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RESEARCH ARTICLE

On Orbit Demonstration of Pointing Accuracy of Ground Antennas by a Flying GEO Satellite

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ABSTRACT

Geostationary Satellites (GEO) are being used commonly in the communication market. The service providers uplink or downlink the signal using their dedicated antennas (whether with or without tracking capability) to the GEO satellite. The satellite down-converts and amplifies the signal before sending it back to the end users on Earth. Usually, the user sets and adjusts their ground antenna to follow or cover the GEO satellite movement as much as possible. As soon as there is no reduction in the link budget, this pointing is assumed to be successful. On the other hand, the input power of the satellite, together with satellite longitude vs. latitude, can give reasonable ideas about the accuracy of the ground antenna pointing. In this study, ground station pointing performance is shown in two different cases: one with tracking and one without tracking capability.

Keywords: GEO satellite, Tracking, Satellite communication, antenna pointing

1. Introduction

Theoretically, the GEO satellites are located at about 42165.8 km from the center of Earth and assumed to be stable with reference to the Earth. But, due to different kinds of perturbations acting on the satellite, this movement cannot be stable and needs to be controlled using propellants on board [1]. The users, who have larger antennas, need to track the GEO satellites since the larger parabolic antennas have narrower beams according to the beamwidth formula [6]. On the other hand, this kind of antenna has more gain that is taken into account in the link budgets. Besides, users with smaller-sized antennas have to point and fix the antennas through the center of the satellite control box, as precisely as possible, to perfectly receive or transmit the power whenever the satellite is inside the dedicated control box. Nominally, for GEO satellites, ±0.1 degrees of the control box in latitude and longitude are used.

In the literature, there are multiple studies regarding optimal tracking of GEO satellites [2], implementation of step-tracking [3], optical calibrations for these systems [4] or finding GEO satellite directions [5]. There are also some studies that detail the importance of pointing accuracy of the ground antenna [7], the movement of the satellite coverage when the inclination of the orbit is not controlled [8] and pointing errors due to perturbation on satellite movement [9]. In [10], the effects of the orbital parameters on the satellite link budget were simulated.

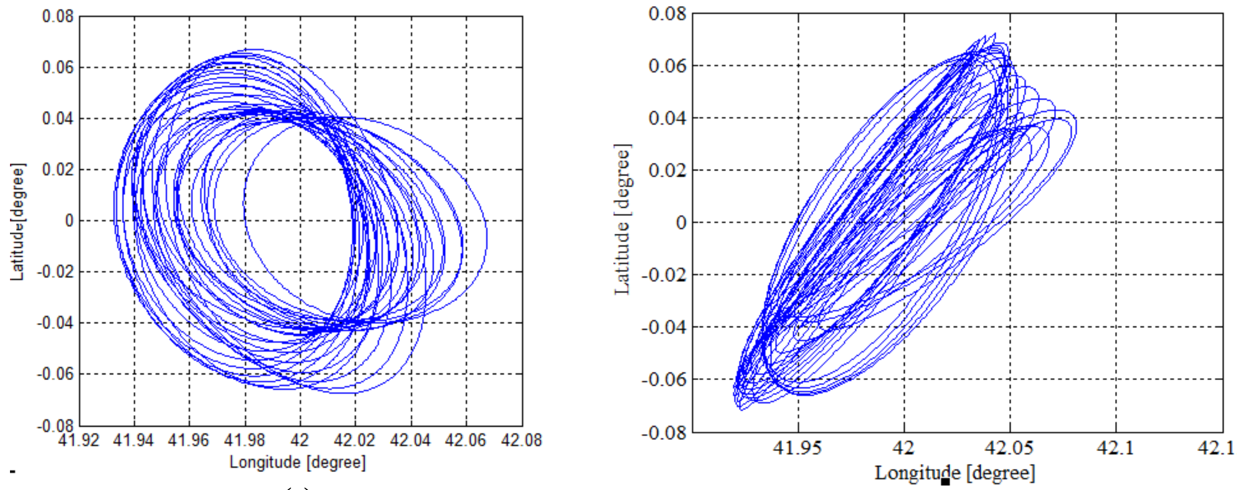
In this study, we figure out, (1) how can we make sure that the tracking performance of the ground antenna is satisfactory? And (2) how the pointing of the fixed antenna can be confirmed? That's why this study focuses on two kinds of users, 'with' and 'without' tracking antennas in the ground station. The latitude and longitude of the GEO satellite, collected from Flight Dynamics Software, with received power of antenna (on satellite or ground-based on the case study) collected from the ground system, are used together. For the complete analysis, a flying GEO satellite is used.

