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Modelling Of C-Band Satellite Link Depointing Angle Impact On Parabolic Antenna Gain And Effective Antenna Diameter

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***Abstract*—Modelling of C-band satellite link depointing angle impact on parabolic antenna gain and effective antenna diameter is studied. The focus in this paper is to determine the maximum antenna gain for a satellite link without a depointing loss, determine the antenna depointing loss when there is a misalignment of the satellite link antennas, determine the effective gain or composite gain for parabolic antenna with depointing loss and finally determine the percentage the change in the receiver figure of merit due to depointing loss. The mathematical models for the computation of the stated parameters are presented along with numerical examples. The study considered only the 6 GHz C-band satellite link with depointing angle in the range of 0 to 1 degree. The results show that that the antenna loss increases nonlinearly with increase in depointing angle, the composite antenna gain, GLθ (dB) decreases nonlinearly with increase in depointing angle, and the change in antenna gain due to depointing loss, %ΔG increases nonlinearly with increase in depointing angle. Also, the depointing loss of about 1° results in about 63 % change in the parabolic antenna effective diameter and 20.2046 % change in the parabolic antenna gain. Also, the change in the receiver figure of merit due to depointing loss ($\Delta G/T|_{dB/K}$) is equal to the depointing loss (L_{θ}). In all, the results show that for the C-band satellite link, there are quadratic and cubic nonlinear relationships between the depointing angle and the antenna depointing loss and percentage change in antenna diameter respectively.**

Keywords:* *Antenna Pointing Loss, C-Band, Parabolic Antenna, Satellite Link, Depointing angle, Antenna Gain

1. Introduction

In recent years, wireless communication is increasingly becoming ubiquitous with wide applications in diverse disciplines, in smart city applications, sensor networks, internet of things and many others [1,2,3,4,5,6,7,8,9,10,11,12,13,14,15]. Organisations are using it for various forms of local and wide and networks. These is due to steady advancements in the wireless technologies. Researchers continuously device ways to address or accurately estimate and hence mitigate some challenges that are associated with wireless signals such as propagation loss, spreading loss, negative atmospherics effects, diffraction loss and other signal strength degrading issues [16,17,18,19,20,21,22,23,24,25]. These negative effects can also lead to reduction in the coverage area or transmission range of the wireless communication system [26,27,28,29,30,31,32,33,34]. In addition to these losses, depointing angle is another issue that has significant negative impact on the antenna gain and receiver figure or merit [35,36,37,38].

Depointing loss occurs when there is misalignment in the line of sight from the transmitting antenna and the receiving antenna [35,36,38,39,40,41,42]. In the downlink, the depointing loss and rain attenuation can significantly reduce the received signal strength [43,44,45,46,47]. Also, due to the very far distance of the satellite from the earth station, the impact of minor misalignment angle is enormous and hence must be avoided at all cost [48,49,50,51,52]. Accordingly, in this paper, the focus is to provide analytical models that can be used to estimate the impact of the antenna misalignment error on the key parameters of the parabolic dish antenna used in a C-band satellite communication link. The ideas presented in this work will enable designers of C-band satellite links to know how much of misalignment error the link can accommodate and still deliver its required quality of service.

2. Methodology

The focus in this paper include the following: determine the maximum antenna gain for a satellite link without a depointing loss; determine the antenna depointing loss when there is a misalignment of the satellite link antennas, determine the effective gain or composite gain for parabolic antenna with depointing loss and finally the change in the receiver figure of merit due to depointing loss. The mathematical models for the computation of the stated parameters are presented along with numerical examples.

