Università
degli Studi
della Campania
Luigi Vanvitelli

Dipartimento di
Ingegneria

Sistemi Spaziali 2

Technical report: Mission analysis of COSMO-SkyMed 1

Lecturer:
Marco D'Errico

Student
Ludovico Aricò
matr. A15000228

Contents

1 Objective

The mission selected for this simulation is Cosmo Skymed 1, the inaugural satellite of a constellation comprising four satellites, and the first SAR mission instituted by the Italian Space Agency (ASI). The launch took place at 02:34:00 UTC on 8 June 2007 from Vandenberg Air Force Base. The COSMO-SkyMed satellites are in a circular Sun-synchronous dawn-dusk frozen orbit at a height of 619.6 km with a local time of ascending node 6:00 a.m.

Each of the 4 satellites is equipped with the SAR-2000 Synthetic Aperture Radar, which observes in the X-band ($\lambda = 3.1\ cm$) to provide global observation under all weather and visibility conditions.

The primary objectives of the COSMO-SkyMed mission are to provide global Earth observation that can be repeated several times a day in all-weather conditions. The imagery obtained can be applied to both military and civil needs, providing defense and security assurance in Italy and other countries, seismic hazard analysis, environmental disaster monitoring, and agricultural mapping.

2 Orbital Simulation

2.1 Orbital parameters

The classical orbital elements at the initial time are delineated in the subsequent table.

- The Argument of Periapsis ω is 90 degrees, considering the frozen orbit.
- Being the orbit frozen, we have computed the eccentricity by using the following relation derived by Kozai:

$$e \approx -\frac{1}{2}\left(\frac{J3}{J2}\right)\sin(\omega)\cos(i) = 0.00095 \tag{1}$$

  Which J3 and J2 represents the coefficient of zonial harmonics which reflects the geometry shape of earth, respectively:

  - J2: represents **earth oblaetness** of Earth.
  - J3: represents the geometric **"pear"** shape of Earth, in other words the asymmetry with respects to the equatorial plane.

- The value of the true anomaly at the initial time ν_0 is computed taking into account that the propagation commences at the Ascending node.
- The Longitude of the Ascending node is calculated by presuming that the propagation initiates on June 8, 2008, at 02:34:00 UT. Utilizing a Sun ephemeris

calculator[1], it is feasible to obtain the Solar right ascension and declination at the initial time.

$\alpha_\odot[deg]$	$\delta_\odot[deg]$
76.62	22.87

Table 1: Right Ascension and Declination of the Sun at local time

Subsequently, given the Sun-synchronous dawn-dusk orbit, the Longitude of the Ascending node can be computed by reffering to relation between Longitude of the Ascending node and Solar right ascension for Sun-synchronous dawn-dusk orbit with a local time of ascending node of 6:00 a.m:

$$\alpha_\odot - \Omega = 90\ deg \longrightarrow \boxed{\Omega = -13.38\ deg} \tag{2}$$

Parameter	Value
Semimajor axis [a]	6997.9 km
Eccentricity [e]	0.00118
Inclination [i]	97.88 deg
Longitude of the Ascending node [Ω]	-13.3800 deg
Argument of Periapsis [ω]	90 deg
True anomaly [ν]	-90 deg

