

Research on Large Aperture Antenna Tracking Method Based on SIGSO Satellite

Junxia CUI, Chang LYU, Huli SHI

National Astronomical Observatories of CAS, 20A Datun Road,
Chaoyang District, Beijing, 100012, China
Tel.: 8610-64848269, fax: 8610-64846485
E-mail: cuijx@nao.cas.cn

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Abstract: In the end-of-life GEO satellite communication system, satellite remaining fuel is not enough to make north-south station-keeping control. As a result, its orbit inclination becomes larger and larger, and its sub-satellite point range becomes bigger and bigger than GEO satellite as time goes on. This kind of GEO satellites is called “slightly inclined geostationary-satellite orbit, SIGSO” satellite. However, as for the larger aperture antenna in the communication center station, even very small point deviation will cause signal level change which can be ignored, due to the beam is very narrow. Nevertheless, if we select appropriate antenna mount form and tracking mode, signal level change caused by the satellite movement will be minimized, thus ensuring the normal operation of the entire communication system. In this paper, various antenna mount forms and tracking modes are studied and compared, and a field test was conducted for 16 m truss mount by step tracking SIGSO satellite Apstar-1. Finally, the conclusion that turntable antenna mount and monopulse tracking mode is optimal for SIGSO satellites is given. *Copyright © 2013 IFSA.*

Keywords: SIGSO satellite, Step tracking, Monopulse tracking, Large aperture antenna, Turntable mount, Truss mount.

1. Introduction

A satellite is ideally geostationary if its orbital elements satisfy some conditions [1]. The orbit gradually departs from the geostationary state, however, due to the perturbation forces acting on the satellite. The distortion of the Earth's gravitational field due to the non-sphericity of the Earth causes either a steady increase or decrease in the semi-major axis, according to the stationary longitude of the satellite. No change however occurs at four special longitudes called the equilibrium points. When the semi-major axis deviates from the synchronous radius by Δa (km) the satellite longitude drifts at the rate of $-0.013 \Delta a$ degrees per day. The solar radiation

pressure, acting in proportion to the ratio of satellite cross section to mass, changes the eccentricity with time. There is also a minor effect due to the Moon's gravity. A non-zero eccentricity e yields a diurnal libration motion in the satellite longitude of as much as $\pm 2e \times 180/\pi$ degrees. The gravity of the Moon and the Sun acting as a tidal force on the satellite changes the inclination at a rate that varies from year to year between 0.75° and 0.95° per year. A non-zero inclination i (degrees) yields a half-diurnal longitudinal libration motion of as much as $\pm(i^2/4)(\pi/180)$ degrees. This becomes significant for longitudinal station keeping when the inclination is greater than a few degrees. Therefore, North-South station-keeping and West-East station-keeping must

be carried out to keep the GEO satellite still. However, geostationary satellites using frequency bands allocated to the fixed-satellite service should maintain their positions within $\pm 0.1^\circ$ of longitude of their nominal positions irrespective of the cause of variation.

The station-keeping fuel on geostationary space stations constitutes an appreciable portion of in-orbit mass and tends to be the limiting factor of a geostationary space station's life. And the North-South station-keeping consumes up to 90 % of the total fuel [2]. After working for several years, when the fuel is consumed to a certain degree because of the station-keeping, the satellites are called end of the life satellites. Generally, these satellites will be pushed away from their original orbits and become space rubbish which is serious pollution of space environment. However, the satellite payload is still effective, and can serve for a longer time. If we only maintain the positions of longitude without the station-keeping of the latitude, the satellites can work for more years. In the absence of North-South station-keeping, the orbit of a geostationary satellite is subject to no more than about 0.9° of orbit change per year, and the inclination will never exceed the natural limit of 15° .

This kind of satellites is called "slightly inclined geostationary-satellite orbits" (SIGSO). If they are used in satellite communication system, there will come up several new problems such as angular tracking, polarization tracking and for digital transmissions also, larger size elastic buffers and more complex synchronization methods. This paper concentrates on the critical problem of angular tracking. Because if antenna angular tracking error turns bigger, the transmission link will get worse at once, and system performance will deteriorate rapidly. In this paper, SIGSO satellite Apstar-1 and 16m-diameter truss-parabolic antenna in Beijing are taken as an example to study the tracking strategy.

