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FEASIBILITY OF PASSIVE BISTATIC GEOSYNCHRONOUS RADAR USING COMSAT TRANSMISSIONS

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ABSTRACT

Communication satellites in geosynchronous orbit are increasingly broadcasting digital signals with high bandwidth and high power. These signals are in principle well-suited to radar imaging and the study presented here is an initial feasibility study for a passive bistatic synthetic aperture radar using satellites in geosynchronous orbit (GEO). The persistent viewing possible from GEO could enable important new applications. The mission concept is outlined and studies of the available signal formats identify digital TV broadcasts in Ku-band as most suitable for radar imaging. The additional space hardware required is a dedicated receive channel, which could be implemented as a hosted payload at modest cost. Our findings so far suggest that the mission concept is feasible for coarse spatial resolution images and that it could therefore provide a low-cost technology demonstration of geosynchronous radar.

***Index Terms*—** bistatic, radar, geosynchronous, passive, comsat

1. INTRODUCTION

Geosynchronous synthetic aperture radar (GeoSAR) has been studied since the early days of spaceborne radar. The field continues to develop with relatively mature concepts being developed in both China [1] and Europe[2, 3], in fact a Chinese mission is expected to be launched in the early 2020s. The concept is not without technical risks and so a cost-effective means of demonstrating the technology would be useful. The aim of this study is to evaluate the feasibility of a passive bistatic geosynchronous radar (Figure 1) re-using existing comsat transmissions. This has the potential to demonstrate GeoSAR at relatively modest cost and to build the confidence and expertise of the user community. GeoSAR is attractive since it combines the benefits of radar (all-weather, day / night imaging; powerful imaging modes which complement visible band imagers) and geostationary orbit (continuous views over continental scales). Visible and infrared imagers already use this orbit, but no geosynchronous radars have yet been flown. Radar would provide valuable new data products.

The mission concept for a bistatic passive GeoSAR uses separate transmitter and receiver spacecraft in geosynchronous orbit. There are already many commercial satellites broadcasting high power, high bandwidth signals for services such as satellite TV. Therefore, in principle a radar can be achieved simply by adding a suitable receiver to another satellite which can view the area illuminated by the transmitter (Fig. 1). The receiver will collect the scattered transmitter signals and if correctly synchronised, the data can be used to form synthetic aperture radar images. The concept is passive, because it re-uses transmissions intended for a different purpose, and bistatic, because the transmitter and receiver are in different places (on separate satellites).

Developments in technology make this study timely. The available comsat signals increasingly transmit digital data at high bandwidth and with high transmitter power. Receiver technology is moving towards software-definition, and therefore great adaptability, and a number of studies have identified significant applications for which the ability of GeoSAR to achieve persistent radar imaging is especially valuable.

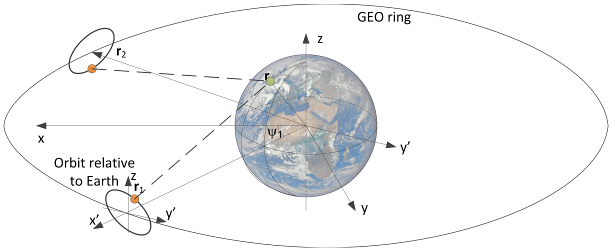

Fig. 1. Outline of the passive bistatic radar mission geometry.

2. USER REQUIREMENTS

A radar in geosynchronous orbit has a continuous view over continental areas and can provide new data products not pos-

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sible with conventional low Earth orbit radar. Mission design should emphasise the innovation rather than duplicating what is already available, as has been done for the GeoSTARe study [4]. For GeoSTARe, the most significant innovation was its ability to make frequent (every 15 min) measurements of integrated water vapour (since it affects refractive index) at horizontal scales of 1–2 km. A similar approach should be adopted for the passive bistatic mission design. Studies suggest that the spatial resolution and power available are sufficient for coarse resolution (around 1 km) user applications; this excludes many applications but does enable some of the most significant ones identified for GeoSTARe, i.e. the atmospheric phase screen.

3. AVAILABLE BROADCAST SIGNALS

Passive radar depends on having suitable signals available. Figure 2 shows geographical coverage of some of the candidate broadcast signals. An initial survey identified several candidate signals:

- L-band transmissions from Inmarsat satellites,
- Ku-band, mainly satellite television signals using DVB-S2,
- Ka-band, mainly data transmissions.

