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• **RESEARCH PAPER** •

Laplace Plane and Low Inclination Geosynchronous Radar Mission Design

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Abstract This study is inspired by the Laplace orbit plane property of requiring minimal station-keeping and therefore its potential use for long-term geosynchronous synthetic aperture radar (GEOSAR) imaging. A set of GEOSAR user requirements is presented and analysed to identify significant mission requirements. Imaging geometry and power demand are assessed as a function of relative satellite speed (which is determined largely by choice of orbit inclination). Estimates of the cost of station-keeping as a function of orbit inclination and right ascension are presented to compare the benefits of different orbit choices. The conclusion is that the Laplace plane (and more generally, orbits with inclinations up to 15°) are attractive choices for GEOSAR.

Keywords Laplace plane, station-keeping, geosynchronous, inclination, GEOSAR

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1 Introduction

Radar imaging from geosynchronous orbit is of growing interest and great potential. It has been studied since the 1970s and 80s [1, 2], and in more recent years significant interest is being shown in the US [3], Europe [4–6] and China [7–9]. The early US concepts used orbits with inclinations around 50° to provide near continental coverage. Similarly, the concepts studied in China have also proposed orbit inclinations up to 50–60° while those studied in Europe have tended to use much lower inclinations. Synthetic aperture radar (SAR) is used in all concepts to achieve a useful ground resolution.

A classification of geosynchronous SAR (GEO SAR) missions based on orbit inclinations is useful. Inclination determines the satellite speed relative to Earth, and this in turn influences the key system parameters such as integration time, antenna area and transmitted power needed. We propose the following classes:

• Quasi Geo-Stationary (QGS): these missions typically use very low inclination orbits so that the satellite stays within the standard GEO station-keeping "box" (±0.1° in longitude) defined by the International Telecommunications Union [10]. These missions have been studied in Europe and include the current GeoSTARe concept [11].

• Low inclination GEO: inclinations up to 15° . (15° is the maximum inclination achieved by geostationary satellites once they start to drift with no orbit control.)

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- Medium inclination: GEO orbits with inclination i: $15° < i \leqslant 45°$.
- High inclination: GEO orbits with inclination greater than 45° are considered high inclination orbits.

This article is concerned with low inclination GEO SAR mission concepts. In particular, we evaluated the design of a Laplace plane [12] mission. In the Laplace plane the gravitational perturbations (mainly) from the Sun and the Moon practically cancel each other; satellites in this orbit plane therefore use very little fuel to oppose these perturbations actively and there is minimal long-term drift. Laplace plane orbits are relatively stable and require less fuel to maintain them [13]. The Laplace plane ($i = 7.4°$, $\Omega \simeq 0$, in the GEO region) is in the middle of the low inclination band.

A second motivation for studying low inclination orbits is that they offer a compromise between the extremes of QGS and high inclination orbits [6]. QGS orbits have very low speeds relative to Earth (a few m s^{-1}) and therefore require long integration times (perhaps a few hours) to image at resolutions of a few times 10 m. On the other hand, high inclination orbits typically require huge antennas (20–50 m diameter) and several kW of transmitter power to achieve wide area coverage. Low inclination orbits offer mission designs with modest integration times and moderate antenna areas and transmitter power demand, and thus potentially offer high performance GEO SAR imaging at a reasonable cost.

The article presents an outline system design, based on representative mission requirements. Technical aspects of the choice of orbit are considered in the next section. The article closes with a general discussion and statement of conclusions.

2 Initial System Design

The aim of initial system design is to quantify key system parameters such as antenna size and transmitter power - this helps to assess the feasibility of a mission concept. However, the starting point for all system design should be a statement of expected user requirements. In practice, the analysis of user needs and development of a system design is iterative: the goal is to find the best match between user requirements and system design so that the system is both useful and practical. This section provides a summary of user requirements identified for the GeoSTARe project and some design rules for sizing the antenna and estimated transmitter power (as a function of the speed of the satellite relative to Earth). The orbit choices are discussed in the next section.

Atmospheric perturbations (ionosphere and / or troposphere) affect image focussing. Their impact on system design is not considered here but can be accounted for [6]. Some useful recent studies [14–16] consider the effects of and compensation for ionospheric perturbations in particular. Compensating atmospheric perturbations affects the data processing more than the hardware design.

