

Spreading Technique of Satellite Beacon to Avoid Jamming Attacks

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Abstract—A jammer or interceptor has to use a huge antenna to precisely track and point on the CW beacon signal from the target geostationary satellite. In this paper, we propose a novel beacon waveform of a spread spectrum type to decrease an effective antenna gain, which causes a pointing error to the attacker. We have analyzed the antenna gain loss of the popular mono pulse tracking scheme for a huge antenna, which causes a pointing error in case of a very low signal to noise ratio and a small half power beam width. From the analysis, we can confirm that the pointing error becomes higher than $1E-2$ when the SNR is lower than 6dB and the half power beam width is lower than 0.1. As the results, the proposed scheme promises the effective capability of the anti-jamming against the attacker using such a large diameter of antenna.

Index Terms—Satellite beacon, Spread spectrum, Mono pulse tracking, Antenna pointing error, Anti-jamming, LPI

I. INTRODUCTION

A military geostationary satellite communication can support wide area networks without additional repeaters and it has played an important role in the military communication of a battlefield. Since the satellite link is easily exposed to a jammer and a signal interceptor, it must be protected by increasing the high signal power or hopping the frequency, but both reduce the power efficiency or the spectral efficiency of the system.

The orbital position of geostationary satellites varies continuously due to various perturbations such as the Sun and the Moon's gravitational forces variation, the solar radiation pressure, and the nonspherical Earth. To overcome those effects, the precise maneuver and orbit location control of satellite is required, but the error cannot be removed and finally is in the range of about 0.1 degrees. The satellite orbital location error causes more pointing errors, and more loss of the effective antenna gain as the antenna diameter of the ground terminal is increasing. So the performance of tracking and pointing is important for a large antenna system. And most of the satellite communication terminals, even the jammer or the interceptor of an attacker, rely on high power CW (Continuous Wave) beacons to increase the accuracy.

If a jammer wants to attack a communication link effectively, it should be almost full band jammer. Then a continuous carrier should be used for an anti-jamming capability and its antenna diameter should be more than tens of meter [1]. For such reasons, the interferer should increase the diameter

of antenna. Therefore, for the interferer, the minimization of pointing error is also important to track and point the beacon of the target satellite. Some satellite tracking and pointing methods have been proposed in a variety of ways. One of the popular methods is an automatic tracking one which receives a signal like a beacon from a satellite for higher accuracy. The other is the conical scan or step tracking which can provide accuracy of about 0.01 degrees at more than 30dB signal to noise ratio (SNR) [2]–[4]. But the best of the methods is the mono pulse tracking which can provide accuracy of about 0.005 degrees at more than 15dB SNR and has been also used for fine or fast tracking of large earth stations or ship-borne terminals [2], [5]–[7].

In this paper, a satellite beacon waveform with low SNR is proposed which can disturb the satellite tracking and pointing function and limit the ability of jammer or interceptor especially with large antenna. There are various methods to offer a low SNR waveform like direct sequence spread spectrum. And under the conditions the accuracy of mono pulse tracking and pointing were analyzed and the maximum allowable antenna gains were analyzed.

II. MONO PULSE ANTENNA POINTING SYSTEM

In satellite communications using geostationary orbit, as all communication signals are relayed through a repeater on the satellite of which orbit information is known, it is easy to be

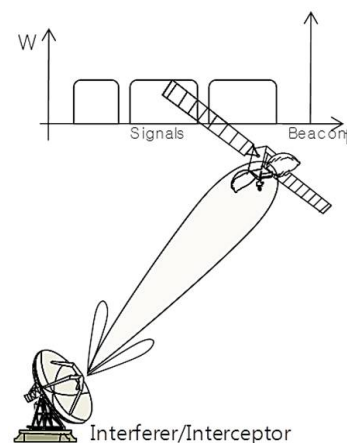


Fig. 1. The concept of satellite pointing of interferer or interceptor

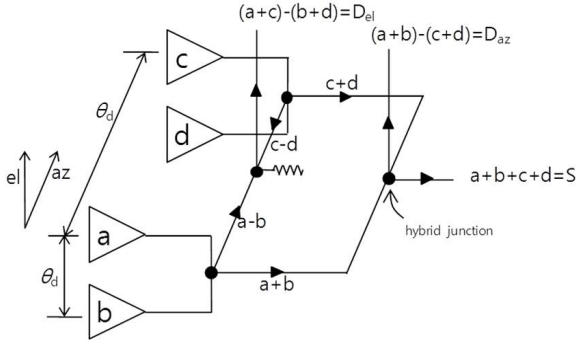


Fig. 2. Mono-pulse configuration

interfered or intercepted. In the electronic warfare perspective, the communication signal is protected by a proper waveform such as the frequency hopping or the direct sequence. That makes the attackers difficult to detect the signal. Therefore, the attacker must accurately track and point on the target satellite as shown in Fig. 1, and a high SNR CW beacon from the satellite is helpful to it.

