A Time Domain Raw Signal Simulator for Hybrid Mode Interferometric SAR

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Abstract

A raw signal simulator for a SAR system operating in stripmap, spotlight and hybrid mode on a Kepler's orbit is presented. The simulator operates in time domain and, unlike frequency domain simulators, it can easily take into account mechanical oscillation of the mast that supports the second antenna, orbit perturbation, etc. The proposed model represents an useful tool to analyze sensors performance also in presence of deviations from nominal conditions.

Introduction

The proposed raw SAR simulator is capable of modeling a wide family of spaceborne SAR sensors, in stripmap, spotlight and hybrid mode ([1], [2]), including the single–pass interferometric case. We employ a direct solution (Time Domain (TD) approach) of the simulation problem, that is, we evaluate the portion of Earth surface illuminated by transmitting antenna, then we subdivide it in a set of *facets* and we sum coherently their response for each SAR sensor position. Electromagnetics characteristics of each facet (including echo correlation used in the single-pass interferometric model) are evaluated through Physical Optics (PO).

The TD approach requires an higher computation time, compared to the Frequency Domain ones, but it can easily model orbital deviations and platform mechanical deformations.

Model description

We consider a single-pass interferometric radar system located on a platform orbiting the Earth and illuminating a portion of Earth surface. We suppose that the trasmitting antenna emits every $1/PRF$ seconds a radiofrequency impulse $s(t)$ having time duration τ. Such impulse impinges on the Earth surface and a part of its energy is backscattered to the system antennas. The sequence of the backscattered echoes recorded by the SAR system is the raw signal. By using the usual start–stop approximation [3] and by sub-dividing the illuminated Earth surface in facets (so small with respect to the system resolution to be considered as elementary targets) the raw signal $r^{(k)}(m,t)$, at the k-th antenna, related to the m–th transmitted impulse is:

$$r^{(k)}(m,t) = \sum_{n \in V(m)} L_n^{(k)}(m)\gamma_n^{(k)} s\left[t - \frac{R_n^{(1)}(m) + R_n^{(k)}(m)}{c}\right] e^{-j\frac{2\pi}{\lambda}(R_n^{(1)}(m)+R_n^{(k)}(m))} \quad (1)$$

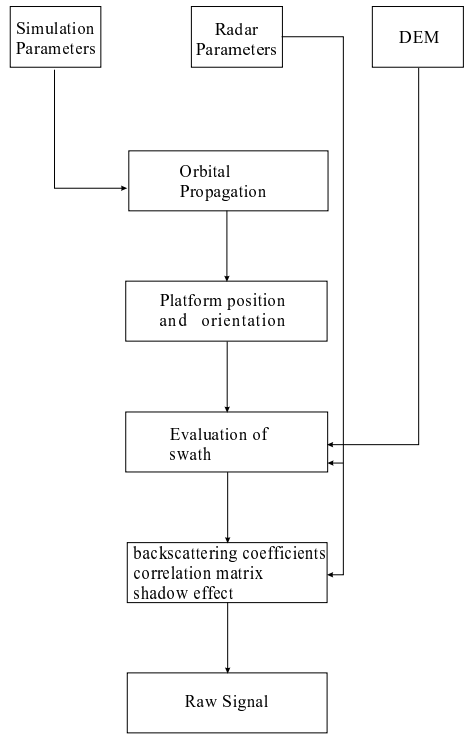

Figure 1: Flow chart for the proposed TD SAR raw signal simulator.

where t is the slant range time, $\gamma_n^{(k)}$ the backscattering coefficient of facet n, c the speed of light, $R_n^{(k)}(m)$ the path length from the k–th antenna to the n–th facet, λ the wavelength and $L_n^{(k)}(m)$ ensembles the antenna gain, the transmitted power and the forward/backward path amplitude loss. The sum is extended over all facets n contained in the illuminated area $V(m)$. The expression (1) is carried out by simulator, following the steps sketched in the flow chart of Fig. 1 and described below.

The platform is considered flighting along a Kepler's orbit (the nominal orbit of the platform). The orbital propagation step evaluates the platform positions on the orbital plane. Since we suppose to know geometry of the Earth in a Earth fixed frame of reference, we require to describe also the system geometry in a such frame, starting from its knowledge in a frame of reference local to the platform.