2.1 Mission Requirements

Mission requirements were taken from the recent GeoSTARe study for ESA [17] which assumes a dual-band payload. These are summarised in Table 1. The applications relate to measurements of (a) atmospheric phase delay and ground deformation, (b) surface backscatter, and (c) coherent change detection, and are envisaged at two frequencies: L-band (23 cm wavelength) and X-band (2.5 cm). Using two bands allows atmospheric effects to be more easily identified and exploits the complementary features of the bands to improve system usefulness. The desired resolution ranges from 1–2 km down to 10 m, with corresponding repeat images needed every 15 min to 12 hr, depending on the application. The rank is a subjective assessment of priority based on the uniqueness of the measurement and its usefulness and is helpful for setting priorities in system design. Note that some applications such as atmospheric phase screen measurement, subsidence monitoring and agriculture (primarily soil moisture estimation) require practically continuous observations, while others will be called on only in response to emergencies (e.g. flooding, earthquake). The operations plan must be able to accept both these types of use.

The most challenging cases for system design are determined by the spatial resolution, integration time and wavelength, since these determine a minimum azimuth speed and transmitted power. The minimum (mean) azimuth speed is found by re-arranging the equation for azimuth resolution Δy:

$$\Delta y = \frac{r_{slant}\lambda}{2\overline{v}_{az}t_{int}} \qquad \overline{v}_{az,min} = \frac{r_{slant}\lambda}{2\Delta y t_{int}} \tag{1}$$

Table 1 lists $\overline{v}_{az}$ calculated for each application. The most demanding is the snow mass measurement with a resolution of 200 m required every 2 hr in L-band (3.1 m s^{-1}), but even this is compatible with many QGS orbits.

Equations 2 to 6 are used for the radar system design. Equation 6 can be used to define a metric to assess the most demanding requirement in terms of transmitted power. The symbols are: B - bandwidth (Hz), θ - incidence angle, L_x, L_y ground resolution across- and along-track, t_{int} - integration time, r - slant range from radar to target, v - typical relative orbit speed, A - antenna area, A_{min} - minimum antenna area to avoid image ambiguities, c - speed of light, $n_{prf,min}, n_{prf}, n_{prf,max}$ - minimum, actual and maximum pulse repetition frequencies (Hz), d_x, d_y - antenna dimensions in the across- and along-track directions, P_t - peak transmitted RF power, f_t - duty cycle factor (0–1), F_{SNR} - signal to noise ratio, F_n - receiver noise figure, k - Boltzmann's constant, T_s - surface temperature (K), σ^0 - surface normalised backscatter coefficient.

$$B = \frac{c}{2L_x \sin\theta} \tag{2}$$

$$t_{int} = \frac{r\lambda}{2L_y v} \tag{3}$$

$$A \geqslant A_{min} = \frac{8vr\lambda\tan\theta}{c} \tag{4}$$

$$n_{prf,min} = \frac{2v}{d_y} \leqslant n_{prf} \leqslant n_{prf,max} = \frac{cd_x}{4r\lambda\tan\theta} \tag{5}$$

$$P_t f_t = \frac{4\pi r^4 F_{SNR} F_n k T_s \lambda^2}{\sigma^0 \cos\theta A^2 t_{int} L_x L_y} \tag{6}$$

The combination of application parameters $c_P = \lambda^2/(t_{int}L^2)$ is proportional to the mean transmitter power needed ($P_t f_t$, hence the subscript P) and depends on the main application parameters (spatial and temporal resolution and band / wavelength). c_P therefore expresses the power demand as a function of each application's key parameters: c_P is given in Table 1 for each application. The most demanding application (assuming all need the same signal-to-noise ratio) is earthquake response in L-band ($c_P = 245\times10^{-12}$ s^{-1}), and earthquake and subsidence response and volcanoes in X-band ($c_P = 145\times10^{-12}$ s^{-1}). It is interesting (and convenient) that high priority applications such as the atmospheric phase screen (APS) measurements are relatively undemanding for both azimuth speed and power.

For system design we initially design for the most demanding applications. The final design choice though may be a compromise between satisfying requirements and the priority of the application - a low priority application should not be allowed to drive the design to an expensive solution.

2.2 Outline System Design

Radar system design is generally an iterative process. A useful first estimate can be obtained using the design process outlined in Figure 1. The inputs relate either to the user requirements (e.g. spatial resolution in across- or along-track directions) or to constraints common to most GEO SAR systems (slant range r, scene noise temperature, efficiencies, etc.). From these several intermediate variables can be calculated. Bandwidth and integration time are useful values, although not used directly in this initial design process.

Antenna area must be chosen larger than A_{min} (equation 4), and if this is satisfied then the inequalities for the antenna dimensions will be possible to meet. The product $P_t f_t$ is the mean transmitted RF power (equation 6) and so is a useful guide to the required input electrical DC power needed by the radar transmitter.