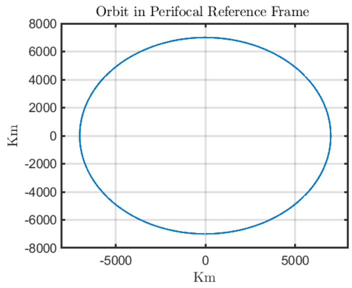
Table 2: Orbital parameters

2.2 Orbital propagation

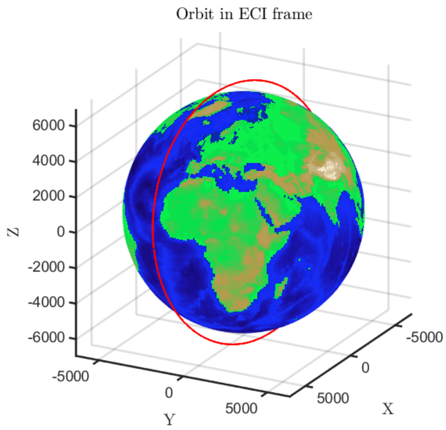
- The software includes a subroutine designed to calculate the Julian day from the initial propagation date. The Julian Date is then used to compute the Greenwich right ascension at the initial time. The software is based on a Keplerian model, in which there is a modular subroutine to evaluate the effects related to J2 zonial harmonic. It has been computed single orbit propagation with step time of 1 second of the period, then, evaluated the position and velocity vectors in the perifocal reference frame, the software proceeds to transform the vectors obtained in a ECI reference frame through a 3-1-3 matrix transformation, following the image of orbit in both reference frames with Keplerian and an image with J2 effect on orbital parameters:

- In order to evaluate the effect of second-order perturbations graphically, the number of simulated orbiters must be increased to an arbitrary number of 200. To

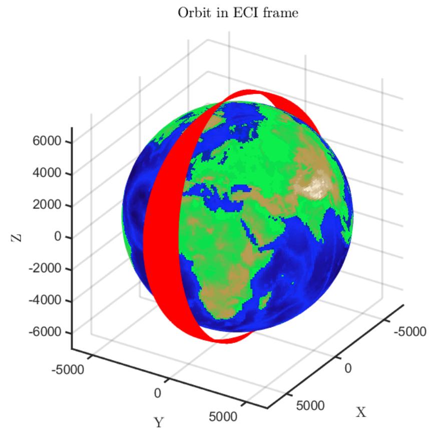
[1]The values have been computed through this website:
`https://www.neoprogrammics.com/de405_usno_ae98/DE405_Sun.php`



(a) Orbit in Perifocal Reference Frame



(b) Orbit in ECI



(c) Orbit in ECI: Effects of J2 perturbations, 200 orbits

Figure 1: Orbit

reduce the computational time, the time step has been increased to 10 seconds.

2.3 Ground track

From the values of position vector in ECI and from Greenwich Right Ascension, we can transform the coordinate of the satellite from ECI reference frame to the Earth reference frame, evaluating Nadiral sub-satellite points on earth in term of latitude λ and longitude ϕ by using these relations:

$$\begin{cases} \lambda = \alpha - \alpha_G \\ \phi = \delta \end{cases} \tag{3}$$

Being the Sun- Synchronous orbit retrograde by definition, so $i > 90\ deg$, the ground track is confined in latitude values of $\phi \in [-(180 - i), 180 - i]$ as expected.

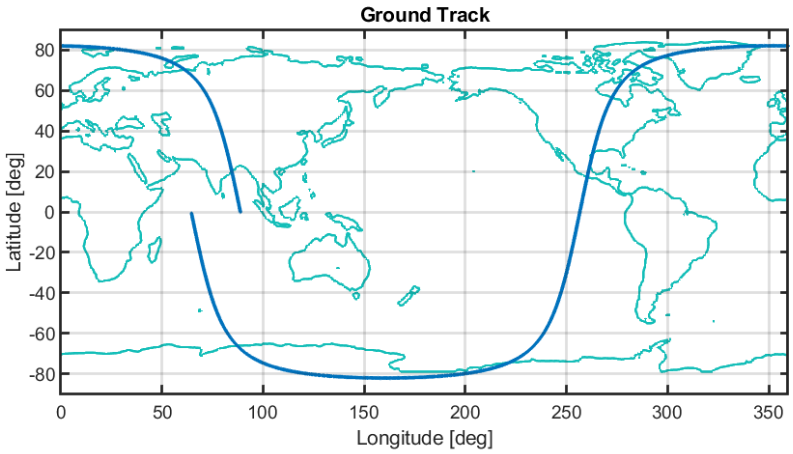


Figure 2: Ground track of satellite.