Case-1 uses a tracking ground antenna with a single uplink carrier to satellite. For case-2, a fixed ground antenna with a single carrier at downlink is used. We paid attention to observing the power level, whether on satellite or on ground, due to a single carrier. The weather was mostly clear sky, sometimes cloudy.

2. Case 1: Tracking antenna received power at satellite

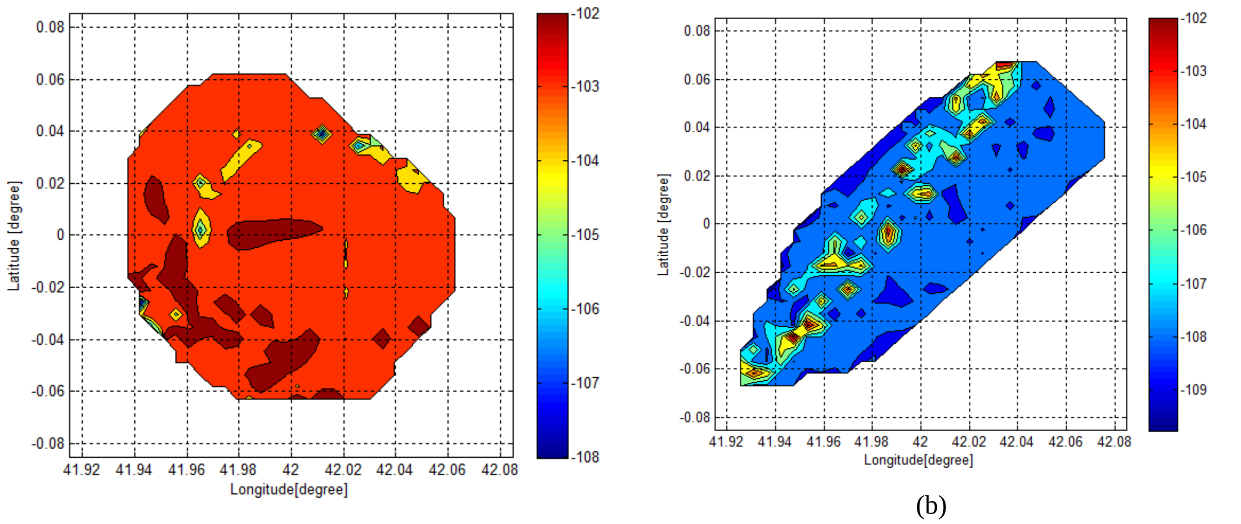
For case 1, an antenna with a diameter of 6.2 meters is used, which has 56.35 dBi gain at 14.425 GHz. The antenna uses the monopulse tracking option to follow the beacon signal coming from the satellite and uplink a single carrier to the satellite receiver. To interpret the tracking accuracy, the input power level of the satellite receiver is used with the same time label of satellite latitude and longitude. Two months of intervals are selected for different cases which show good representations. The GEO satellite, used in this study, had two chemical orbital control maneuvers in 14 days cycles; first, a North/South maneuver to control the inclination and after a couple of days, an East maneuver to control the longitude and drift of the satellite.

The hypothesis in this case-1 is; if the satellite always had the same level of input power reception during its movement inside the box for the selected period, this shows that the ground antenna is following the satellite perfectly. As two examples, Figure 1 below shows the satellite movement in latitude and longitude during (a) February 2020 and (b) May 2020.