2. SIGSO Satellite Movement Characteristics

In order to track the satellite precisely, it is very necessary to figure out satellite movement characteristics. Under North-South station-keeping and West-East station-keeping adjustments, a typical geostationary sub-satellite trajectory (Anik-C3 satellite of Canada) [3] is shown in Fig. 1.

As we can see from Fig. 1, under station-keeping adjustments, deviations from its nominal orbital position are very small, within $\pm 0.05^\circ$ both for North-South and West-East directions. For 16 m diameter parabolic antenna, its beam width is about 0.2° . Generally, step tracking mode is adopted for geostationary satellite communication earth station antenna [4]. However, when it comes to a SIGSO satellite, we must choose an appropriate tracking mode according to SIGSO satellites movement characteristics.

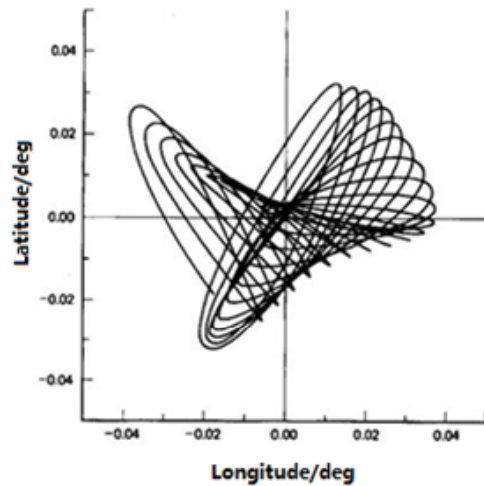


Fig. 1. Typical geostationary sub-satellite trajectory.

Take Apstar-1 satellite as an example. Apstar-1 satellite was launched in July 1994 and located at 138°E originally [5]. In August 2004, Apstar-1 satellite was drifted to a new location of 142°E . From then on, only West-East station-keeping adjustments were kept on Apstar-1 satellite. As a result, its inclination increases every year with the increasing rate of about 0.9° per year. Until August 2012, Apstar-1 satellite inclination has been increased to 7° . Its sub-satellite trajectory variation from October 2005 to November 2008 is shown in Fig. 2. Its daily variation is shown in Fig. 3.

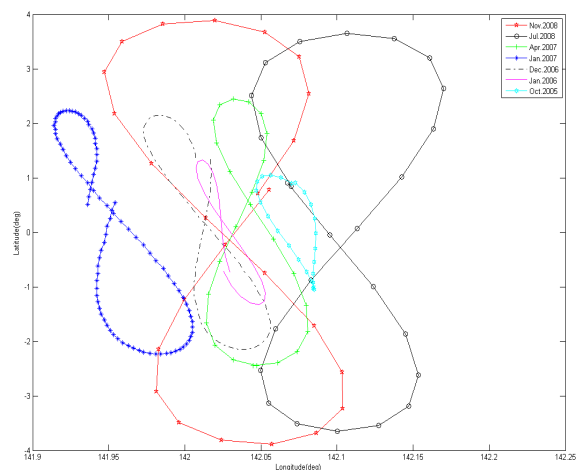


Fig. 2. Apstar-1 sub-satellite annual trajectory.

Fig. 2 and Fig. 3 show that APSTAR-1 satellite's 24-hour trajectory is basically showing "8" on the north and south sides of the equator, but within 1° sub-satellite trajectory is still similar to that of geostationary orbit satellites in Fig. 1. With inclination increase, SIGSO Apstar-1 sub-satellite trajectory longitude and latitude change every day. As shown in Fig. 3, in the short term, it turns out to be moving in parallel on the east-west direction. In

longer period of time, it shows not only drifts in west-east direction but also increase in north-south direction around 142°E. SIGSO Apstar-1 sub-satellite trajectory longitude and latitude variations in 24 hours from December 15, 2006 to November 17, 2008 are shown in Table 1 and Table 2.

