GATHERING SAR DATA UNDER DIFFERENT BISTATIC ANGLE: A NEW POTENTIAL OF COSMO/SKYMED CONSTELLATION

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ABSTRACT

Modifications required to a SAR constellation mission are addressed in order to achieve bistatic observations under a range of bistatic angles, in a cost effective and flexible fashion. In particular, the paper investigates achievable performance deriving from an evolution of COSMO/SkyMed towards bistatic applications. A mathematical model is presented, which allows evaluation of bistatic angles as a function of latitude and longitude, on the basis of orbits’ propagation and spherical trigonometry. Results show that while nodal separation increases, a target is observed under a variable bistatic angle, which is not an increasing monotonic function of time due to the varying position of orbits’ intersections and thanks to electronic beam steering capability.

1. INTRODUCTION

A bistatic synthetic aperture radar (BSAR) mission offers a number of new applications and can also enhance the value of standard SAR missions achievements, thanks to the combination of monostatic and bistatic data reflected by common covered areas or targets [1]. Nevertheless, only a few spaceborne BSAR missions have been proposed [2,3] under the assumption of a small platform flying in tandem with a main SAR satellite.

In the case of COSMO/SkyMed constellation [4] with four SAR satellites in the same orbital plane, it is possible to implement a cost effective bistatic Earth observation mission either incrementing recurrent costs only (additional satellite) or reducing lifetime of one nominal satellite for a 3-6 months bistatic mission phase. In any case, a small amount of additional propellant mass suffices to modify a satellite (BISSAT) orbit parameters to achieve SAR interferometry (InSAR) and then BSAR with another constellation member (COSMO) [5]. Transfer from InSAR to BSAR is achieved exploiting differential $J_2$ effects deriving from a slight difference in orbits’ inclination. Periodic correction of anomaly to contrast $J_2$-induced in plane relative drift allows to perform continuous bistatic acquisitions with neither impacts on COSMO, nor roll maneuvers by BISSAT, thanks to electronic steering capability of both active and passive antenna.

In the following, concepts of bistatic access area and coverage are introduced and a model for evaluation of bistatic angles for given latitude or test site (latitude and longitude) is presented. Finally, numerical results are reported showing application potential.
2. BISTATIC OBSERVATIONS AT VARIABLE BISTATIC ANGLE

Orbit design is performed in order to guarantee the acquisition of bistatic data by means of the passive radar and to achieve a stable natural relative dynamics. Thus, for BISSAT it is appropriate to choose the same semi-major axis, eccentricity, argument of perigee and inclination of COSMO, leaving to the ascending node separation and to the difference in the times of passage at the ascending node the role to guarantee the bistatic geometry. Small (with respect to nominal) inclination difference is exploited for orbital maneuver purposes. Mathematical models to evaluate attitude/pointing angles necessary to achieve swath superimposition along the orbit can be found in [3,5]. In general, bistatic acquisition is feasible over a “bistatic access area” (BAA), which is obtained by intersection of radars’ potential swaths. BAA dimensions decrease with growing horizontal separation between the platforms. When BAA is larger than radar real swath, bistatic target can be selected within BAA by COSMO and BISSAT pointing. Thus, since a target could be observed under different angles, a mathematical model for bistatic angles evaluation is needed. To this end, the following assumptions are considered: spherical Earth (from the geometrical point of view), flat terrain, approximation of circular orbits, orbital propagation calculated taking into account $J_2$ secular effects. At any given time, it is possible to compute COSMO and BISSAT positions with respect to the rotating Earth and, consequently, to identify nearest and furthest points which can be observed along the elevation direction [3] by COSMO’s radar taking into account the whole steering range (COSMO potential swath). Then, BISSAT yaw and azimuth/pitch rotations [3] are applied in order to align radars’ elevation directions and nearest and furthest points which can be observed along the elevation direction by BISSAT’s radar are determined taking into account the whole BISSAT steering range (BISSAT potential swath). Intersection of potential swaths gives instantaneous BAA.

![Figure 1 – Geometry of BAA when COSMO argument of latitude is between 0 and 90°](image)

Geometry is shown in Fig. 1 when COSMO argument of latitude is between 0 and 90°. $\theta_{gN}$ (N for Near Range) and $\theta_{gF}$ (Far Range) identify geocentric angles corresponding to
the extremes of COSMO off nadir angle range which define instantaneous BAA.

After some spherical trigonometry, longitude and latitude of N and F can be determined. Then, geocentric coordinates of N and F are computed and it is possible to determine if a given test site belongs to instantaneous bistatic access area. In this case, bistatic angle can be calculated operating in the ECEF reference frame.

3. NUMERICAL RESULTS

Focusing on the passage from InSAR to BSAR, COSMO and BISSAT are assumed coincident at t=0. Then, a small (0.1°) inclination change is applied to establish a δΩ between satellites, but an additional in-plane differential drift is produced δ(\dot{M} + \omega). In order to foresee bistatic angle variation, the effects of δi (constant), ΔΩ = δΩ Δt, and Δu = δ(\dot{M} + \omega) Δt must be analyzed separately.

At t=0, orbits intersect on the equator, but intersection latitude increases depending on ΔΩ. While ΔΩ alone produces an increase of satellite distance and a consequent increase of bistatic angle, for parallel above the intersection the combined effect of ΔΩ and δi cause a reduction of bistatic angle, the other way round if the parallel is below the intersection. The effect of Δu is an increase of along-track satellite separation which drives an additional increase of bistatic angle. Nevertheless, orbital maneuver are periodically foreseen to cancel the in-plane relative drift.

Simulation results are shown in Fig. 2 considering different pointing angles of COSMO radar (steerable within 23.3°-43.7°) for a target at 60°N latitude. For the first 15 days the major effect is related to δi since latitude of orbit intersection is less than 60°. Then, the dominant effect is related to ΔΩ. The effect of the increasing Δu can be observed for t<15days (presence of minima), while orbital maneuver to control Δu re-
sults in discontinuities.

When longitude is also considered (Fig. 3), bistatic angle history is complicated by the relative position along the parallel (longitude direction) between target and orbit tracks. In particular, Figure 3 has been obtained considering active pointing of both radars in order to observe the selected targets.

![Figure 3 - Achievable bistatic angles over selected test sites while maneuvering (Δi=0.2°)](image)

4. CONCLUSIONS

This paper focused the potential of an evolution of the Italian COSMO/SkyMed constellation towards BSAR applications. Changing one satellite inclination, to generate a positive drift in the right ascension of the ascending node allows a number of bistatic observations under variable bistatic angle. Numerical results, based on the presented model for bistatic angle evaluation, showed that, for increasing latitude, the theoretical number of bistatic acquisitions during the maneuver grows, but the average bistatic angle decreases. Of course, it is possible to obtain bistatic observations at high latitudes with larger bistatic angle, but this implies the loss of bistatic performance at lower ones, unless a roll maneuver is envisaged for one of the two satellites.

5. REFERENCES