(a) (b)

Figure 1 GEO Satellite orbit at 42-degree East in (a) Feb. 2020 (b) May 2020.



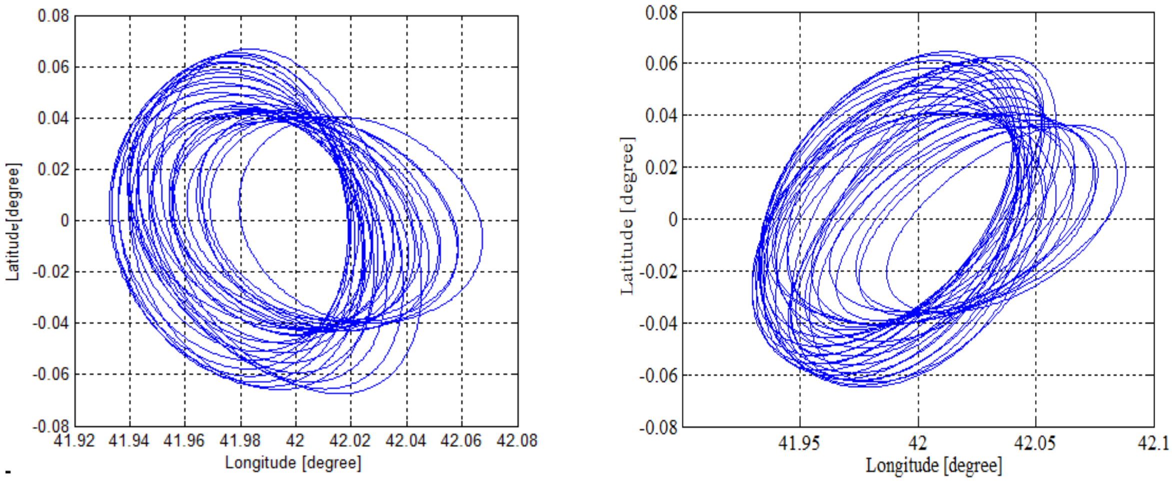
(a) (b)

Figure 2 The input power level at the GEO satellite from tracking ground antenna (a) Feb 2020 and (b) May 2020

Figure 2 below shows the input power level of the satellite receiver in color code while the satellite moves in its dedicated control box. As can be seen, there are some small areas where the link budget degraded during the weather condition and different power levels between the months. But overall, the input power level is almost stable and homogenous at each individual duration, as mentioned in the hypothesis. That shows the excellent performance of the tracking capability of the ground antenna, and we can easily confirm this result from the plot in Figure 2 below. The received power in the color codes is in dBm. The level decreased from February to May 2020 due to operational requests, but the distribution of the power level shows a small variation in time. This means the tracking performance of the ground antenna is successful.

3. Case 2: non-tracking antenna, received power at ground antenna:

For case-2, a non-tracking ground antenna is used with its received power. The hypothesis here is; while the satellite transmits the beacon signal continuously if the ground antenna is correctly pointed towards to center of the control box, it should receive the maximum level, especially when the satellite travels through the center of the box, which is 42-degree East in longitude and 0-degree in latitude in our case. For this case, February 2020 and April 2020 are used, and the satellite movements inside the box are shown in Figure 3 below.