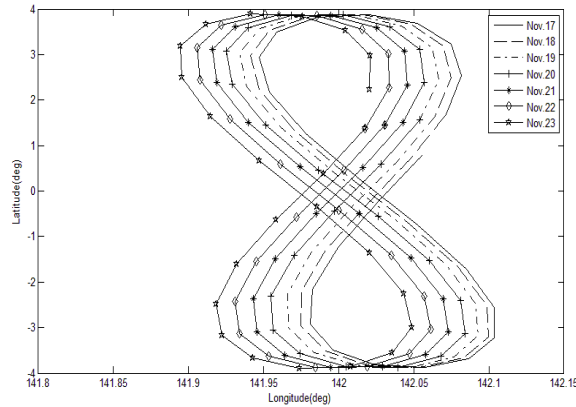


Fig. 3. Apstar-1 sub-satellite daily trajectory.

Table 1. Apstar-1 sub-satellite longitude variations.

Date	Max. longitude(°)	Min. longitude(°)	Longitude variation(°)
2006.12.15	142.06	141.97	0.08
2007.01.09	142.01	141.91	0.09
2007.04.20	142.08	142.01	0.07
2008.07.31	142.17	142.04	0.13
2008.11.17	142.10	141.95	0.16

Table 2. Apstar-1 sub-satellite latitude variations.

Date	Max. latitude(°)	Min. latitude(°)	Latitude variation(°)
2006.12.15	2.15	-2.15	4.30
2007.01.09	2.23	-2.23	4.47
2007.04.20	2.45	-2.45	4.90
2008.07.31	3.65	-3.65	7.31
2008.11.17	3.88	-3.88	7.77

We can see from Table 1 and Table 2 that SIGSO satellite latitude variation is much bigger than longitude variation. As a result, earth station antenna azimuth and elevation vary along with SIGSO drifts, as shown in Table 3 and Table 4.

Table 3. Apstar-1 Beijing earth station azimuth variations.

Date	Max. Az (°)	Min. Az (°)	Az variation (°)
2006.12.15	144.37	141.71	2.66
2007.04.20	144.54	141.45	3.09
2007.12.17	144.89	141.03	3.86
2008.03.03	145.17	141.02	4.15

Table 4. Apstar-1 Beijing earth station azimuth variations.

Date	Max. El (°)	Min. El (°)	El variation(°)
2006.12.15	38.71	34.50	4.22
2007.04.20	38.96	34.16	4.79
2007.12.17	39.61	33.59	6.02
2008.03.03	39.86	33.46	6.40

We can get a conclusion from Table 3 and Table 4 that El variation is about 50 % bigger than Az variation. Then for the satellite communication terminal, we can utilize broad beam-width antenna or shaped beam antenna to realize low data rate satellite communication by SIGSO satellite, such as micro-strip patch antenna and so on [6-7]. However, for the large aperture antenna in the communication center station, because its beam-width is very narrow, the selection of tracking mode becomes critical.

3. Tracking Mode and Characteristics

Antenna tracking system's task is to ensure the antenna can stably and reliably align the satellite, thereby making the satellite communication system maintain normal working. According to the way of antenna tracking target, tracking mode can be classified into three types: manual tracking, program tracking, and automatic tracking. It is basically made up of antenna, feed, receiving equipment, servo control unit, and so on [8].

3.1. Manual Tracking

Manual tracking is to adjust the antenna directivity manually on schedule according to experience or predict target position data (satellite orbital position) variation with time, or to make the received signal strongest by manually control the tracking system based on the received signal strength. Manually tracking can be carried out once every certain interval by the antenna, spectrum analyzer (receiver), the servo controller, etc.

3.2. Program Tracking

Program tracking is to input data of satellite ephemeris, the geographical coordinates and the posture of antenna platform into the computer for processing, calculation and comparison, and get the difference between the satellite orbit and antenna actual angle within the standard time. Then this value will be put into the servo controller and drive the antenna to eliminate the error angle. Continuous comparison and drive ensures that antenna points at the satellite.

The advantage of the program is that there is no requirement of tracking receiver to provide tracking

signal, but realization of program tracking needs effective tracking parameters which need to be updated regularly. The drawback of program tracking is that ephemeris data change a little with time due to the Earth's uneven density and other disturbances. As a result, it is difficult to calculate the precise orbit data in a long term in general so there will be accumulated error for a long time tracking. In addition, there is higher precision requirement in axis angle indication and pointing accuracy.

3.3. Automatic Tracking

Automatic tracking is to automatically align the antenna by driving the antenna mount with servo controller according to azimuth and elevation error signal levels and directions, which are obtained by earth station antenna receiving satellite beacon signal and frequency conversion, amplification and tracking receiver processing. Its characteristic is no error accumulation in long-time continuous tracking.