2.1 The Maximum antenna gain, G_{max} of a parabolic antenna

Maximum antenna gain, G_{max} of a parabolic antenna with effective aperture area, A_e is expressed as;

$$G_{max} = \frac{(4\pi(A_e))}{\lambda^2} = \frac{\eta(4\pi(A))}{\lambda^2} \quad (1)$$

Where η is the efficiency of the antenna and A is the actual antenna aperture area given as;

$$A = \pi\left(\frac{D^2}{4}\right) \quad (2)$$

$$G_{max} = \frac{\eta(4)(\pi^2)(r^2)}{\lambda^2} = \frac{\eta(4)(\pi^2)\left(\frac{D^2}{4}\right)}{\lambda^2} = (\pi^2)\eta\left(\frac{D}{\lambda}\right)^2 \quad (3)$$

$$G_{\max(dB)} = 10Log\left((\pi^2)\eta\left(\frac{D}{\lambda}\right)^2\right) \quad (4)$$

$$G_{\max(dB)} = 10Log(\pi^2) + 10Log(\eta) + 10Log\left(\left(\frac{D}{\lambda}\right)^2\right) \quad (5)$$

$$G_{\max(dB)} = 9.942997 + 10Log(\eta) + 20Log\left(\frac{D}{\lambda}\right) \quad (6)$$

2.2 Antenna depointing loss, L_θ

The antenna 3 dB beam width , θ_{3dB} is defined as;

$$\theta_{3dB} = \frac{70(\lambda)}{D} = \frac{70}{d}\left(\frac{3x10^8}{f}\right) \quad (7)$$

Where f is the frequency in Hz, D is the antenna aperture diameter and λ is the wavelength.

$$\theta_{3dB} = \frac{70(\lambda)}{D} = \frac{210}{D(f)} \quad (8)$$

Where f is the frequency in GHz . The antenna depointing loss, L_θ is defined as;

$$L_\theta = 12\left(\frac{\theta}{\theta_{3dB}}\right)^2 = 12\left(\frac{\theta}{70}\left(\frac{D}{\lambda}\right)\right)^2 \quad (9)$$

$$L_\theta = 12\left(\frac{D(f)(\theta)}{21x10^9}\right)^2 \quad (10)$$

Where in Eq 10 f is the frequency in Hz

$$L_\theta = 12\left(\frac{D(f)(\theta)}{21}\right)^2 \quad (11)$$

Where in Eq 11 f is the frequency in GHz .

2.3 Affective antenna gain or composite gain, $G_{LG_{L\theta(dB)}\theta}$ of a parabolic antenna with pointing loss, L_θ;

$$G_{L\theta(dB)} = G_{max(dB)} - L_\theta \quad (12)$$

$$G_{L\theta(dB)} = 10\,Log\left((\pi^2)\eta\left(\frac{D}{\lambda}\right)^2\right) - 12\left(\frac{\theta}{70}\left(\frac{D}{\lambda}\right)\right)^2 \quad (13)$$

Determination of the required antenna aperture diameter, $D_{L\theta}$ and aperture area, $A_{L\theta}$ for a parabolic antenna with pointing loss, L_θ that will give equivalent gain as $G_{L\theta(dB)}$. The expressions for $D_{L\theta}$ and $A_{L\theta}$ are as follows;

$$G_{L\theta(dB)} = 10\,Log\left((\pi^2)\eta\left(\frac{D_{L\theta}}{\lambda}\right)^2\right) \quad (14)$$

$$D_{L\theta} = \lambda\sqrt{\frac{10^{\frac{G_{L\theta(dB)}}{10}}}{(\pi^2)\eta}} \quad (15)$$

$$A_{L\theta} = \frac{\pi^2({D_{L\theta}}^2)}{4} \quad (16)$$

$$A_{L\theta e} = \eta(A_{L\theta}) = \eta\left(\frac{\pi^2({D_{L\theta}}^2)}{4}\right) \quad (17)$$