With respect to Fig. 2, the coordinates transformation between the different frames of reference, is given by

$$\begin{bmatrix} x^{(e)} \\ y^{(e)} \\ z^{(e)} \end{bmatrix} = M^z_{-\Lambda} M^x_{-i} M^z_{-\omega} \left(\begin{bmatrix} x^{(o)} \\ y^{(o)} \\ 0 \end{bmatrix} + M^z_{-\xi} M^z_{-\phi} M^y_{-\theta} M^x_{-\psi} \begin{bmatrix} x^{(p)} \\ y^{(p)} \\ z^{(p)} \end{bmatrix} \right) \tag{2}$$

where $(x^{(e)}, y^{(e)}, z^{(e)})$, $(x^{(o)}, y^{(o)}, z^{(o)})$, $(x^{(p)}, y^{(p)}, z^{(p)})$ are respectively the coordinates in Earth, orbital, and platform frame of reference. In Fig. 2 is also shown the flight frame of reference $(x^{(f)}, y^{(f)}, z^{(f)})$ built to take into account pitch, roll and yaw angles during the platform flight. In eq. 2, Λ is the longitude of ascending node, i the orbit inclination, ω the argument of perigee, ξ is the angle between $x^{(o)}$ and $x^{(f)}$ axis, θ is the pitch angle, ψ is the roll angle, ϕ is the yaw angle and $M_\alpha^{(v)}$ indicates the rotation matrix of angle α around axis v. For each position of the platform, and the relative antenna line of sight, we evaluate the direction corresponding to bandwidth limits. Intersections of these directions with Earth ellipsoid define the succession of the limits of illuminated area during platform flight. In order to define

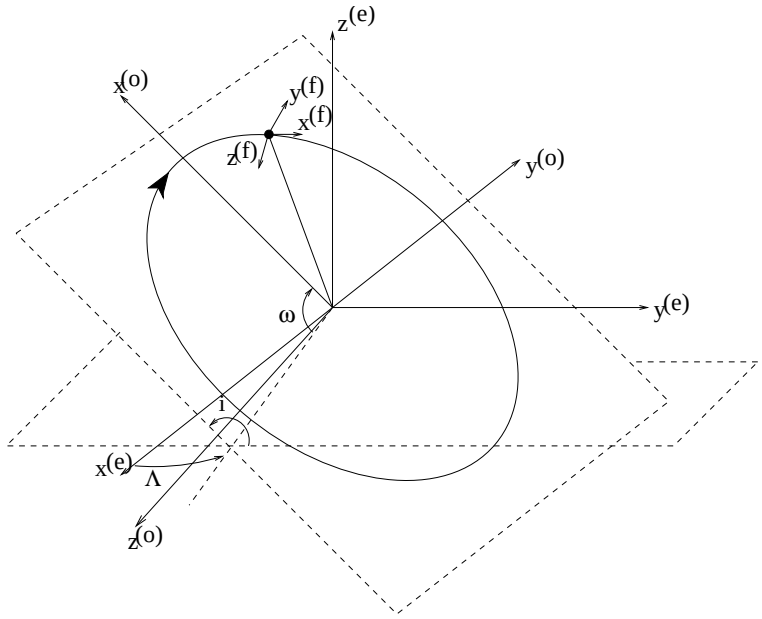

Figure 2: Flight, orbital and Earth fixed frame of reference.

a facet grid, these limits (in latitude and longitude) are interpolated at desired spacing by using a bilinear method. Each facet is considered sufficiently small to consider the backscattering coefficient constant over SAR integration time. For each antenna of the interferometric system a Physical Optics (PO) solution and Kirchhoff Approximation have been used for evaluating the backscattering coefficients, of each facet and, for a single-pass interferometric system, the echo correlation. In fact, in the latter case we also need to calculate the facets contribution to the raw signal collected by the second antenna since the different looking geometry makes the relative backscattering coefficient not completely correlated. When mean root square and correlation value of backscattering coefficients of each facet for the two antennas has been evaluated, we generate two sets of backscattering coefficients having a complex joined gaussian statistics.