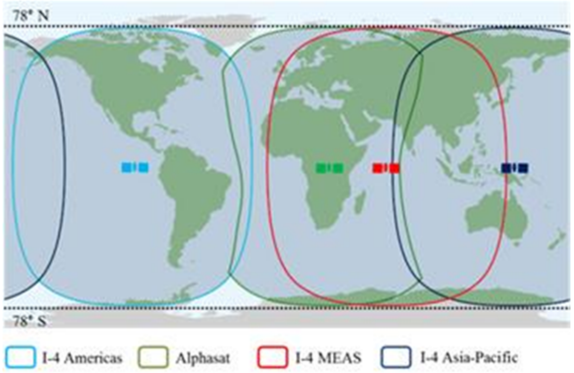
Of these, the L-band signals have global coverage but are low bandwidth. The Ka-band signals have high bandwidth and good power, but the data formatting is time-dependent and so the correlation properties of the signals are not stable. Ku-band satellite TV signals have good bandwidth, high power and stable correlation properties and are therefore the main priority for further work.

An additional factor in signal selection is the wavelength of the transmissions. Surface backscatter is generally more coherent for longer wavelengths: this favours L-band over shorter wavelengths, and Ka-band in particular may be limited in its usefulness over vegetated surfaces.

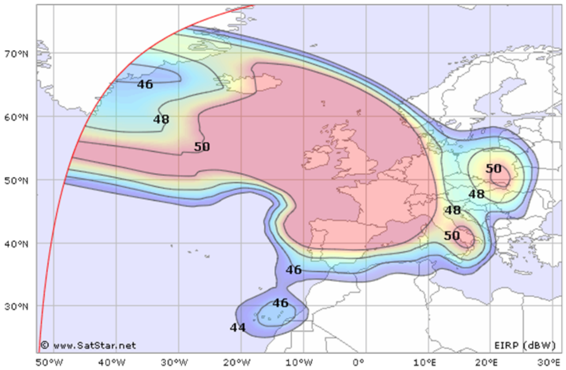
For radar imaging it is important that the signals have suitable correlation properties [5, 6]. Figure 3 shows example results for the Inmarsat class 5 L-band signals (bandwidth approximately 190 MHz). There is good agreement between the theoretical and observed correlations. Theoretical evaluations have also been made for the DVB-S2 signal format used for most satellite TV broadcasts and this too has good correlation properties. The shift from analogue to digital TV signals has significantly improved the correlation properties of the signals for passive radar use.

4. MISSION DESIGN

Figure 1 shows the mission geometry. The transmitter is a transmitter of opportunity and so the only dedicated hardware needed in space is a suitable receive channel; this can conveniently be implemented as a hosted payload on another comsat. Based on discussions with satellite operators, it should be possible to add a suitable receive channel with a dedicated feedhorn added to an existing antenna (2–3 m diameter) as long as the antenna is not used for transmissions at the same frequency as the passive radar receive channel. The signals from the receiver can be time-stamped and then transmitted to ground using one of the available transponder channels (standard bandwidth up to 72 Mbit s^{-1}). It is clearly important that the footprints of the transmit and receive antennas overlap: for populated regions such as Europe with many customers available, this should not be difficult to achieve.



(a) Inmarsat L-band



(b) Astra 2E Ku-band

Fig. 2. Example beam footprints.

We assume that the receiver will be reconfigurable under software control (using software-defined radio technology). This is to allow the system to adapt to whatever transmissions are available. The mass and power consumption of the receiver are expected to be modest (less than 10 kg or 100 W). The components of the demonstrator are each individually at high TRL since the transmitters are already operating (TRL9) and the receiver components are standard technology too: the demonstrator as a system is however only around TRL4 since some ground-based demonstrators exist but there are no spaceborne versions generating truly repre-

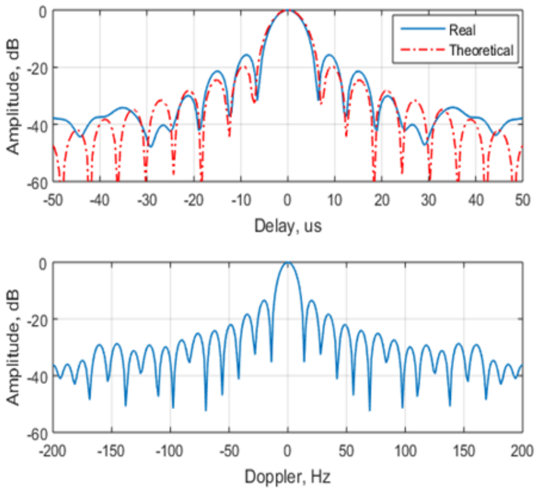


Fig. 3. Measured and simulated range and Doppler cuts for the Inmarsat class 5 L-band signal.

sentative data.