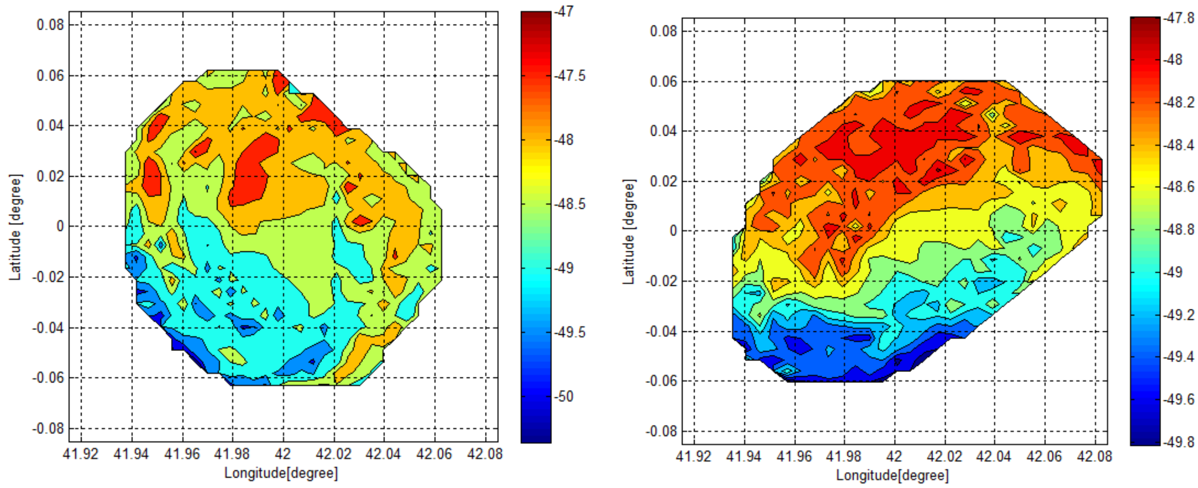


(a) (b)

Figure 3 GEO Satellite orbit at 42-degree East in (a) Feb. 2020 (b) April 2020.

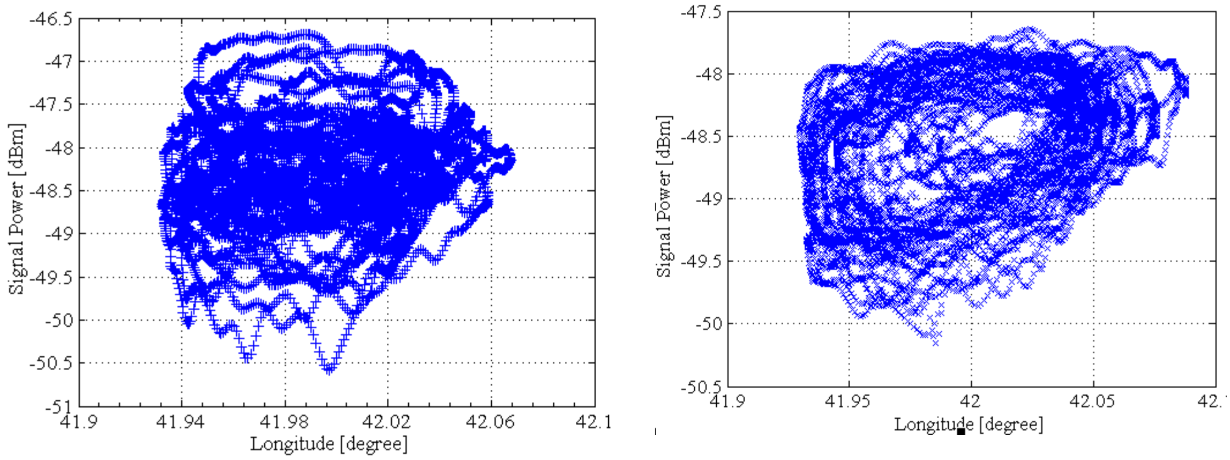
The used ground antenna has 2.4 meters of diameter with 26 dB/K of G/T (@ 20° elevation, 10.7 GHz) and about 0.79545 degrees of theoretical 3 dB beamwidth for 11.0 GHz receiver frequency [6]. The power levels in Figure 4 below are in dBm.

As shown in Figure 4 above, the input power level of the fixed antenna is not homogenous even though the satellite emits no or negligible variation in time. For this example, the ground antenna does not precisely point to the center of the box. Still, it has a minor error in Azimuth (longitude) but more in Elevation (latitude). For more details, Figure 5 and Figure 6 show the power level versus longitude and latitude for given time durations.