3 Radar module

In this section will be analyzed the performance of radar mounted. The radar has the following specifications:

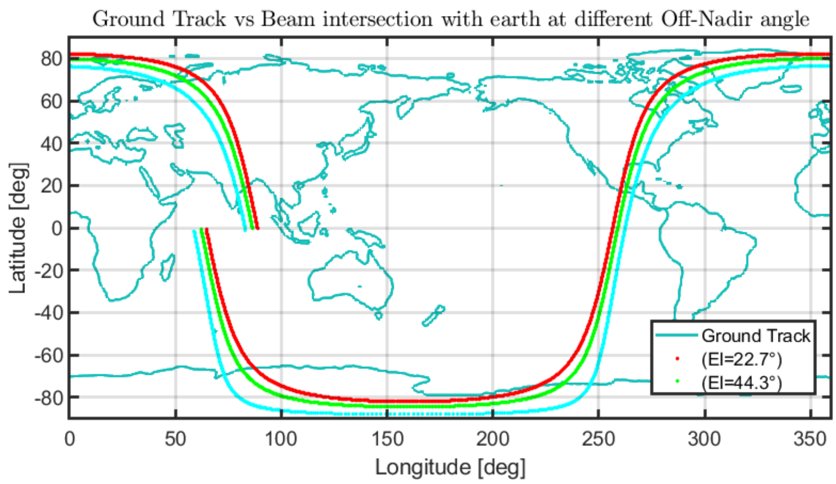
Wavelength λ	$3.125cm$
Antenna Length in Range L	$1.4m$
Antenna Length in Azimuth W	$5.7m$
Off-nadir Steering range	$[22.7, 44.3]deg$
$\theta_{3db,Az}$	$0.276\ deg$
$\theta_{3db,Az}$	$1.126\ deg$

Table 3: Radar data

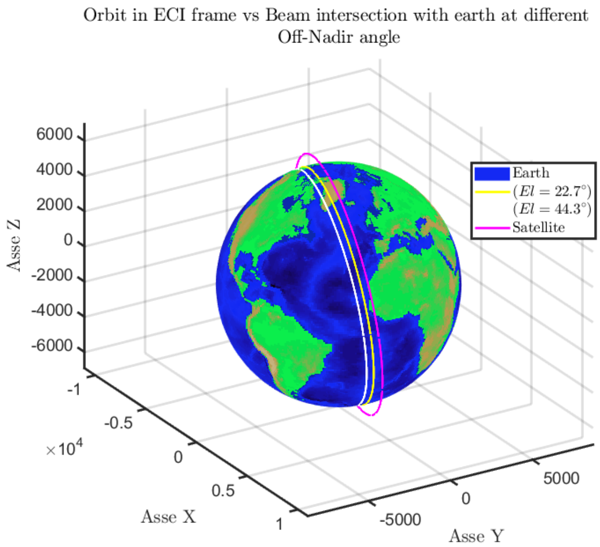
Through a sub routine, it has been computed the intersection point between the direction of antenna and the Earth surface. In order to achieve this, the bearing vector of antenna in his own reference frame, has been transformed to a vector in ECI reference thanks to a Matrix 1-2-3 Transformation. This direction is called line of sight, then it has been computed the intersection between the line of sight and earth surface. The earth surface has been considered as an ellipsoid with the following semi-axes:

$$\begin{cases} a = R_\oplus \\ b = R_\oplus \\ c = R_p \end{cases} \rightarrow \frac{x^2}{a} + \frac{x^2}{b} + \frac{x^2}{c} = 1 \tag{4}$$

Being $R_{\oplus}$ and R_p respectively the equatorial radius of earth and polar radius of earth. Evaluated the intersection point, we can move it into Geographic coordinate system evaluating the latitude and longitude of intersection. In the following picture we have evaluated the intersection for both off-nadir angles of antenna:



(a) Intersection of line of sight at different off-nadir angles in GCS



(b) Orbit in ECI

Figure 3: Intersection of line of sight at different off-nadir angles in ECI

COSMO Skymed orbit is repetitive, so after R+1 orbital periods (or N+1 earth rotations) the orbit will repeat itself.

$$Q = \frac{R}{N} = \frac{\dot{M} + \dot{\omega}}{\Omega_{\oplus} - \dot{\Omega}} = \frac{237}{16} \tag{5}$$

This has been verified by plotting ground track of 238^{th} orbit and overlapping it with the first one:

