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LEO Satellite Tracking Using Monopulse

[1]M.B. Nasrollahnejad, [2]S. Arabi Nowdeh, [3]Y. Mokhtari and [4]P. Moharlooei

[1,4]Department of Electrical Engineering,
Kordkuy Center, Gorgan Branch, Islamic Azad University, Kordkuy, Iran
[2]Department of Electrical Engineering, Behbahan Branch, Islamic Azad University, Behbahan, Iran
[3]Department of Electrical and Computer Engineering, Shahid Beheshti University, Tehran, Iran

Abstract: LEO satellites orbit very fast respect to the Earth stations, so the tracking of these satellites is important. But due to some challenges, such as structural deformations caused either by loads or by the temperature gradient, atmospheric distortion, or azimuth track unevenness, the position of beam is slightly different from the antenna position as measured by the encoders. Thus, the monopulse technique as the most accurate type of Auto-tracking techniques is used and analyzed. Also, the reduction of beam error and increment of received power versus signal to noise ratio are investigated. Finally, estimation parameters such as variance mean and RMSE of monopulse technique versus signal to noise ratio are investigated.

Key words: Auto-tracking · Earth Station Antenna · Monopulse · Satellite

INTRODUCTION

Orbit tracking programs require information about the shape and orientation of satellite orbits. These data are known as Keplerian elements [1]. By using these elements, the trajectory of LEO satellites can be estimated. This method is called program tracking. But the accuracy of this method is not reliable. *Also, due to* structural deformations caused either by loads (e.g., gravity, wind) or by the temperature gradient, atmospheric distortion, the position of beam is slightly different from the antenna position as measured by the encoders [2]. Thus, Automatic tracking methods should be used. Monopulse technique is most accurate and reliable of Auto-tracking methods. In this paper, various aspects of this technique are analyzed.

The paper organized as follows. The monopulse detection technique is analyzed in section 2. The beam error and received power versus signal to noise ratio (SNR) by using simulation are shown in section 3. Finally, conclusion is presented.

Monopulse Detection Technique: In monopulse technique, angle error information is obtained on a single pulse. The monopulse tracking technique has different kinds of feed techniques [3]. One of the most accurate of these techniques is four-horn monopulse.

The feedhorns of the monopulse tracker are slightly displaced so that each receives the signal from a slightly different position, that is, at slightly different power. The received power of the opposite horns is added, to form a sum beam and subtracted, to form a difference beam. The difference beam characterizes the pointing error. If the difference beam is zero, the antenna is at the target. If the difference beam is nonzero, the pointing error is generated.

Analyses of antenna tracking performance generally are concerned with the antenna's main beam alignment. A convenient representation of the high-level portions of the antenna's main beam is a Gaussian function that is a good fit for practical antenna designs and is given by [4],

$$f(\theta) = \exp\left[-k\left(\frac{\theta}{\theta_{hp}}\right)^2\right] + v_i \quad (\text{voltage}) \tag{1}$$

Where θ_{hp} is the antenna's half-power beamwidth, θ is the angle measured from the main beam boresight, v_i is the signal noise and k is determined by evaluating the expression at the half-power point, $\theta_{hp}/2$.

Then, θ is calculated respect to each horn, as shown in Fig. 1.

In Fig. 1, θ_0 is angular offset of feed horns respect to the antenna axis, θ_t is the satellite angle displacement respect to the antenna axis, $\theta_{sat\text{-}horni}$ (i=1,2,3,4)

Corresponding Author: M.B. Nasrollahnejad, Dept. of Electrical Engineering, Gorgan Azad University, Kordkuy Centre, Iran.

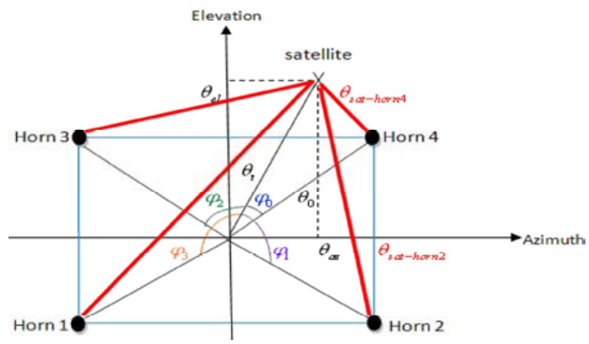

Fig. 1: The locus of centers of four-horn, satellite signal and antenna axis in monopulse technique (first quarter)

is the satellite angle respect to each horn, θ_{az} and θ_{el} are the offset of satellite azimuth and elevation angle respect to the antenna axis.