2.4 The receiver figure of merit for a receiver with antenna pointing loss, L_θ

The system noise temperature, T_{sys} is expressed as;

$$T_{sys} = T_A + T_R \quad (18)$$

where T_A is the noise temperature (in Kelvin) of the antenna and T_R is the noise temperature (in Kelvin) of the receiver with antenna gain of G_R. The receiver figure of merit, $\frac{G}{T}$ is expressed as;

$$\frac{G}{T} = \frac{G_R}{T_{sys}} = \frac{G_R}{T_A + T_R} \quad (19)$$

In decibels per Kelvin, $\frac{G}{T}$ is expressed as;

$$\left.\frac{G}{T}\right|_{dB/K} = 10\,log\left(\frac{G_R}{T_{sys}}\right) = 10\log(G_R) - 10\log(T_{sys}) \quad (20)$$

$$\left.\frac{G}{T}\right|_{dB/K} = 10\,log\left(\frac{G_R}{T_A + T_R}\right) = 10\log(G_R) - 10\log(T_A + T_R) = G_{R(dB)} - 10\log(T_A + T_R) \quad (21)$$

In terms of $G_{max(dB)}$ and $G_{L\theta(dB)}$, $\frac{G}{T}$ is expressed as;

$$\left.\frac{G_{max}}{T}\right|_{dB/K} = 10\,log\left(\frac{G_{max}}{T_A + T_R}\right) = G_{max(dB)} - 10\log(T_A + T_R) \quad (22)$$

$$\left.\frac{G_{L\theta}}{T}\right|_{dB/K} = 10\,log\left(\frac{G_{L\theta}}{T_A + T_R}\right) = G_{L\theta(dB)} - 10\log(T_A + T_R) \quad (23)$$

In terms of $G_{max(dB)}$ and $G_{L\theta(dB)}$, the change in $\frac{G}{T}$ is expressed as;

$$\Delta G/T|_{dB/K} = \left.\frac{G_{max}}{T}\right|_{dB/K} - \left.\frac{G_{L\theta}}{T}\right|_{\frac{dB}{K}} = G_{max(dB)} - G_{L\theta(dB)} = 12\left(\frac{\theta}{70}\left(\frac{D}{\lambda}\right)\right)^2 = L_\theta \quad (24)$$

Hence, the change in the receiver figure of merit due to depointing loss ($\Delta G/T|_{dB/K}$) is equal to the depointing loss (L_θ).

3. Results and discussion

Sample numerical computations were performed for a 6GHz satellite link with a 3 m parabolic antenna and the results are presented in Table 1, Figure 1, Table 2 and Figure 2. The results of the maximum antenna gain, composite antenna gain, antenna pointing loss and change in antenna gain due to depointing loss are shown in Table 1 and Figure 1. The results in Table 1 and Figure 1 show that the antenna loss increases nonlinearly with increase in depointing angle, as follows;

$$L\theta = 8.8163(\theta)^2 - 7x10^{-15} \quad (25)$$

On the other hand, the composite antenna gain, GLθ (dB) decreases nonlinearly with increase in depointing angle, as follows;

$$GL\theta\ (dB) = -8.8163(\theta)^2 - 2x10^{-13}\ (\theta) + 43.635 \quad (26)$$

In addition, the change in antenna gain due to depointing loss, %ΔG increases nonlinearly with increase in depointing angle, as follows;

$$L\theta = 20.205(\theta)^2 - (1x10^{-13})\theta \quad (27)$$

Table 1 The results of the maximum antenna gain, composite antenna gain, antenna pointing loss and change in antenna gain due to depointing loss

θ	**Maximum antenna gain, Gmax(dB) at D = 3 m and f = 6GHz**	**Composite antenna gain, GLθ (dB) at D = 3 m and f = 6GHz**	**Antenna pointing loss, Lθ at D = 3 m and f = 6GHz**	**Change in antenna gain due to depointing loss, %ΔG (dB) D = 3 m and f = 6GHz**
0.00	43.6352	43.6352	0.0000	0.0000
0.10	43.6352	43.5470	0.0882	0.2020
0.20	43.6352	43.2825	0.3527	0.8082
0.30	43.6352	42.8417	0.7935	1.8184
0.40	43.6352	42.2245	1.4106	3.2327
0.50	43.6352	41.4311	2.2041	5.0512
0.60	43.6352	40.4613	3.1739	7.2737
0.70	43.6352	39.3152	4.3200	9.9003
0.80	43.6352	37.9927	5.6424	12.9310
0.90	43.6352	36.4939	7.1412	16.3658
1.00	43.6352	34.8188	8.8163	20.2046