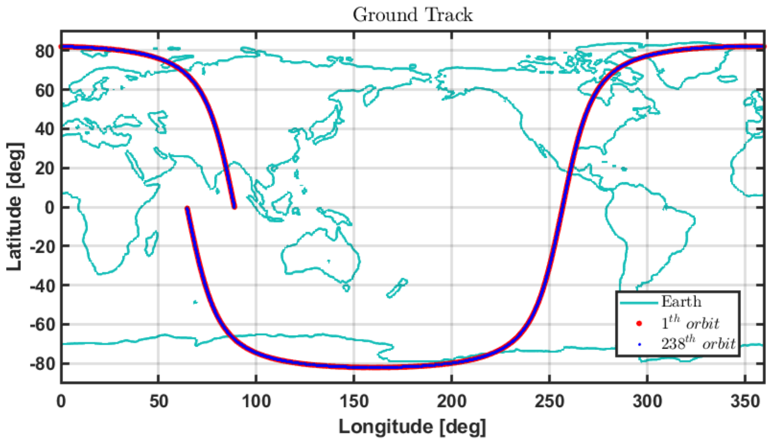
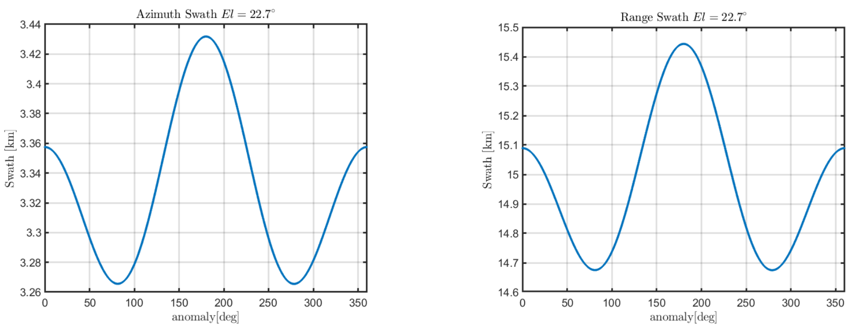


Figure 4: Repetitive orbit

3.1 Swath and Doppler effect

Has been evaluated the Swath in Azimuth and range by considering the $\theta_{3db,Az}$ in Azimuth and $\theta_{3db,El}$ in Range e valuating intersection of the beam in $[Az + \frac{\theta_{3db,Az}}{2}]$ and $[Az - \frac{\theta_{3db,Az}}{2}]$ and $[El + \frac{\theta_{3db,El}}{2}]$ and $[El - \frac{\theta_{3db,El}}{2}]$, the Az angle has been considered null, while El has been fixed to the $El = 22.7°$:



(a) **(b)**

Figure 5: Swath in Azimuth and Range

3.2 Doppler effect

Doppler effect along Azimuth length of antenna has been analyzed, in particular will be considered the doppler frequencies in the beam center and in the vertexes of Azimuth swath. The evaluation of doppler frequencies are discerned by considering the effect of manoeuvre of Yaw Steering This maneouvre is born to mitigate the effect of

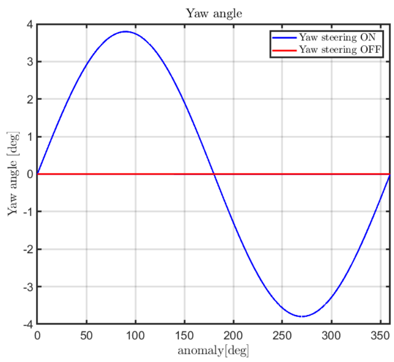
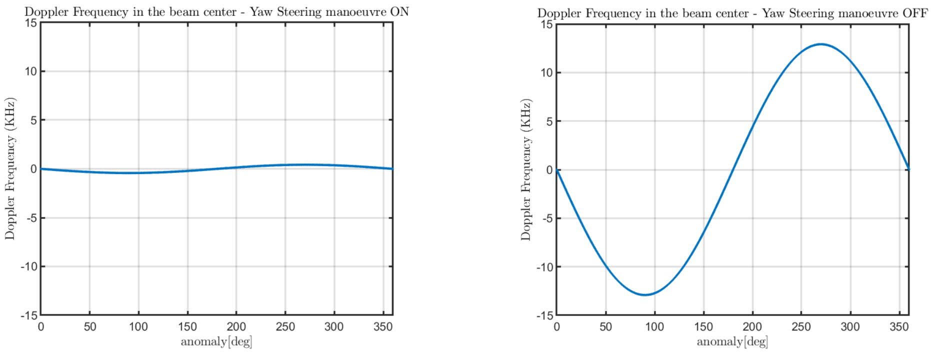