In accordance with the tracking principles and equipment components, automatic tracking can be divided into three types: stepping tracking, conical scan tracking and monopulse tracking.

3.3.1 Step Tracking

Step tracking is also known as extreme value tracking. It is to control the antenna to turn in the azimuth plane and the elevation plane alternately to progressively align the antenna and the satellite. The tracking system will go into a state of rest until the signal received by the antenna reaches the maximum value. When the received signal exceeds a preset threshold decreased or tracking cycle, the system begins to enter the tracking state and repeat it again and again.

The advantage of step tracking is its simple to achieve. While its shortcoming is that in the tracking process, the antenna turns to swing around the alignment direction of the satellite continuously. In addition, when the tracking signal fluctuates, because of inability to find a stable maximum value, the antenna will rotate around the maximum value for a long time and can't stop, but also exacerbated the antenna mechanical wear. If you take an extended time for filtering the signal sampling, it will result in a longer track time. So at harsher electromagnetic environment place, step tracking is not so effective. Furthermore, step tracking is not competent for tracking inclined orbit satellites.

3.3.2. Conical Scan Tracking

Conical scan tracking is to rotate the feed around the antenna symmetry axis in circular motion, or rotate the sub-surface aslant. In such a way, antenna beam rotates in a cone. When the antenna axis aligns

with satellite, the beacon level received in the earth station is a constant value. If antenna axis deviates from the satellite, the reception level will have a low-frequency amplitude modulation. Antenna beam pointing error can be detected according to the modulation signal amplitude and phase.

Meanwhile, continuous circumferential mechanical movement of the feed results in poor reliability. During tracking, a series of echo pulses must be get at first to obtain angle error signal with poor real-time capability.

3.3.3. Monopulse Tracking

In monopulse tracking mode, antenna feed outputs added signal and difference signal, which are conversed and processed by the radio frequency front-end and then sent to the tracking receiver. The tracking receiver outputs two-way signals, including the azimuth error signal and elevation error signal, which are proportional to the angle of antenna axis deviation from the orientation satellite. The two-way signals are sent into the servo control unit to control the antenna movement. In this way, real-time tracking of the satellite is completed.

According to the number of channels, there are three different implementations, including single-channel, dual-channel, and three-channel.

Monopulse tracking is able to determine satellite antenna beam deviation direction and the deviation value in a pulse interval, according to which the servo system adjusts antenna in real time to align with the satellite. The tracking speed and accuracy of monopulse tracking is much higher than step tracking. But it requires a complex feed system and tracking receiver system, which results in high cost.

3.4. Characteristics Analysis

There are both advantages and disadvantages for each kind of tracking method.

Manual tracking needs the most simple equipment and is suitable for small aperture earth station antenna pointing GEO satellite at a lower accuracy and real-time requirements.

Program tracking can be applied in satellite tracking for ground and on-board small aperture antenna systems.

Automatic tracking's characteristic is no error accumulation, and is able to realize continuous tracking in a long term.

Step tracking is applicable in systems with slower tracking speed, such as tracking a slow drift velocity synchronous orbit satellite.

For conical scan tracking, the advantage is that tracking equipment is relatively simple; the disadvantage is that the feed always deviates off the focus of the paraboloid, which makes the antenna gain decrease.

Monopulse tracking can obtain complete angular error from every received pulse. This tracking mode is a closed-loop system, with good real-time tracking and high accuracy.

As there are too many factors affecting the satellite location, and we can't predict the long-term satellite orbit, large or medium earth station mainly uses automatic tracking method, with supplement of manual tracking and program tracking currently. And especially for GEO satellite communication system, because the inclination angle is very small (its value is 0 in theory), GEO satellite inclination can be controlled within a small range by North-South station-keeping periodically in actual applications. In addition, this kind of adjustment is not very frequent, so truss mount antenna can track GEO satellite normally.

Step tracking is usually adopted in the truss mount antenna system to track GEO satellites. It is based on AGC (Automatic Gain Control) level of GEO satellite telemetry signal to assess whether the antenna align with the satellite or not. If AGC level of the telemetry signal is lower than a certain preset value, the antenna system will adjust its pointing in four directions, including up, down, left and right, in stepping mode. And antenna servo control system will monitor whether AGC level reaches its maximum or not. If it has reached the extreme value, the antenna must have been aligned with the satellite.