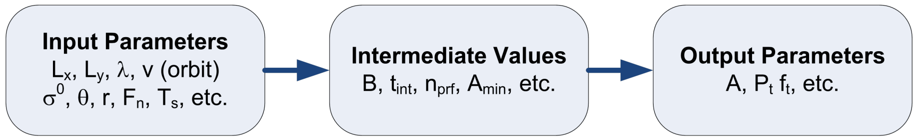
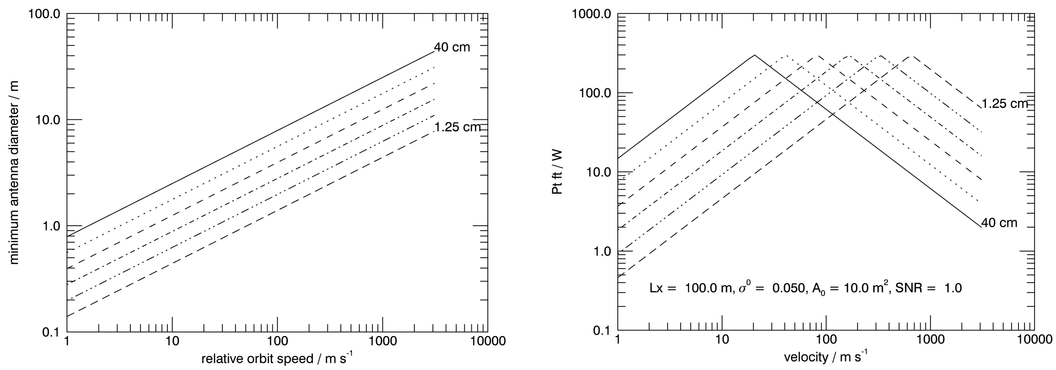


Figure 1 Outline initial system design process.



(a) Minimum antenna diameter to avoid aliasing

(b) Mean effective RF power per beam (antenna area is the larger of 10 m^2 and the minimum to avoid aliasing)

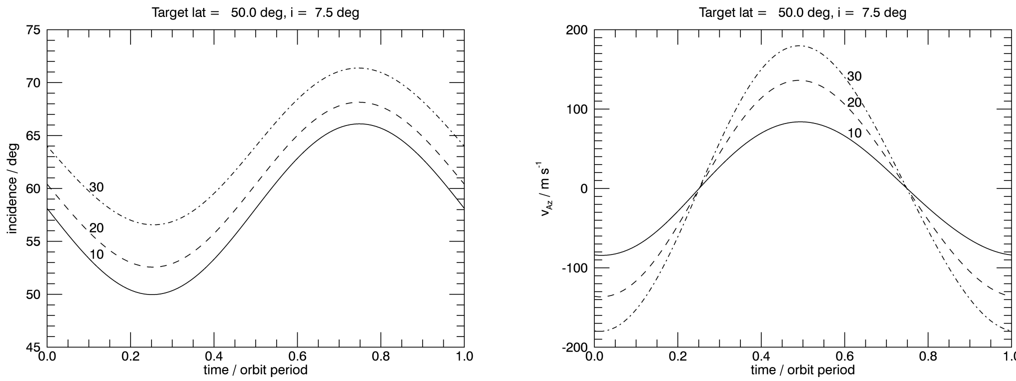
Figure 2 Representative dependence of minimum antenna diameter and required RF power on the azimuth component of the relative orbit velocity (for wavelengths of 1.25, 2.5, 5.0, 10, 20 and 40 cm; incidence angle = 50° , range = 38 500 km).

Figure 2 shows the minimum antenna diameter (derived from A_{min} for a circular antenna) to prevent imaging ambiguities. In practice the antenna diameter is not reduced below a certain size, because below this the beam is so wide that the transmitter power needed becomes impractical. Figure 2 also shows example values for the mean effective RF transmitted power needed (assuming a minimum antenna area of 10 m^2). For high speeds, the power (for a single spot beam) reduces because the larger antenna collects more power and illuminates a smaller footprint. At low speeds, the area is fixed at a value (A_0) larger than the minimum needed, and the power required reduces in proportion to the speed (using a longer integration time). Allowing for transmission and power conversion efficiencies, the required electrical power may be four times $P_t f_t$. The power given here is the power per beam: at high orbit speeds many beams are used simultaneously to give sufficient area coverage and therefore the total power demand does not decrease.

