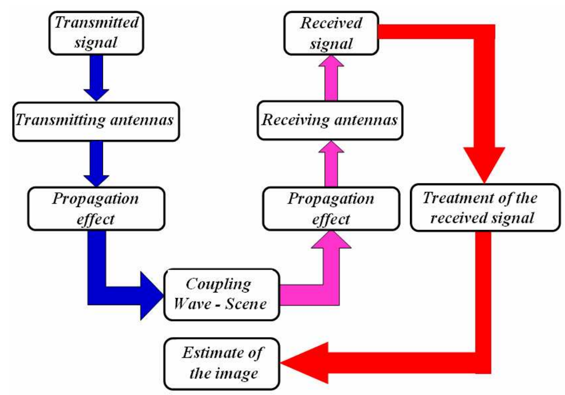

Fig. 6. Block diagram of the computation of the received signal and image reconstruction

The received electric field at the receiving antenna is obtained as a function of transmitted waveform, transmitting antenna radiation, scattering matrix, and propagation delay. It is expressed in the BSA basis, "Fig. 7" , by (4.1)[4].

$$\vec{E}^r(t) = \begin{bmatrix} E^r_{v_r}(t) \\ E^r_{h_r}(t) \end{bmatrix} = KE_0 \frac{S_r(t)}{c^2 \Delta t_{EC} \Delta t_{CR}} \left[S(t)\right]\left[P^e(t)\right]\left[G^e(t)\right]\vec{q} \quad (4.1)$$

Where the received waveform $S_r(t)$ is defined as the waveform of the signal transmitted at time *t* delayed from Δt_{ER} such as

$$S_r(t) = S_e(t - \Delta t_{ER}) \quad (4.2)$$

$\left[S(t)\right]$ is the matrix of Sinclair, $\left[P^e(t)\right]$ is the basis transformation matrix in transmitting site, $\left[G^e(t)\right]$ is the transmitting antenna radiation matrix, and $\vec{q}$ is the transmitting Jones's vector that defines polarization of the transmitting antenna.

The detected tension at the receiving antenna is obtained by calculating the scalar product of the received electric field $\vec{E}^r(t)$ by the effective length $\vec{h}^r_{eff}(t)$ of the receiving antenna. Applying the reciprocity principle, $\vec{h}^r_{eff}(t)$ is similar to the electric radiated by the antenna if it was used for emission.

Then the expression of the detected tension is given by (4.3)

$$V_{qp} = KE_0 \frac{S_r(t)}{c^2 \delta t_{EC} \delta t_{CR}} \vec{p}^* \left[G^r(t) \right]^* \left[P^r \right]^* \left[S\left(t - \frac{\delta t}{2} \right) \right] \left[P^e \right] \left[G^e(t - \delta t) \right] \vec{q} \quad (4.3)$$

Where $\vec{p}$ is the receiving Jones vector that defines polarization of the receiving antenna, $\left[G^r(t) \right]$ is the receiving antenna radiation matrix, and $\left[P^r(t) \right]$ is the basis transformation matrix in receiving sites.

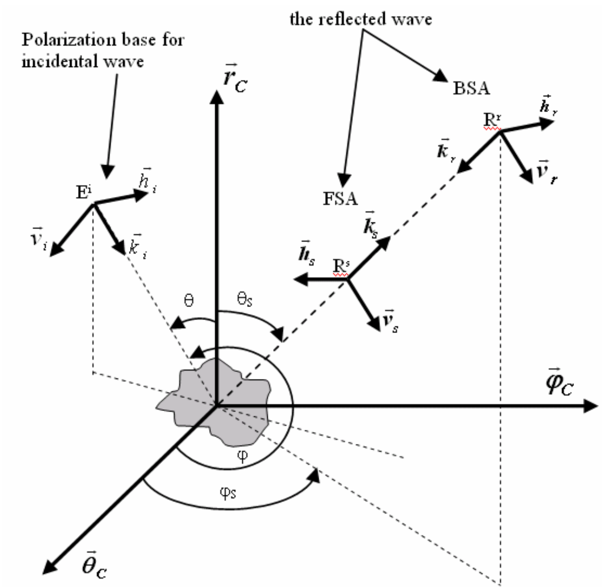

Fig. 7. Bistatic scattering configuration

V. BISAR MAPPING

The receiving signal is received sequentially pulse by pulse and is stored to be treated. The reconstruction of the high resolution image is obtained by two treatments on the table image of the received signal. A first treatment is a convolution of the received signal by a returned and conjugated of the emitted signal. This operation allows to have a better resolution in distance. To have an azimuth resolution similar to that found in site, two methods are used, The first consists in adding in a coherent way all signals scattering by the same pixel when this one is crossed by the common lobe of the transmitting antenna and the receiving antenna. The second is the method of adapted filtering.