However, for the SIGSO satellites, because its inclination angle becomes larger and larger with time, whether the most common antenna working style of truss mount working in step tracking is suitable needs to be verified.

In the following section, we carry out a series of tests taking use of a truss mount parabolic antenna with the diameter of 16 m working in step tracking. By analyzing the AGC level of the telemetry signal and the E_b/N_0 value from the communication receiver, we can get a suitable conclusion for SIGSO tracking method.

4. SIGSO Earth Station Tracking Test

As shown in Table 1, Table 2, Table 3 and Table 4, with SIGSO satellite inclination increases, its sub-satellite longitude, latitude, azimuth and elevation variation scopes increases, too. In October 2011, we carried out an experiment in Beijing. Earth station antenna diameter is 16 m, with truss mount and step tracking. This system worked at C band. 16 m diameter antenna transmitting beam width is 0.22° and receiving beam width is 0.33° . Apstar-1 satellite inclination angle was 6.4° . In the experiment, the 16 m antenna tracking cycle was 30 minutes, tracking start threshold was 0.2V, the azimuth tracking step was 0.1, and elevation tracking step was 0.1. And the system worked at self-transmitting and self-receiving mode. The experimental diagram is shown in Fig. 4.

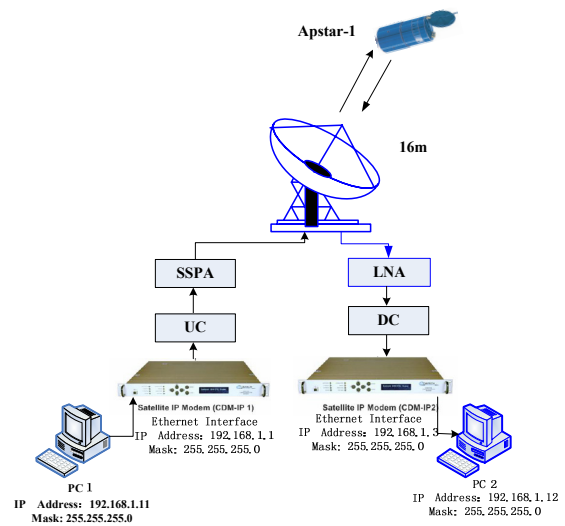


Fig. 4. Experiment diagram.

The experiment system parameters are shown in Table 5.

Table 5. Experiment system parameters.

Item	Value	Item	Value
Modulation	QPSK	Downlink frequency	3920 MHz
Data rate	2.048Mbps	Transmit antenna gain	58.0 dBi
FEC	3/4 Viterbi	Receive antenna gain	54.1 dBi
Video coding	H.264	Transmit power	-14.3 dBm
Audio coding	MPEG 4 Audio	EIRP _e	43.7 dBw
Uplink frequency	6145 MHz	Demodulation threshold E_b/N_{0th}	2 dB

Comprehensive analysis of 16 m truss-mount antenna step tracking impacts on SIGSO Apstar-1 satellite communications are carried out according to 16-meter antenna beacon tracking receiver AGC level changes and received signal E_b/N_0 , as shown in Fig. 5 and Fig. 6.

The data of first four hours of the first sub-graph in Fig. 5 is shown in Fig. 7. And the data of first four hours of Fig. 6 is shown in Fig. 8.

We can conclude from Fig. 5 and Fig. 6 that both AGC and E_b/N_0 values changes grammatically daily. AGC changed from 7.5 V to 8.4 V on Nov. 29th, 2011, which equals to variation of 4.5 dB. E_b/N_0 changed from 9.9 dB to 1 dB, with the variation of 8.9 dB. And we can see from Fig. 7 and Fig. 8 that the values of AGC and E_b/N_0 change very frequently and greatly, and both of AGC value and E_b/N_0 value have a certain relation with the step tracking cycle.

We changed the tracking cycle to 10 minutes, tracking start threshold was 0.3 V, the azimuth

tracking step was 0.05, and elevation tracking step was 0.05. However, this kind of operation didn't influence the AGC level changes and E_b/N_0 changes obviously.