For low inclination orbits the satellite speed relative to Earth is typically tens of m s^{-1} to a few hundred m s^{-1} (see next section for a more detailed analysis). In these orbits, all the applications of Table 1 can easily be satisfied in terms of resolution / repeat period. For a moderately large antenna (50–100 m^2) the required RF power per beam is on the order of 100 W (equation 6, Figure 2) which would allow several beams to be used simultaneously.

3 Choice of Orbit

Orbit choice affects the satellite's motion relative to Earth and the cost of orbit maintenance. The motion has two effects: its primary effect is to create a synthetic aperture which is useful for radar imaging. A secondary effect is to increase its motion relative to other satellites in the GEO region and so precautions may be needed to minimise collision risks. The cost of orbit maintenance depends on the mission requirements but a radar mission is likely to require accurate control of the orbits to enable interferometry (which needs a ground track which repeats within a few 10s of km typically): this can be quite demanding. There is a final manoeuvre cost to prevent the satellite from entering the protected GEO region after its end-of-life when orbit control is no longer possible.



(a) Local incidence angle (b) Azimuth speed

Figure 3 Azimuth speed and local incidence angle during the whole orbit period for points at latitude 50° , and longitude offsets from the satellite of 10, 20 and 30° .

3.1 Orbit motion creating the synthetic aperture

A wide variety of synthetic apertures is possible for a given geosynchronous orbit inclination. Geosynchronicity defines the period (equivalently the semi-major axis): other parameters which can be chosen are the eccentricity, argument of perigee and the right ascension. The eccentricity is the dominant factor controlling east-west motion; inclination determines the north-south motion. The argument of perigee controls the relative phase of these two motions and the right ascension determines the orientation of the orbit plane in inertial space. Feasible ground track shapes include ellipse, circle and straight line. For simplicity, this section considers an orbit with zero eccentricity. The ground track of these orbits is a figure-of-eight elongated in the north-south direction, with maximum excursion equal to the inclination (a type of analemma).

East-west motion is especially useful for imaging areas to the north and south of the satellite; north-south motion is useful for imaging to east or west. The azimuth speed is the component of the velocity of the satellite relative to Earth which is perpendicular to the slant range and local surface normal, i.e. the component which creates the synthetic aperture to give azimuth resolution. Figure 4 shows contours of the highest azimuth speed observed by points in view of the satellite for a circular orbit with inclination 7.5° and which crosses the equator at -10° (west). The maximum speed is over 400 m s^{-1} but along the analemma axis the azimuth speed drops practically to 0. The figure also shows local incidence angles at the time of equator crossing. Figure 3 shows how the azimuth speed (and the local incidence angle) change during an orbit for three example positions (all have latitude 50° N, their longitudes are 10, 20 and 30° east of the satellite).

The local azimuth speed changes during an orbit, with a sinusoidal motion. The times when speed is close to zero will not be useful for synthetic aperture imaging, but the minimum useful orbit speeds in Table 1 are all low and therefore these imaging gaps are short for low inclination orbits (but not QGS orbits). The fact that the azimuth speeds change so much during an orbit (and depend on target position) means that image focussing must adapt to the changing velocity and is therefore more complicated than for conventional low Earth orbit radar.

Incidence angles of 20–65° are satisfactory for radar imaging. Much of Europe falls inside these limits for the example geometry, although high latitudes and the equatorial region “below” the satellite cannot usefully be imaged. The change in local incidence during an orbit is modest for the example positions and so should not generally be significant.