A ground segment is required for data processing to create the radar images. For this mission concept, the image focussing requires good synchronisation of the transmitter and receiver, and probably phase compensation for effects such as orbit perturbations, clock drift and atmospheric refractive index changes. We expect that reference targets will be used to enable this, with techniques such as autofocus to adapt the phase compensation actively. Studies in these areas are being performed for more general studies of geosynchronous radar and provide most of the capability required.

5. RADAR PERFORMANCE

The main expressions for bistatic radar performance are those for spatial resolution and the signal-to-noise ratio (SNR). These are similar to the expressions for conventional monostatic radar, but allow for the different ranges to transmitter and receiver, and for the "bistatic angle" β subtended at the target between the directions to the transmitter and receiver. Zeng et al. [7] derive the range and azimuth resolution expressions (L_x and L_y respectively), given in slightly modified forms below. The range resolution is along the bisector direction ($\mathbf{e}_b = a(\mathbf{e}_t + \mathbf{e}_r)$, where $\mathbf{e}_{t,r}$ are the unit vectors from the target to the transmitter or receiver, and a is a scalar to ensure $\mathbf{e}_b$ has unit magnitude).

$$L_x = \frac{c}{2B \cos \beta/2 \sin \theta_b} \tag{1}$$

$$L_y = \frac{\lambda}{t_{int}|\mathbf{v}'_t + \mathbf{v}'_r|} \tag{2}$$

where B is the signal bandwidth, θ_b the incidence angle defined by $\mathbf{e}_b$, λ is the radar wavelength and t_{int} is the integration time. $\mathbf{v}'_t$ is a normalised velocity defined by the transmitting satellite's velocity component normal to $\mathbf{e}_t$ divided by the slant range from the target to the transmitter. Similarly, $\mathbf{v}'_r$ is the normalised velocity of the receiving satellite as observed from the target. The denominator of Eq. 2 is therefore the angle subtended by the resultant of these two normalised velocities during t_{int}. Figure 4 shows simulated resolutions illustrating how the phasing of the velocities of the two satellites can affect "azimuth" resolution (range resolution is always along the bisector direction). The nominal range resolution is fixed at 250 m; the azimuth resolution varies with satellite velocity and is around 150 m at best. The direction in which azimuth resolution is most sensitive varies with the direction of the resultant normalised velocity; when it is parallel to the bisector direction then resolution is lost in the other coordinate (part (c) of Fig. 4).

A simple link budget evaluation for typical values for Ku-band transmissions and a receiver using an existing antenna on a commercial comsat suggests that adequate SNR can be achieved only for resolutions around 1 km or greater. This allows user applications such as atmospheric monitoring and coarse resolution soil moisture estimation to be satisfied, but not applications which require spatial resolution of 100 m or better.

6. DISCUSSION

The primary aim of this study is to identify a method of synthetic aperture radar imaging from geosynchronous orbit which is low-cost but *good enough* to demonstrate the principles, i.e. for technology demonstration. The demonstration is focussed on potentially useful applications so that it is a step towards operational services.

Our study so far shows that suitable signals are available for passive bistatic radar (e.g. Ku-band digital TV). The potential resolution matches possible applications, and the engineering implementation also seems feasible. Our work suggests that the concept is worthy of further study and we are now planning a series of technology demonstrations of the imaging concept so that both the technology and potential applications can be advanced. As computing power increases, we expect passive bistatic radar concepts to become increasingly feasible and hope that this study will lead eventually to an on-orbit demonstration.

7. REFERENCES

[1] Cheng Hu, Teng Long, Tao Zeng, Feifeng Liu, , and Zhipeng Liu, "The accurate focusing and resolution analysis method in geosynchronous sar," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 49, pp. 3548–3563, 10 2011.