Figure 6: Yaw Angle

aerodynamic drag by nullifying the cross section area of satellite. As a side effect, it can observed a zero doppler frequency in the beam center:



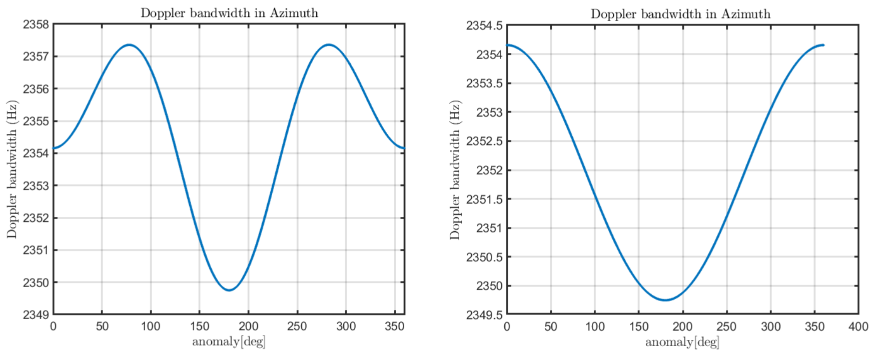
(a) (b)

Figure 7: Doppler Frequency in the beam center: effects of Yaw Steering maneouvre

If the orbit was circular we would expect the doppler frequency to be null in the beam center. Since the orbit has a very small value of eccentricity, it can be seen a small oscillation in the frequency 7.

3.2.1 Doppler Bandwidth

In the following pictures we can see the effect of Yaw Steering on Azimuth bandwidth: the bandwidth is considered by evaluating the difference of doppler frequencies in the $[Az + \frac{\theta_{3db,Az}}{2}]$ and $[Az - \frac{\theta_{3db,Az}}{2}]$:



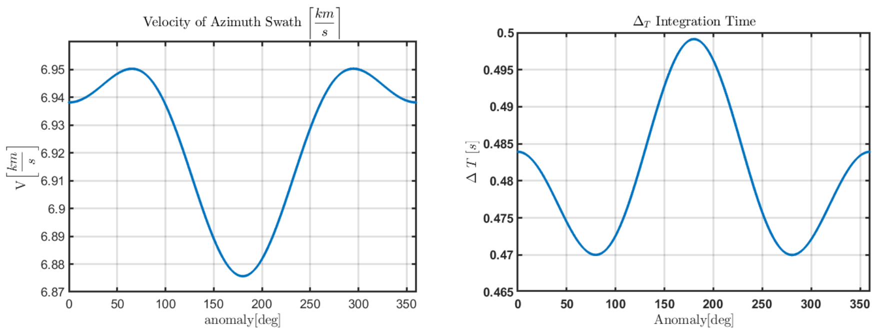
(a) Azimuth bandwidth **(b)** Azimuth bandwidth without Yaw Steering

Figure 8: Azimuth bandwidth by considering the Yaw Steering Maneouvre

3.3 Beam velocity and Integration time

Now, we can consider the beam velocity at the swath center on the ground. This velocity has been computed taking into account the curvature of the Earth, and it represents the speed at which the beam is sweeping the area on the ground. This velocity can be used to compute the integration which is an important for the sizing of a SAR radar (Raney (1991)). It represents the time necessary to sweep the Swath 3db in Azimuth and represents the time necessary for the radar to pass over a target:

$$\Delta T = \frac{S_w}{V_{beam}} \tag{6}$$



(a) Beam velocity **(b)** Integration time

Figure 9

4 Conclusions and Future Developments

- The software developed has been imagined with a modular scheme, so that it can be updated with modules if required by the mission simulation:
- For example a module that can account the drag resistance and orbital decay can be added easily in the software. This could be useful for simulating the orbits that does not have manoeuvre of orbit maintenance.
- A module that simulates the position of real sun in ECI
- A module that simulates Pitch Steering maneouvre which has not been considered in this report

References

Raney, R. K. (1991). Considerations for sar image quantification unique to orbital systems. *IEEE Transactions on Geoscience and Remote Sensing*, 29(5):754–760.