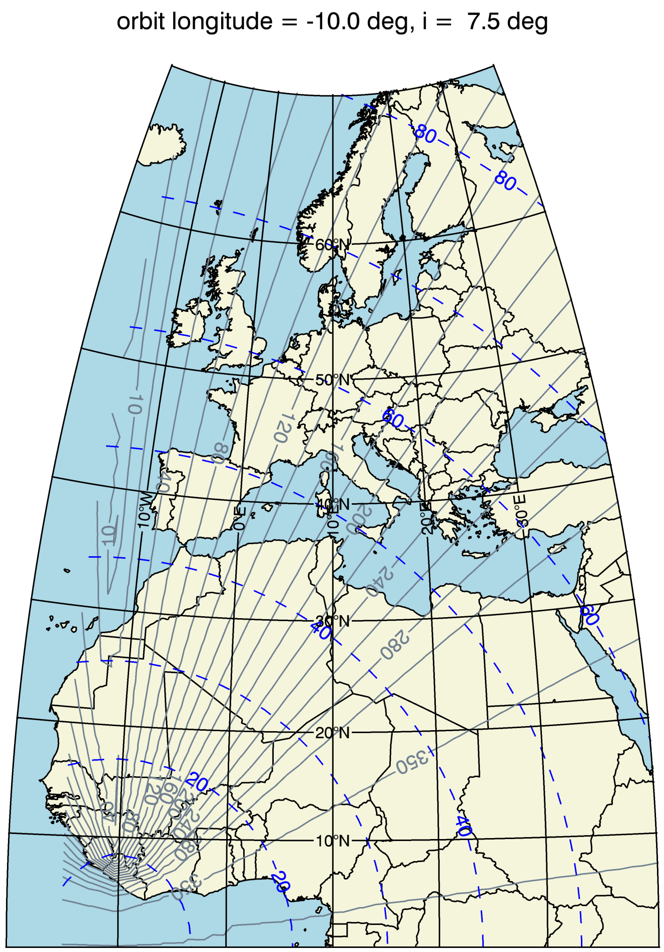


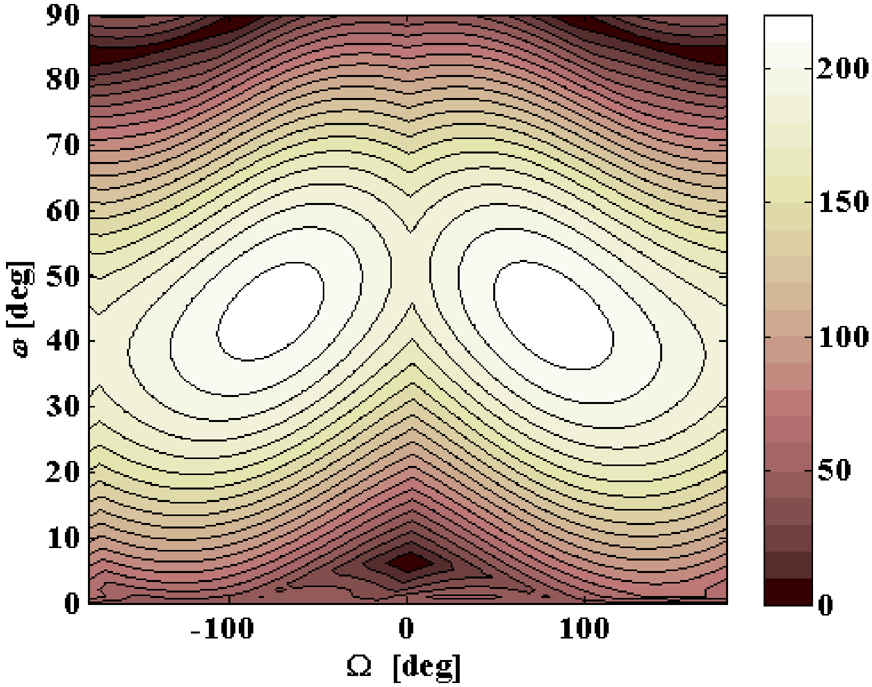
Figure 4 Contours of maximum azimuth speed (m s^{-1}) and local incidence angle for a GEO SAR satellite with a circular orbit, inclination 7.5° , positioned at longitude -10° .

3.2 Cost of orbit maintenance

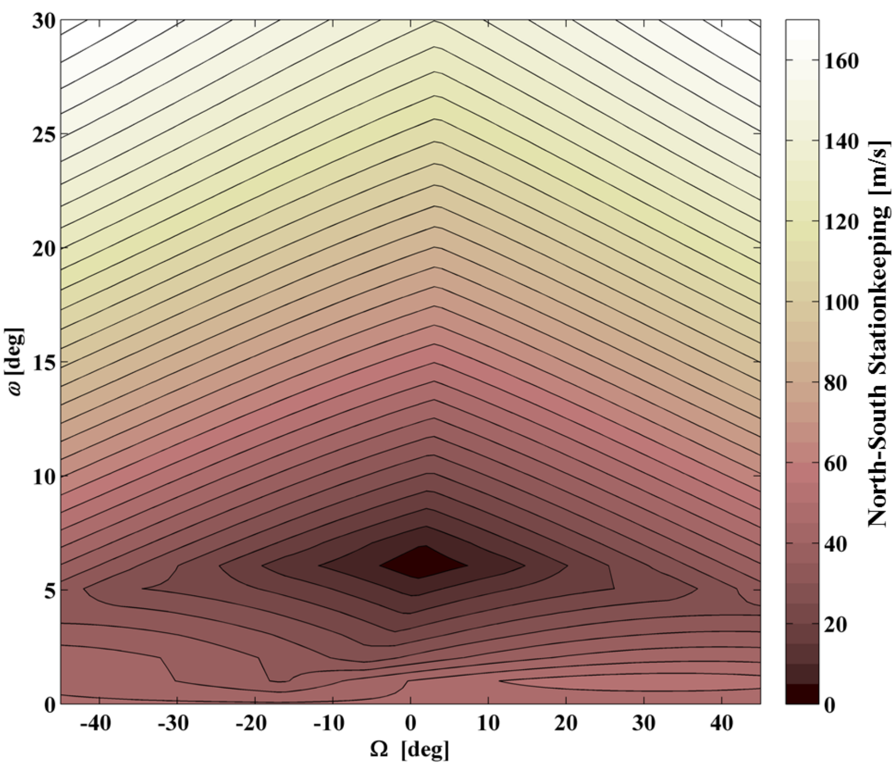
For satellites, the cost for station-keeping is measured in terms of the cumulative velocity change the thrusters must achieve, often expressed as m s^{-1} per year. For typical communication satellites in the GEO region, this cost is about 50 m s^{-1} yr^{-1}. For satellites with non-zero inclination, this cost varies with inclination and right ascension. There is a minimum cost for the Laplace orbit plane [13], but away from that the cost increases.