A. Coherent summation

This method is based on the coherent summation of all signals compressed in site (*SCS*) of the same target when this one is crossed by the lobe of the antenna, "Fig. 8".

An estimation of the reflectivity of the point $M_i(x_i, y_i)$ is given by (5.1).

$$\hat{I}(r_i, y_i) = \sum_{n=i-\frac{L}{2}}^{i+\frac{L}{2}} S_{r_n cs}\left(\frac{2R_{in}}{c}, y_n \right) = \iint K(r_i, y_i) G^r S(r_i, y_i) G^e \Gamma_{S_{e_d}}\left(\frac{R_{in}}{c} - \frac{R_n}{c} \right) e^{-j\frac{2\pi}{\lambda_0}\chi} e^{j\frac{2\pi}{\lambda_0}\mu_i} \frac{\sin\left[(q+1) \frac{2\pi}{\lambda_0} \frac{\mu}{2} \right]}{\sin\left[\frac{2\pi}{\lambda_0} \frac{\mu}{2} \right]} drdy \quad (5.1)$$

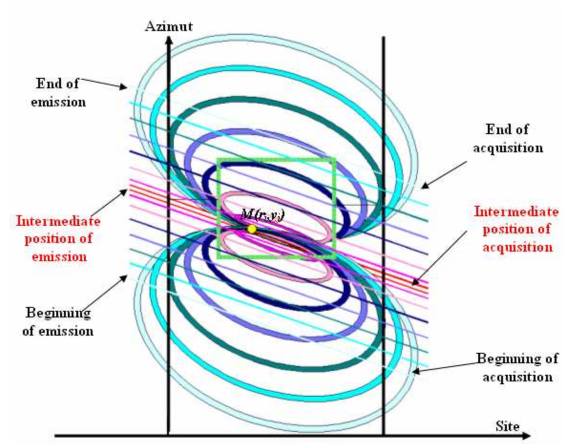

Fig. 8. Acquisition geometry

Where

i being the intermediate position For which the transmitter and the receiver see simultaneously the point $M_i(r_i, y_i)$.

L is the number of position of the transmitting antenna for which common lobe illuminates the target. It is given by (5.2).

$$L = \frac{y_f - y_d}{v_E T_r} \quad (5.2)$$

y_d corresponds to the position of the beginning of acquisition,

y_f corresponds to the position of the end of acquisition.

$K(ri, yi)$ represents the gain of the antenna, the factor of radiation decline, The losses and the gain of the channel of broadcast - reception,

$S(ri\ yi)$ is the reflectivity of the surface element $dxdy$,

$\Gamma_{S_{e_d}}$ is the function of ambiguity in the site direction. It is given by (5.3).

$$\Gamma_{S_{e_d}}\left(\frac{R_{in}}{c}-\frac{R_n}{c}\right)=\left[T-\left|\frac{R_{in}-R_n}{c}\right|\right].$$

$$\frac{\sin\left[\pi a\left(\frac{R_{in}-R_n}{c}\right)\left(T-\left|\frac{R_{in}-R_n}{c}\right|\right)\right]}{\pi a\left(\frac{R_{in}-R_n}{c}\right)\left(T-\left|\frac{R_{in}-R_n}{c}\right|\right)} \qquad (5.3)$$

χ, μ, and μ_i are given respectively by (5.4),(5.5) and (5.6).

$$\chi = r - r_i + \frac{1}{2}\frac{y^2-y_i^2}{r_i^E} + \frac{1}{2}\frac{y^2-y_i^2}{r_i^R} + \frac{(y-y_i)Y_0}{r_i^R} \qquad (5.4)$$

$$\mu = \left[\frac{(y-y_i)}{r_i^E} + \frac{(y-y_i)}{r_i^R}\right] y_1 \qquad (5.5)$$

$$\mu_i = \left[\frac{(y-y_i)}{r_i^E} + \frac{(y-y_i)}{r_i^R}\right] y_i \qquad (5.6)$$

$\hat{I}(r_i, y_i)$ well corresponds to the estimate of the reflectivity at the point $M_i(r_i, y_i)$.