(a) (b)

Figure 4 The input power level at the non-tracking ground antenna receiver on (a) Feb 2020 and (b) April 2020



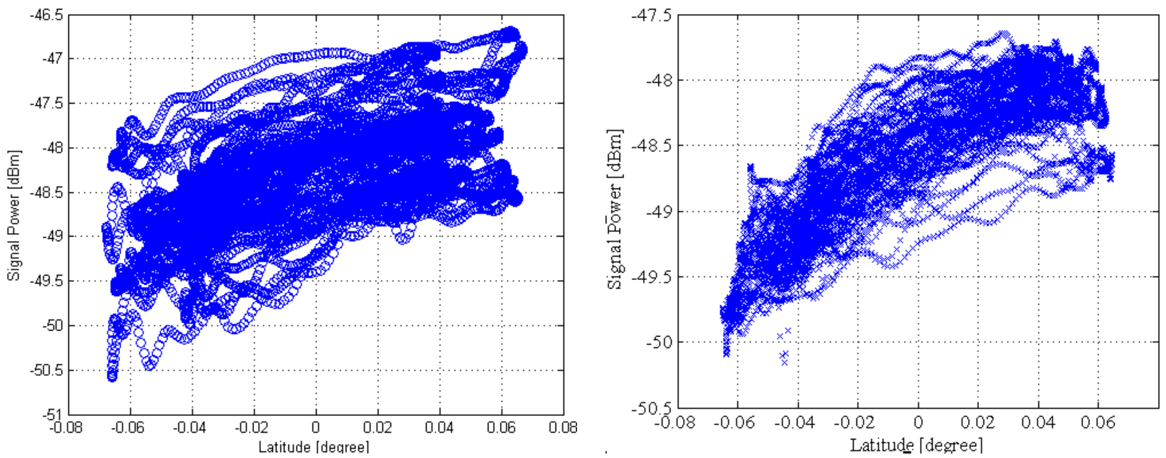
(a) (b)

Figure 5 Power level versus satellite longitude (a) Feb 2020 and (b) April 2020

As seen from Figure 5, there is a variation in signal power level due to the thermal behavior of ground equipment. There is no significant variation in Longitude concerning the signal power.

On the other hand, Figure 6 below shows the observed variations in time, which causes a similar variation as in longitude. As can be seen, there is a trend to increase when satellite travels in the North hemisphere for both time durations. This variation can explain the de-pointing of the ground antenna. When the satellite moves through the North, the input power level of the ground antenna increases and vice versa when it moves to the South.

As can be seen from Figure 5 and Figure 6, the input power distribution inside the box is more stable in Figure 5. But the input power shows some trend behavior in Figure 6. This is evidence that this ground antenna has not been fixed to the center of the box of the related GEO satellite perfectly. It can be seen that the origin of the power distribution diagram is at almost 42.0 degrees in longitude and 0.03 degrees in latitude. This means the azimuth and/or elevation must be corrected to eliminate the error in latitude. It has been noted here that the correction of the latitude for about 30 mdeg requires about -9 mdeg of correction in azimuth and about 34 mdeg of correction in elevation (based on the ground antenna location) by a generic Az/El calculation [6].



(a) (b)

Figure 6 Power level versus satellite latitude (a) Feb 2020 and (b) April 2020

4. Conclusion

For GEO satellite communication links, it is essential to be sure that both the transmitters and receivers are well-pointed to each other. This study shows that the orbital information of the satellite gives reasonable outputs regarding the pointing of the ground antenna if they are used together with the received or transmitted power. This would allow the user to calculate the pointing losses more accurately in link budgets.

It is found in this study that pointing a ground antenna to a GEO satellite requires a good setting of azimuth and elevation angles or good tracking of the GEO satellite. In that sense, the GEO satellite operators may provide more realistic values to the end users regarding the pointing performance of their antennas and possible pointing loss in link budgets.

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Conflict of Interest Notice
The authors declare that there is no conflict of interest regarding the publication of this paper.

Ethical Approval and Informed Consent
It is declared that during the preparation process of this study, scientific and ethical principles were followed, and all the studies benefited from are stated in the bibliography.

Availability of Data and Material
Not applicable.

Plagiarism Statement
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