One of the widely used methods to track and point on a satellite is the mono pulse tracking, which can provide the accuracy of about 0.005 degrees at more than 15dB SNR and has been used for the fine or fast tracking of large earth stations. The configuration of the mono pulse tracking is shown in Fig. 2. In Fig. 2, a, b, c, and d are the feeders that have same characteristics and they are mounted in a form of perfect square with distance θ_d . Each output of the feeders is summed or subtracted to indicate the angle error of the elevation or the azimuth direction, D_{el} , D_{az} and divided for normalization by S which is the sum of all signals. In the configuration the values of D_{el}/S and D_{az}/S indicate the error of the elevation and the azimuth angle, respectively. Since

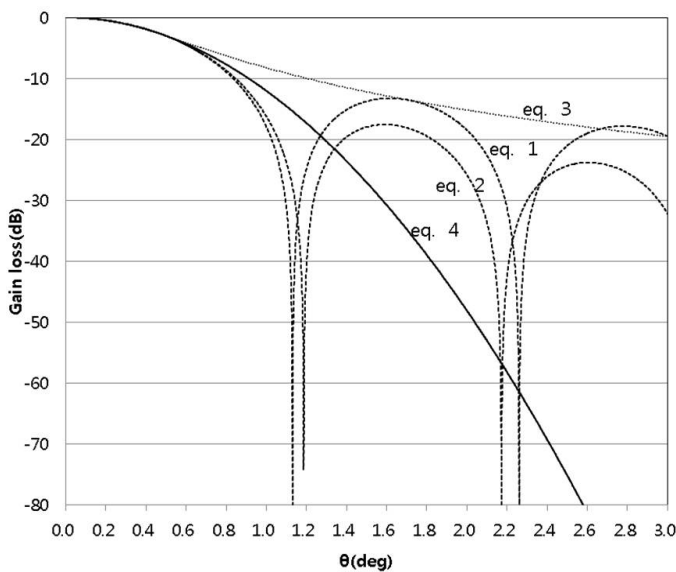


Fig. 3. Various gain loss models due to pointing error

the characteristics of the both arrivals are same, one of them can be selected as an error. This is the role of D/S to analysis in satellite communication environment.

III. MONO PULSE PERFORMANCE ANALYSIS DUE TO POINTING ERROR

When the error of pointing is θ , the general antenna gain loss, G_e , can be modeled in various ways as follows, where θ_{3dB} is the half power beam width [8], and J_1 is the 1st Bessel function:

$$G_e(\theta) = \left\{ \frac{\sin(1.39 \frac{2\theta}{\theta_{3dB}})}{1.39 \frac{2\theta}{\theta_{3dB}}} \right\}^2 \quad (1)$$

$$G_e(\theta) = \left\{ \frac{2J_1(3.23 \frac{\theta}{\theta_{3dB}})}{3.23 \frac{\theta}{\theta_{3dB}}} \right\}^2 \quad (2)$$

$$G_e(\theta) = \left\{ 1 + \left(\frac{2\theta}{\theta_{3dB}} \right)^{2.5} \right\}^{-1} \quad (3)$$

$$G_e(\theta) = e^{-2.77 \left(\frac{\theta}{\theta_{3dB}} \right)} \quad (4)$$

Fig. 3 depicts those loss pattern and we select the last one to analysis considering a large reflector is used for the antenna. Then the error of angle of mono pulse D/S using equation (4) is as below:

$$D/S = \frac{1 - e^{-11.08 \left(\frac{\theta_d \theta}{\theta_{3dB}^2} \right)}}{1 + e^{-11.08 \left(\frac{\theta_d \theta}{\theta_{3dB}^2} \right)}} \quad (5)$$

Fig. 4 depicts the ratio when θ_d/θ_{3dB} is between 0.1 to 1. In the Fig. 4, we confirm that as the distance between the feeders of mono pulse d increases, the D/S ratio also increases with respect to the pointing error, and finally it will be saturated