Alcalda Barahona [18] estimated the cost of north-south station-keeping in GEO as a function of orbit inclination and right ascension. The method was to simulate the orbit (including the most significant gravitational perturbations), and then to calculate the manoeuvre needed after a given period of time to return a satellite to its original orbit. The manoeuvre cost was then normalised by the period to give the annual cost: the results are shown in Figure 5 (and were largely insensitive to the reference period chosen). This method does not give exact values, but should be useful for feasibility studies. As expected, there is a clear minimum cost for the Laplace orbit plane, and the value around the equatorial ring is close to 50 m s^{-1} yr^{-1}. Away from these orbits, the cost varies significantly and can be above 200 m s^{-1} yr^{-1} for some high inclination orbits.

Figure 5 suggests that care should be taken in choosing the orbit for GEO SAR. Orbits with high inclinations may be expensive to maintain to the accuracy needed to allow interferometry. To take



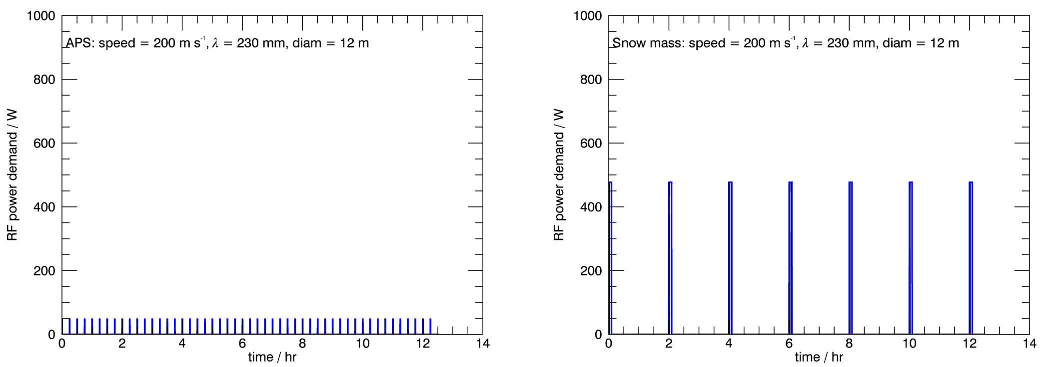
(a) Annual station-keeping cost as a function of orbit inclination and right ascension



(b) Annual station-[keeping cost, detail around the Laplace orbit

Figure 5 Annual station-keeping cost to cancel the North-South drift due to luni-solar gravitational perturbations in GEO (Alcalda Barahona, 2015).

advantage of the Laplace orbit properties, the inclination and right ascension must be within a few degrees of the ideal values which limits the choice of orbit. Although the calculations have been done for



(a) Atmospheric phase screen

(b) Snow mass

Figure 6 RF power requirement timeline based on three beams steered sequentially for two representative user applications (L-band, azimuth speed = 200 m s^{-1}, 12 m diameter antenna).

circular orbits, we do not anticipate any significant change in these values if the eccentricity is non-zero but modest (up to 0.1, say).