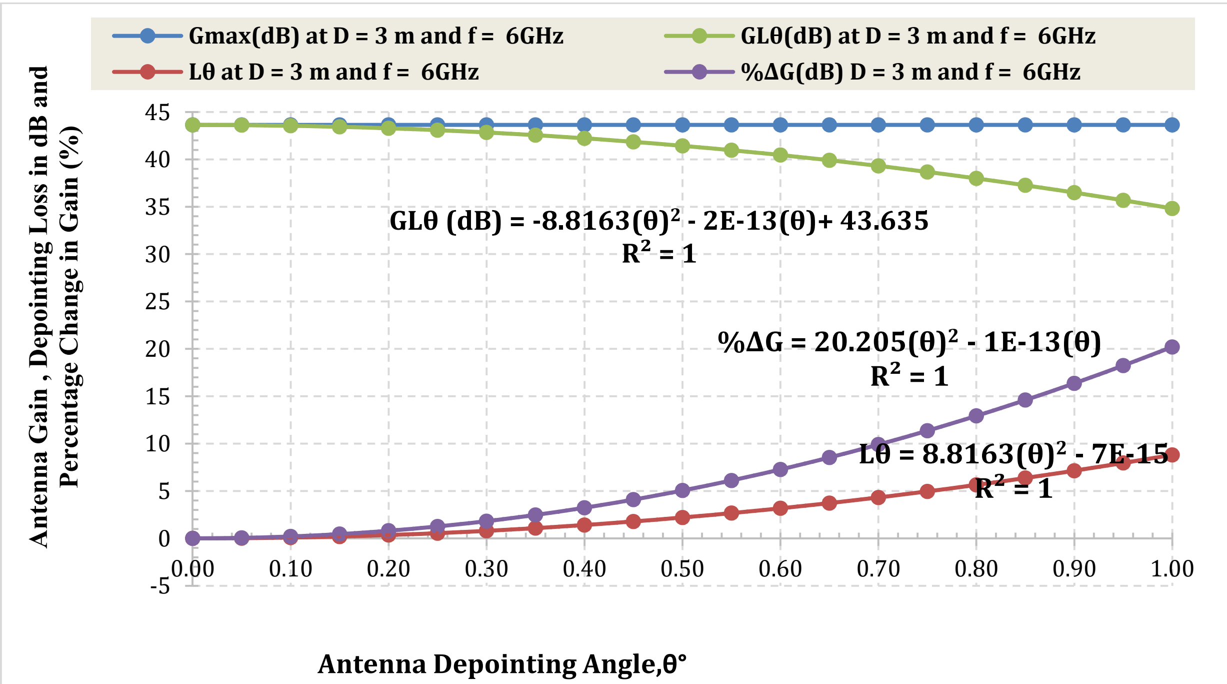

Figure 1 The graph of the maximum antenna gain, composite antenna gain, antenna pointing loss and change in antenna gain due to depointing loss versus depointing angle in degrees

Again, the results of the parabolic antenna diameter without depointing loss, parabolic antenna diameter with depointing loss and change in parabolic antenna diameter due to depointing loss are shown in Table 2 and Figure 2. The results in Table 2 and Figure 2 show that the parabolic antenna diameter with depointing loss, DGLθ decreases nonlinearly with increase in depointing angle, as follows;

$$DGL\theta(dB) = 1.76(\theta)3 - 3.7784(\theta)2 + 0.109(\theta) + 2.997 \quad (28)$$

In addition, the change in parabolic antenna diameter due to depointing loss, %ΔD increases nonlinearly with increase in depointing angle, as follows;

$$\%\Delta D = -58.666(\theta)^3 + 125.95(\theta)^2 - 3.6327(\theta) + 0.0989 \quad (29)$$

In all, the depointing loss of about 1° results in about 63 % change in the parabolic antenna effective diameter and 20.2046 % change in the parabolic antenna gain. Also, the change in the receiver figure of merit due to depointing loss ($\Delta G/T|_{dB/K}$) is equal to the depointing loss (L_θ).