Examples of applications

In this section we show some examples with particular attention to the possibility to model the effects of mast oscillations in a single-pass interferometric system. We consider a spotlight system with the following radar characteristics: pulse width = 40 μs, chirp band = 15 MHz, PRF = 1512, $\lambda = 3.1$ cm, integration time $t_i = 0.25$ sec, baseline length = 60 m and baseline angle = 45°. A platform flight on a circular orbit, having radius of 6604 Km, and an inclination angle equal to 57° is also considered. Fig. 3 shows the focalized impulse response of three scatterers on an absorbing background. The targets are distributed on the swath due to an antenna beamwidth equal to 1°. Fig. 4 (left) shows an azimuthal cut of the focalized impulse response at the slave antenna of the central target. Evident are the oscillation effects, described by the superposition of two independent movements of the mast, in azimuth and slant range direction respectively, represented by a sinusoidal angular deviation, having an amplitude of 90, 180, 270 Arcsec and frequency of 1 Hz. Furthermore, in Fig. 4 (right) we have considered the variation of the interferometric phase of the central target for a mast oscillation having frequency of 1 Hz and an amplitude variable from 0 to 50 Arcsec.

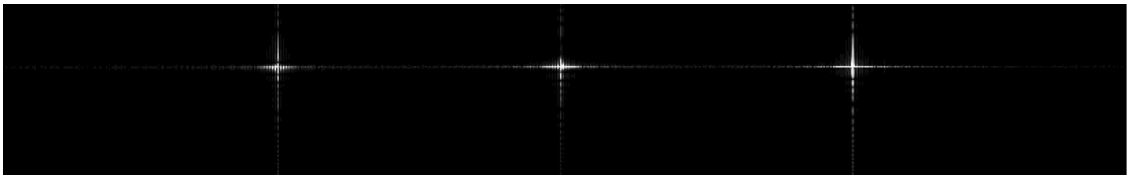

Figure 3: Focalized impulse response for three scatterers on an absorbing background of the above mentioned system. The image corresponds to a $160m \times 7500m$ scene.

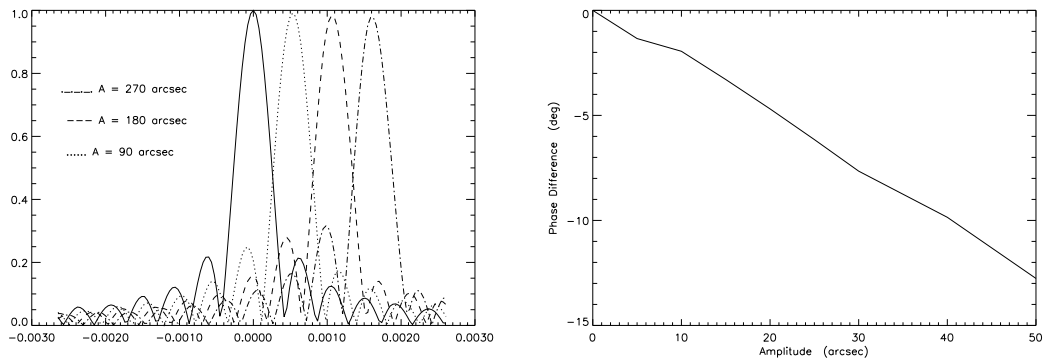

Figure 4: *Left:* Azimuthal cuts of the central target focalized impulse response without oscillation effect (continuous line) and with oscillation effect. *Right:* Error on interferometric phase between master and slave antennas response in presence of oscillations.

References

[1] W. G. Carrara, R. S. Goodman, R. M. Majewski, *Spotlight Synthetic Aperture Radar, Signal Processing Algorithms*, Artech House, 1995.

[2] D. P. Belcher, C. J. Baker, *High resolution processing of hybrid strip–map/spotlight mode SAR*, *IEE Proceedings Radar, Sonar and Navigation*, vol. 143, n. 6, December 1996, pp. 366–374.

[3] J. C. Curlander, R. N. Donough, *Synthetic Aperture Radar system and signal processing*, John Wiley and Sons, New York, 1991.