3.3 Cost of end-of-life disposal

Space debris mitigation standards define graveyard orbits to which GEO satellites should be moved at end of life [19]. The GEO graveyard region is 200 km above (and below) the geostationary ring: therefore an end-of-life manoeuvre is required to transfer the satellite to outside the geosynchronous protected region (and the final orbit should be close to circular to minimise orbit perturbations which might cause it to re-enter the protected region). For a circular geosynchronous orbit this is a modest demand of 10–15 m s^{-1}. If the orbit is eccentric then the propulsion demand can be higher: in this case the manoeuvre assumed is a single thrust to circularise the orbit at its apogee height (similar to the second half of a Hohmann transfer [20]), and the cost is proportional to eccentricity (up to at least $e = 0.1$) and is 15 m s^{-1} per 0.01 of eccentricity. Enough propellant should be reserved for this final manoeuvre.

4 Discussion

Two aspects of mission design relating to low inclination orbits are discussed here. The first is the usefulness of beam steering and the second is the usefulness of Laplace plane orbits for GEO SAR.

4.1 Using multiple beams

For the QGS GEO SAR concepts there may only be a single beam which stares continuously at the target area. The footprint may be large enough for these missions to cover a wide area on the order of 1 000 km in size using L-band. However, for higher inclination orbits than QGS the antenna is likely to be larger resulting in a smaller beam footprint. In these cases it will be necessary to use multiple beams to cover a large region. The beams may be simultaneous by using multiple feeds for the antenna or an electronically-steered antenna, or may be imaged sequentially. Figure 6 shows the RF power demand timeline for two representative applications from Table 1: in both cases the power demand for three sequential beams is shown. It can be seen that the RF power demand is modest (about 500 W RF for the snow mass case and less than 50 W for the APS measurements). With the orbit speed assumed (200 m s^{-1}) the images are acquired quickly leaving time to increase the total area covered by steering the beam to new areas before repeat images are needed.

A simple metric for imaging "efficiency" is the energy needed per unit area (E_0) to form an image of a given quality. This is obtained by dividing the product of mean power $P_t f_t$ and integration time

t_{int} by the footprint area of a beam ($A_f = r^2\Omega/\cos\theta$, where $\Omega = \lambda^2/A$ is the solid angle subtended by the antenna). Based on equation 7 a large antenna leads to more efficient imaging, but to use a large antenna well the beam should be steered. Imaging modes will typically be either spotlight or squint: the conventional strip-map mode is unlikely to work well for orbits where the ground track velocity keeps changing.

$$E_0 = \frac{P_t f_t t_{int}}{A_f} = \frac{P_t f_t t_{int} A \cos\theta}{r^2\lambda^2} = \frac{4\pi r^2 F_{SNR} F_n k T_s}{\sigma^0 A L_x L_y} \tag{7}$$

Both these aspects point to a need for agile steering of the beam footprint, and possibly being able to use multiple beams simultaneously, to maximise the usefulness of GEO SAR missions with medium to large antennas. This corresponds to missions using inclinations above a degree or so.

4.2 Laplace plane orbits for GEO SAR

The Laplace plane is an intriguing option for GEO SAR missions. Much reduced station-keeping demands compared to other orbits is attractive and offers the possibility of long lifetime missions since propellant demand should be lower. However, to preserve any benefits of the Laplace plane, the orbit inclination and right ascension should not differ much from those of the Laplace plane (perhaps within 30° in right ascension and just a few degrees in inclination). This constrains mission design.

An initial assessment of the constraints on mission lifetime (assuming that propellant consumption no longer dominates this) suggests that critical components such as batteries may become life-limiting. This probably means that the extended lifetime (beyond the standard 15 yr life of GEO communication satellites) may be 20–25 yr. This improves the mission cost-effectiveness, and Earth observation (EO) is a service for which the requirements are not expected to change radically over a few decades (unlike commercial communications) - in fact continuity of observations is a significant advantage in EO. On-orbit servicing could change this perspective and may become a reality within a few decades.

4.3 A baseline Laplace plane GEO SAR mission design

A specific GEO SAR mission design was developed to evaluate the benefits of Laplace plane orbits [12]. The study includes all the main aspects of mission design. The mission requirements were to use the Laplace plane orbit for GEO SAR imaging for the applications listed in Table 1. The study team's proposed design is dual-band with two 13 m antennas. A relatively high eccentricity of 0.089 was chosen so that the East-West and North-South motions were similar, giving a circular ground track. The estimated dry mass of the satellite was 2153 kg. Assuming chemical propulsion, the fuel mass was 3087 kg (most of which is needed for the initial orbit insertion). The total electrical power demand of 6.2 kW is mainly for the payload (4.5 kW).