B. Adapted filtering

This method uses the term of azimuth phase of the received signal which enables us to find the impulse response of the filter adapted in azimuth to the target $M(Y,d)$.

A point to the ground will be tracked down "Fig. 9", either by its cartesian coordinates $(x,y,0)$, or by its coordinates in the oblique plan (ρ, y), or by its site and azimuth angles with regard to the axis of the antenna (θ, β).

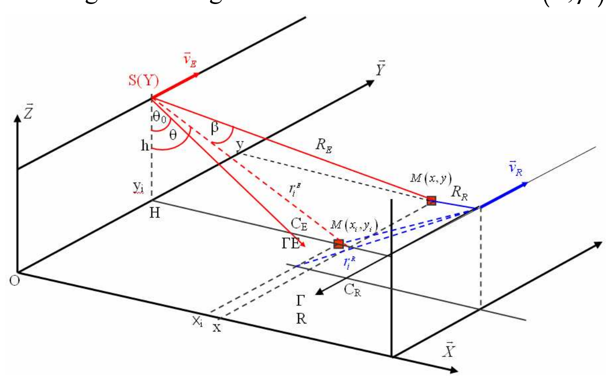

Fig. 9. Bistatic connection

An estimation of the reflectivity of the point $M_i(x_i, y_i)$ is given by (5.7).

$$\hat{I}(Y,d) = \sigma(Y,d) \underset{Y}{\otimes} \Gamma_\mu(Y,d) \underset{d}{\otimes} \Gamma_{\xi_d}(d) \qquad (5.7)$$

$\Gamma_{S_{e_d}}$ is the function of ambiguity in the direction of the site and is given by (5.8)

$$\Gamma_{\xi_d}(d) = (cT - |d|)\frac{\sin\left[\frac{2\pi a d}{c^2}\left(\frac{cT}{2}-\frac{|d|}{2}\right)\right]}{\frac{2\pi a d}{c^2}\left(\frac{cT}{2}-\frac{|d|}{2}\right)} \qquad (5.8)$$

Γ_μ is the function of ambiguity in the azimuth direction and is given by (5.9)

$$\Gamma_\mu(Y,d) = 2\vartheta(Y,d)e^{-j\eta y_c}\Delta Y \frac{\sin(\eta \Delta Y)}{\eta \Delta Y} \qquad (5.9)$$

Where

$$\vartheta(Y,d) = g_A^2(Y)\, e^{j\frac{2\pi}{\lambda_0}\frac{Y^2}{2(d-r_0^R)}} e^{j\frac{2\pi}{\lambda_0}\frac{2YY_0}{2(d-r_0^E)}} e^{j\frac{2\pi}{\lambda_0}\frac{Y^2}{2(d-r_0^E)}} \qquad (5.10)$$

And

$$\eta = \frac{2\pi}{\lambda_0} Y \left[\frac{2d - r_0^E - r_0^R}{(d-r_0^E)(d-r_0^R)}\right] \qquad (5.11)$$

VI. SIMULATION RESULTS

The two methods of BISAR mapping, presented previously, are applied in the case of a scène made up of five individual reflectors are simulated.

Figure 10 show the Model of simulation.