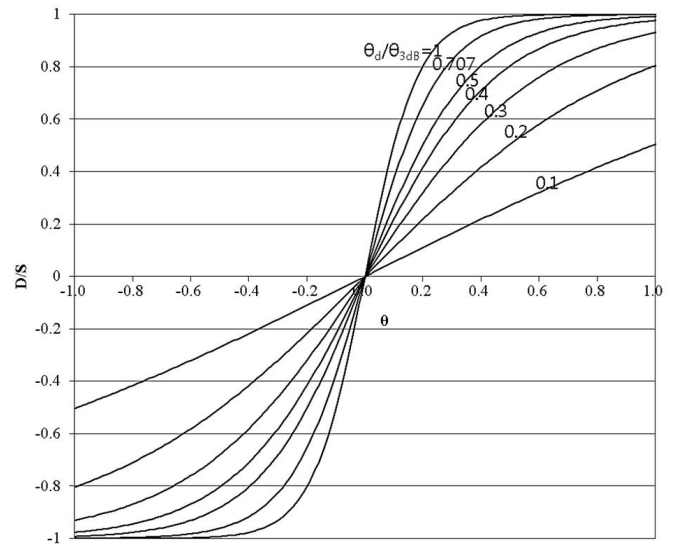


Fig. 4. D/S ratio of mono pulse due to pointing error

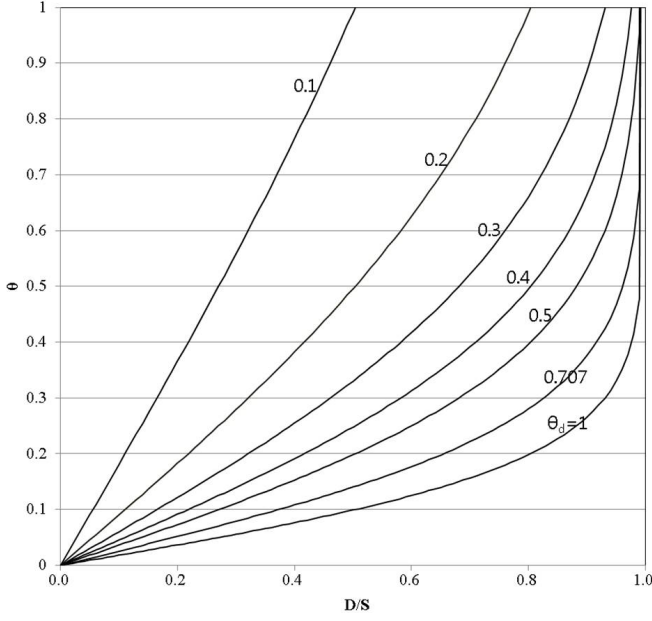


Fig. 5. Pointing error according to D/S ($\theta_{3dB} = 1$)

to value 1. We can calculate θ in the above equation (5) as below:

$$\theta = \frac{-\theta_{3dB}^2}{11.08 \theta_d} \ln \left(\frac{1 - D/S}{1 + D/S} \right) \quad (6)$$

And at 0.707 θ_d/θ_{3dB} is known as the best performance case of a multi feeder mono pulse system [4], we also select this value to analysis in this paper.

Fig. 5 shows the error correction degrees to the D/S depending on the value of the elevation and azimuth angles. If the distance is 3dB (i.e. $\theta_d=1$), then it is possible to be corrected within 0.2% to the beam side, while it is difficult to correct the errors when the distance between the two mono pulse feeders is short.

IV. POINTING ERROR ANALYSIS AT LOW SNR

If the mono pulse feeders have the same noise power without correlation, then the pointing error θ_e is given by [9].

$$\theta_e = \frac{\theta_{3dB}}{k_m} \frac{1}{2S/N} \left\{ 1 + \frac{1}{S/N} + (D/S)^2 \left(1 + \frac{2}{S/N} \right) \right\} \quad (7)$$

Where S/N is the signal and noise power ratio, and k_m is the slope of D/S which can be calculated by the derivative of the equation (5) with respect to θ as follows:

$$k_m = \frac{d(D/S)}{d\theta} = \frac{22.16 \cdot \left(\frac{\theta_d}{\theta_{3dB}^2} \right) \cdot e^{-11.08 \left(\frac{\theta_d \theta}{\theta_{3dB}^2} \right)}}{\left(1 + e^{-11.08 \left(\frac{\theta_d \theta}{\theta_{3dB}^2} \right)} \right)^2} \quad (8)$$

From the equation (8), the distribution of k_m is depicted in Fig. 6 when θ_d is between 0.1 to 1 degree.