This mission design illustrates some of the points discussed above:

- The Laplace plane orbit does reduce station-keeping costs (to below 15 m s^{-1} yr^{-1}) although the orbit insertion and disposal manoeuvres are more expensive for eccentric orbits. For mission lifetimes beyond about 7 yr the Laplace plane orbit required less fuel than a geostationary orbit, and the fuel load for a typical 15 yr comsat lifetime would be sufficient for about 30 yr of the Laplace plane mission.
- For good area coverage it is useful to have a large antenna which can form many beams simultaneously. This baseline study assumed 19 spot beams creating a hexagonal footprint. Antennas are thus a key technology for this type of GEO SAR mission.

5 Conclusions

The analysis and discussion presented above support the suggestion that low inclination orbits are useful for GEO SAR imaging. The Laplace plane does have attractive features, but it is also a relatively constrained opportunity if the benefits of low orbit maintenance are to be realised. Low inclination orbits do seem to offer good imaging performance which can be achieved without needing especially challenging antenna sizes or transmitter power.

User requirements such as those presented in Table 1 are the core of mission design. Requirements should be reviewed as a design develops to ensure the best match between user needs and the design solution. A prioritisation of the requirements is useful to guide designers when compromises in the design have to be accepted. One of the challenges for GEO SAR will be to plan the operations to serve both those requirements needing continuous, regular imaging and those needing rapid response to specific emergencies. Another challenge is the wide range of imaging geometries across the satellite's field of view and during a day. This certainly complicates the data processing: however, it seems difficult rather than impossible.

Although the antenna size needed is not demanding, the ability to use multiple spot beams simultaneously (perhaps with full polarisation capability and more than one band) may be. The analysis above and the baseline mission design suggest that multiple beams will be needed to achieve useful area coverage and to exploit the radar effectively: antenna design to enable this requires further study. Unlike low Earth orbit radars, a permanent communication link to ground should be easy to achieve since the satellite will be continuously in view of ground stations and a duty cycle well above 50% seems realistic.

In summary, low inclination orbits offer several advantages over the quasi-geostationary orbits for GEO SAR while also being simpler to implement than the high inclination orbit missions. Orbits close to the Laplace plane may be useful if the limited choices of orbit inclination and right ascension are acceptable.

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Conflict of interest The authors declare that they have no conflict of interest.

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Table 1 User requirements based on the GeoSTARe study (TN01v7, *pers. comm.*, Table 2) (APS = Atmospheric Phase Screen, EQ = EarthQuake; $\lambda = 23$ cm for L-band or 2.5 cm for X-band; t_{repeat} is shown as 24(12) if data are needed every 24 hr since 12 hr is the maximum period before the satellite motion starts to repeat; $\overline{v}_{az,min}$ and c_P relate to mission performance requirements and are defined in section 2.1)

(a) Phase

Application	Band	L (m)	t_{repeat} (hr)	δl (mm)	Rank	$\overline{v}_{az,min}$ (m s^{-1})	c_P (10^{-12} s^{-1})
APS	L	2000	0.25	10	1–3	2.5	15
EQ interseismic	L	100	24(12)	10	6	1.0	122
EQ response	L	100	6	10	7	2.0	245
Snow mass	L	200	2	10	4	3.1	184
Glacier	X	20	24(12)	1	16	0.6	36
Landslide (motion)	X	20	6	2	14	1.1	72
Subsidence	X	10	12	2	15	1.1	145
Volcano (intra)	X	20	3	10	5	2.2	145

(b) Backscatter

Application	Band	L (m)	t_{repeat} (hr)	NEσ^0 (dB)	Rank	$\overline{v}_{az,min}$ (m s^{-1})	c_P (10^{-12} s^{-1})
Agriculture	L	100	24(12)	-18	12	1.2	15
Hydrology	L	1000	1	-18	13	1.0	122
Snow cover	L	200	24(12)	-23	11	0.5	31
Agriculture	X	50	3	-14	12	0.9	23
Flooding	X	30	2	-14	8	2.2	96
Snow cover	X	50	2	-14	11	1.3	35

(c) Coherent change detection

Application	Band	L (m)	t_{repeat} (hr)	Rank	$\overline{v}_{az,min}$ (m s^{-1})	c_P (10^{-12} s^{-1})
EQ response	L	100	6	7	2.0	245
Volcano (intra)	L	100	12	5	2.0	122
EQ (response)	X	10	12	7	1.1	145
Flooding	X	30	2	8	2.2	96
Landslide (response)	X	30	6	10	0.7	32
Volcano (response)	X	20	3	9	2.2	145

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