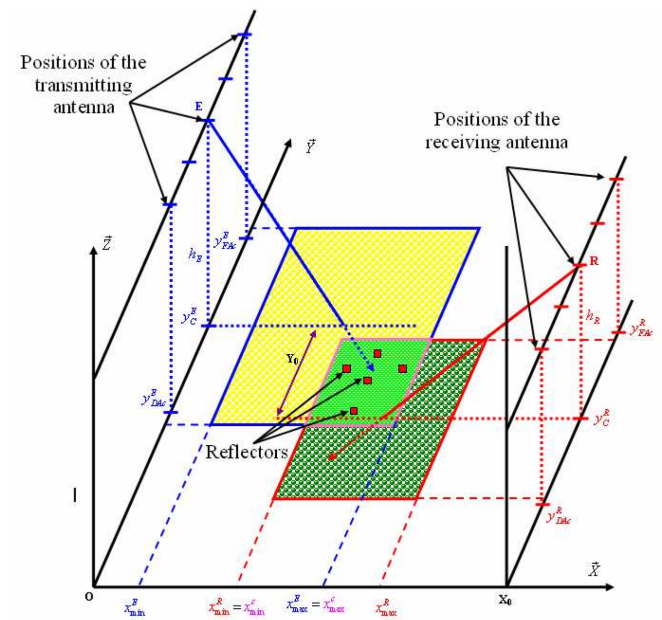

Fig. 10. Model of simulation
Bistatic mapping

Figure 11. show the reconstructed map by the way of coherent summation method. The five individual reflector are found.

The five individual reflector are also found by the way of adapted filtering "Fig. 12".

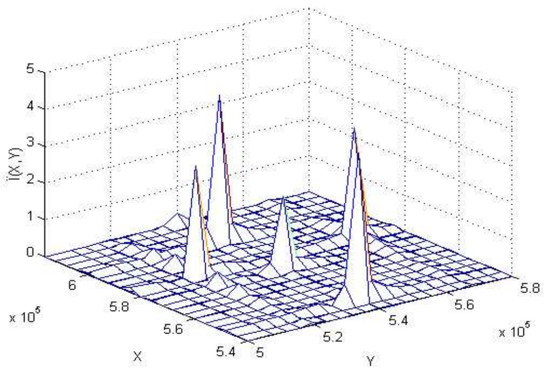

Fig. 11. Image reconstructed by coherent summation

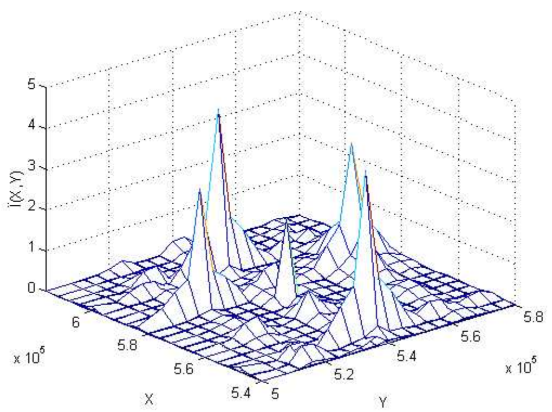

Fig. 12. Image reconstructed by adapted filtring

VII. CONCLUSION

In this paper, the vectorial expression of the received signal by a BIstaic Synthetic Aperture Radar (*BISAR*) is given. This signal is expressed according to the field scattered by the target, it is given like a tension in output of the reception antenna, function of parameters of the antenna and the geometrical parameters of the chain of transmitting-receiving

Various processing which the received signal must undergo to be able to estimate the reflectivity are established in the bistatic case.

Simulations are carried out by using two methods of reconstructing the image, coherent summation and adapted filtering.

A bistatic mission allows the simultaneous acquisition of two samples of the target backscattering pattern, opening the way to new research activities concerning, for example, sea and water surface studies and land cover classification.

Consequently, the observation under two different angles allows either to observe in a bistatic image areas of reflection which are dark in a Monostatique SAR image or to improve spectral surface analysis combining two images[9].

Bistatic mission allow the contemporaneous acquisition of multifrequency, multipolarisation, and, in particular, multiangle data sets, the statistical analysis of which improves the probability of correct classification.

The acquisition of two images of the same area under different angle, also gives the capability of obtaining digital elevation models.

The signal collected at the receiving antenna is calculated as a function of time by taking into account the vectorial aspect of the electromagnetic waves and various elements operating in the radar radiolink. The radar radiolink is designed in a modular structure for a general configuration where the transmitter, the target and the receiver are moving.

The interest of this model is great because it permits, for a defined scenario, to generate radar data which can be used in signal processing algorithms for target detection.

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