Substituting $\theta_{sat\text{-}horni}$ into the equation (1), received power (electrical signals) from each horn is obtained. Devices which produce a sum signal and two difference signals, is called comparator or convertor. The comparator using quadrature hybrid is selected for fourhorn monopulse feed. The sum signal and two difference signals are obtained as following equations [5]:

$$E_{\text{sum}} = \frac{f_1 + f_2 + f_3 + f_4}{2} \quad (2)$$

$$E_{\text{AZ-difference}} = \frac{(f_2 + f_4) - (f_1 + f_3)}{2} \quad (3)$$

$$E_{\text{EL-difference}} = \frac{(f_3 + f_4) - (f_1 + f_2)}{2} \quad (4)$$

The error signals are obtained as following equations [6]:

$$E_{\text{AZ-error}} = \frac{E_{\text{AZ-difference}}}{E_{\text{sum}}} \quad (5)$$

$$E_{\text{EL-error}} = \frac{E_{\text{EL-difference}}}{E_{\text{sum}}} \quad (6)$$

Also,

$$E_{\text{AZ-error}} = k_{\text{m}} \frac{\hat{\theta}_{\text{AZ}}}{\theta_{\text{hp}}} , \ E_{\text{EL-error}} = k_{\text{m}} \frac{\hat{\theta}_{\text{EL}}}{\theta_{\text{hp}}} \quad (7)$$

In Equation (7), is the slope of error signals and equal to:

$$k_{\text{m}} = 4\ln(2)\frac{\theta_0}{\theta_{\text{hp}}} \quad (8)$$

Also, $\hat{\theta}_{\text{AZ}}$ and $\hat{\theta}_{\text{EL}}$ are estimated offset value of satellite Azimuth and Elevation angle respect to antenna axis.

SIMULATION AND RESULTS

In this section, performance of monopulse algorithm for IRS-P6 satellite is investigated. To evaluate performance of the algorithm, we add offset to satellite trajectory and show that after using the monopulse algorithm, the beam error has been considerably decreased. Used parameters in the simulations are listed in Table 1.

The requirements for antenna tracking depend on the system's application. Communication system applications require maintaining signal alignment within a specified accuracy. Commonly, alignment within one-tenth of the antenna's beamwidth limits the signal loss to about 0.1dB lower than the peak antenna gain level on the boresight axis [7].

The reduction of beam error versus signal to noise ratio is shown in Fig. 2.

Table 1: Used parameters in the simulations

Quantity	Value	Description
D	8.2 m	Antenna diameter
θ_{hp}	1.5 deg	Half-power beamwidth
P_O	1 W	Maximum carrier power
-	X-band: 8.025-8.4 GHz S-band: 2.2-2.3 GHz	Frequency range
	0.3 deg	Angular offset of feedhorns respect to the antenna axis
SNR	40, 60 dB	Signal to noise ratio