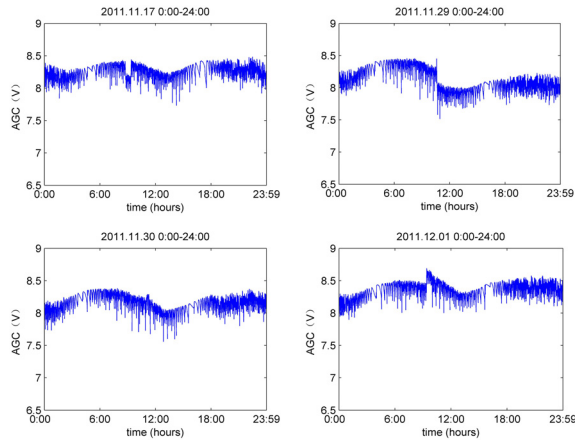


Fig. 5. AGC level changes.

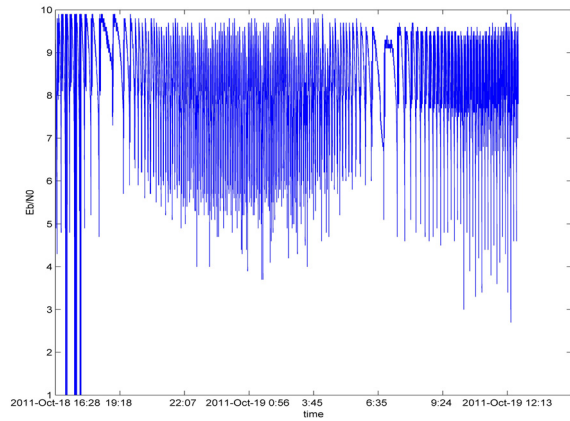


Fig. 6. E_b/N_0 changes.

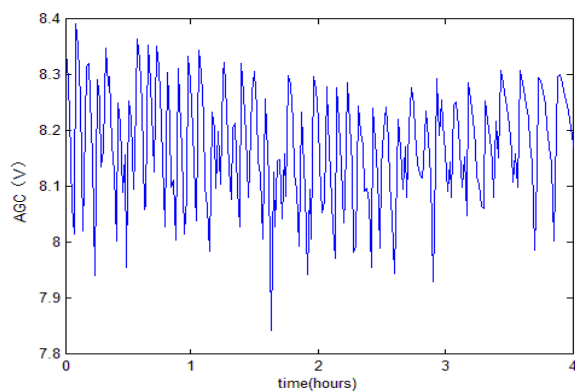


Fig. 7. AGC changes during the first four hours.

These variations are too big for C band satellite communication. That is to say, in the SIGSO satellite communication system, if we choose step tracking and truss mount for 16m-diameter antenna system, the system performance deteriorates greatly. Besides, for

the truss-mount antenna system, because the tracking frequency is very high, the screws wear very seriously. In long terms, the antenna system life expectancy will be shortened greatly.

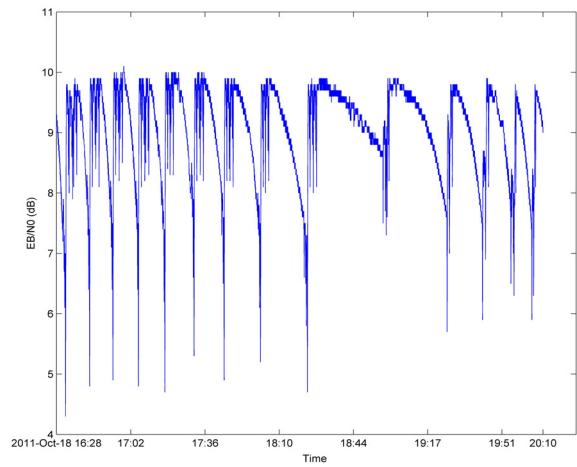


Fig. 8. E_b/N_0 changes during the first four hours.

5. Conclusions

We can get a conclusion that although step tracking with truss mount is adopted commonly for GEO satellite communication antenna, it is not suitable for SIGSO satellite communication system. This kind of tracking method and antenna mount can bring about the grammatical signal decrease and antenna component mechanical wear.

By the actual field test and theoretical analysis in section 3, the most suitable tracking mode for the SIGSO satellite communication system is monopulse tracking, and the most appropriate antenna mount is turntable mount.

The recommendation of monopulse tracking and turntable antenna mount has been adopted in our actual project for SIGSO satellite communication system.

Acknowledgements

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