[2] A. Monti Guarnieri, F. Djelaili, D. Schulz, V. T. Khang,

A. Recchia, F. Rocca, D. Giudici, S. Hobbs, T. Strozzi, C. Werner, R. Venturini, A. Broquetas, J. Ruiz Rodon, and G. Wadge, “Wide coverage, fine resolution, geosynchronous SAR for atmospheric and terrain observations,” in *Proc. Living Planet Symposium*, Edinburgh, UK, September 2013, number SP-722, p. 147, ESA.

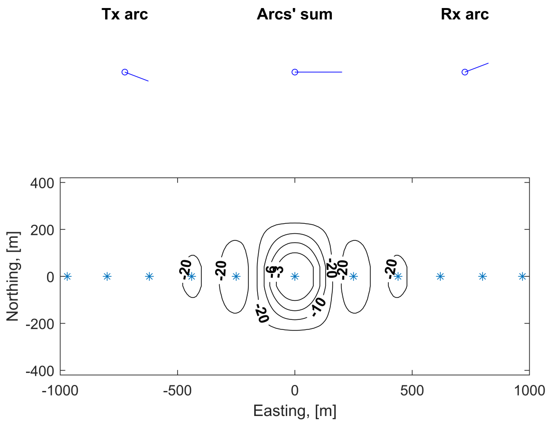
[3] S. Hobbs, A. Monti Guarnieri, G. Wadge, and Detlef Schulz, “GeoSTARe initial mission design,” in *Proc. IGARSS 2014, Quebec, July 2014*, 2014.

[4] G. Wadge, A. Monti Guarnieri, S.E. Hobbs, and D. Schulz, “Potential atmospheric and terrestrial applications of a geosynchronous radar,” in *Proc. IGARSS 2014, Quebec, Canada*, 2014.

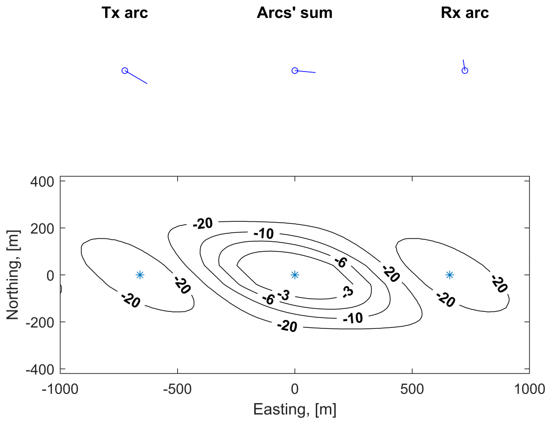
[5] Xiaoyong Lyu, Andrew Stove, Marina Gashinova, and Mikhail Cherniakov, “Ambiguity function of Iridium signal for radar application,” *Electronics Letters*, vol. 52, pp. 1631–1633, Sep 2016.

[6] Xiaoyong Lyu, Andrew Stove, Marina Gashinova, and Mikhail Cherniakov, “Ambiguity function of Inmarsat BGAN signal for radar application,” *Electronics Letters*, vol. 52, pp. 1557–1559, Sep 2016.

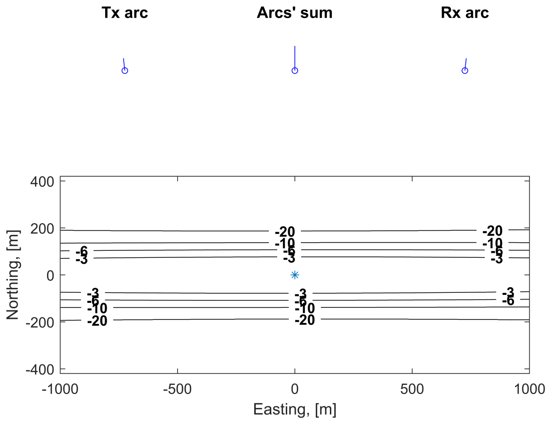
[7] Tao Zeng, Mikhail Cherniakov, and Teng Long, “General approach to resolution analysis in BSAR,” *IEEE Transactions on Aerospace and Electronic Systems*, vol. 41, pp. 461–474, 4 2005.



(a) Azimuth and range directions perpendicular



(b) Azimuth and range directions arbitrary



(c) Azimuth and range directions parallel

Fig. 4. Spatial resolution simulations for various cases of transmitter and receiver velocities (range direction is north-south; contour labels in dB; the asterisks shows the peak of each sidelobe; the three pointers at the top of each sub-figure show the corresponding normalised velocities of the transmitter and receiver, and their resultant).