When an attacker tries to jam or intercept a target communication satellite, the initial pointing error can be assumed as

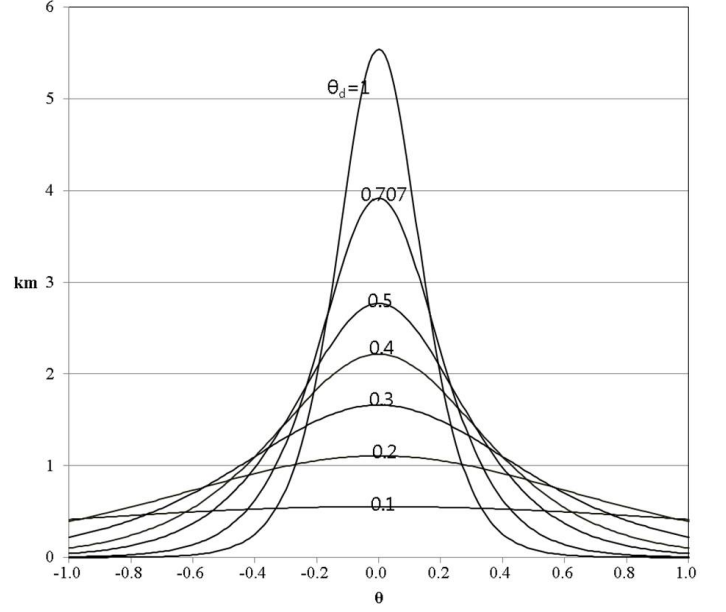


Fig. 6. Distribution of k_m ($0.1 \leq \theta_d \leq 1$)

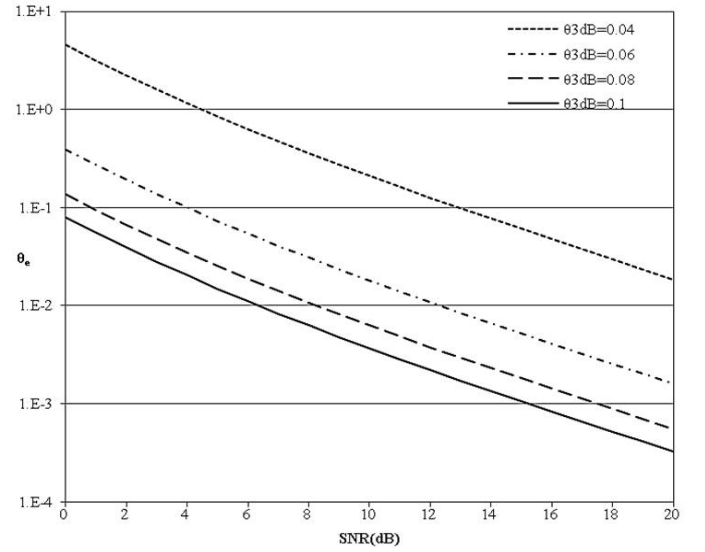


Fig. 7. Pointing error analysis results at low beacon SNR

± 0.05 degree, because the requirement for a station to keep the error of a general geostationary satellite is 0.1 degree. When a beam width θ_{3dB} is 0.04, 0.06, 0.08, 0.1 which represent the diameter of a large jammer antenna, and θ_d/θ_{3dB} is 0.707, the Fig. 7 shows the results of the pointing error analysis at low SNR. The results show that when SNR is lower than 6dB, the pointing error becomes higher than 1E-2 at lower than 0.1 half power beam width (i.e. more than 6m diameter reflector is used in a Ka band). The low SNR beacon is confirmed to be ineffective with less than 0.1 beam widths, and this doesn't impact anti jamming link because of its low antenna gain.

V. CONCLUSION

Since a satellite communication link is easily exposed to a jammer or a signal interceptor, it must be protected to overcome the hostile attacks. However, the normal beacon waveform is designed to minimize the pointing error, thus a jammer or interceptor equipped a huge antenna can also use this beacon signal and the target geostationary satellite is easily detected. In this paper, we propose the spread spectrum type beacon waveform which can decrease its effective antenna gain and then make the hostile site difficult to interfere or intercept. From the analysis results about the antenna gain loss of the mono pulse tracking scheme due to pointing loss, we have confirmed that the pointing error becomes higher than $1\text{E-}2$ when the SNR is lower than 6dB and the half power beam width is lower than 0.1 (i.e. when used more than 6m diameter for the reflector in Ka band).

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