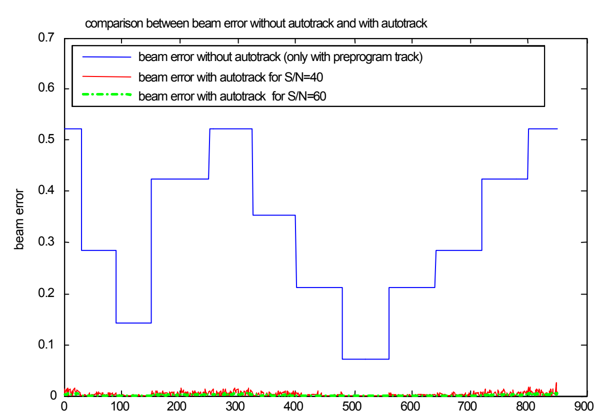

Fig. 2: Reduction of beam error with monopulse technique for SNR=40,60 dB

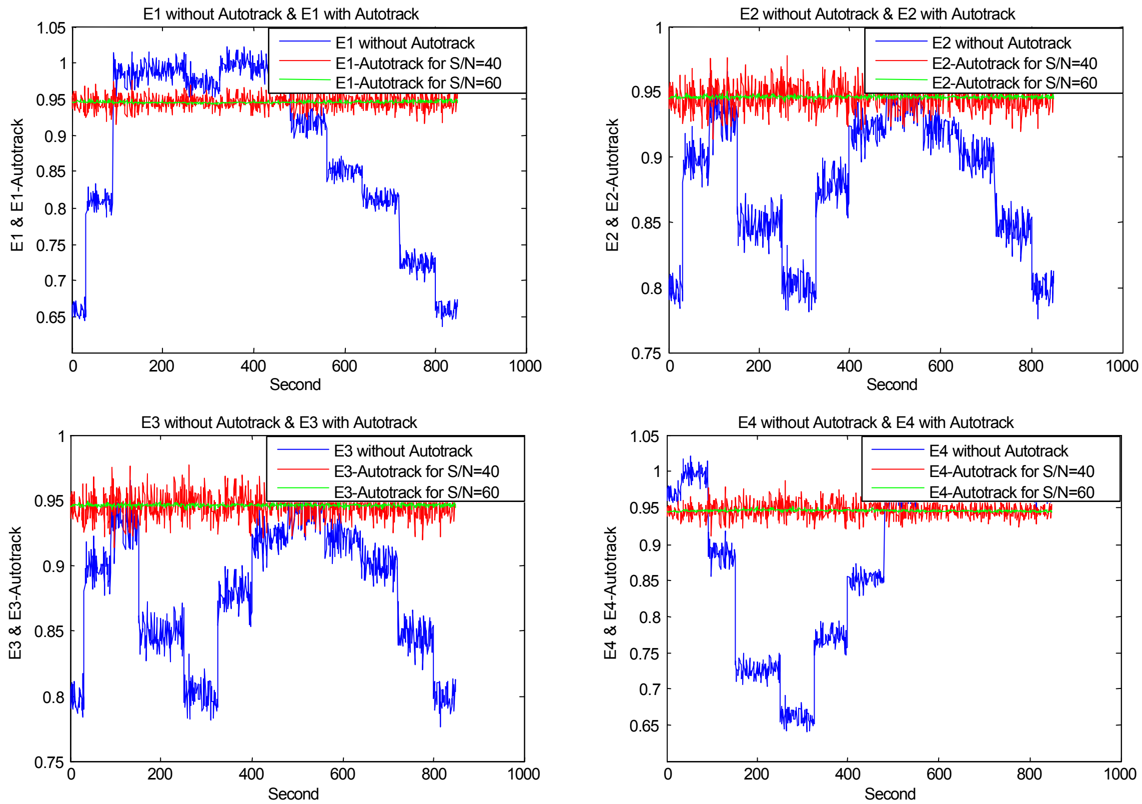

Fig. 3: Increment of received power with monopulse technique for SNR=40,60 dB

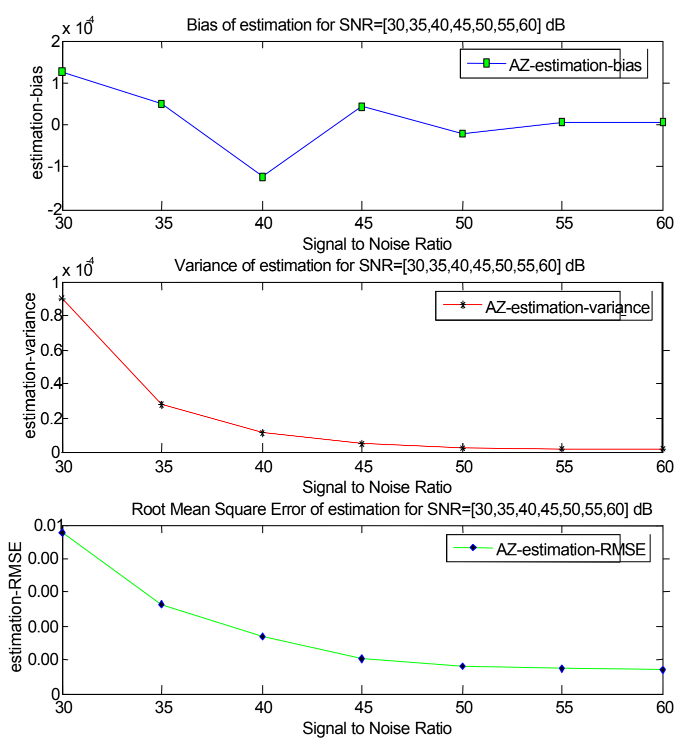

Fig. 4: Variance, mean and RMSE of estimation error in monopulse technique for SNR= [30:5:60] Db

As expected, received power in each horn is increased after using monopulse algorithm. It is shown in Fig. 3.

Finally, estimation error parameters such as variance, mean and root mean square error (RMSE) of monopulse technique versus SNR are shown in Fig. 4. It can be concluded that, as signal to noise ratio increases the estimation error variance and RMSE decrease.

CONCLUSION

In this paper monopulse tracking technique is analyzed. The analysis and simulations were based on Gaussian model of parabolic antenna pattern. The results shown that the reduction of beam error is much lower than the one-tenth of half-power beamwidth. Also, the received power from satellite with this technique is increased. Also, it can be concluded that, as signal to noise ratio increases the estimation error decreases.

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