Table 2 The results of the parabolic antenna diameter without depointing loss, parabolic antenna diameter with depointing loss and change in parabolic antenna diameter due to depointing loss

θ	Parabolic antenna diameter without depointing loss, Dgmax at f = 6GHz	Parabolic antenna diameter with depointing loss, DGLθ(dB) at f = 6GHz	Change in parabolic antenna diameter due to depointing loss, %ΔD at f = 6GHz
0.00	3.0000	3.0000	0.0000
0.10	3.0000	2.9697	1.0099
0.20	3.0000	2.8806	3.9788
0.30	3.0000	2.7381	8.7303
0.40	3.0000	2.5503	14.9901
0.50	3.0000	2.3276	22.4118
0.60	3.0000	2.0817	30.6085
0.70	3.0000	1.8244	39.1865
0.80	3.0000	1.5667	47.7751
0.90	3.0000	1.3184	56.0520
1.00	3.0000	1.0872	63.7604

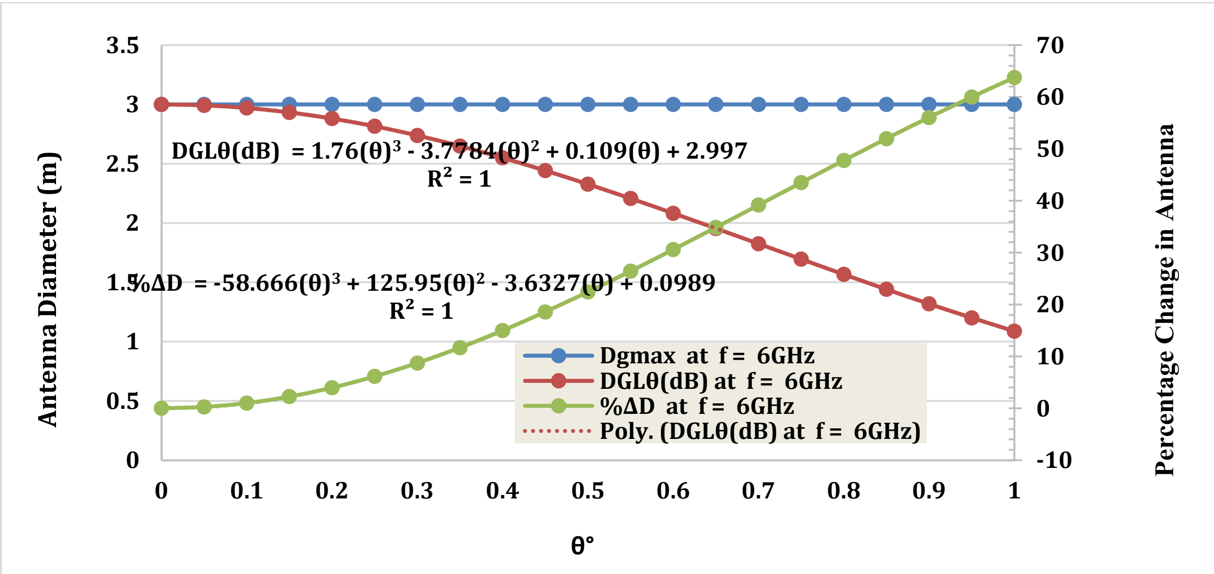

Figure 1 The graph of the parabolic antenna diameter without depointing loss, parabolic antenna diameter with depointing loss and change in parabolic antenna diameter due to depointing loss versus depointing angle in degrees

4. Conclusion

Analytical model for estimating the impact of depointing angle on satellite link on parabolic antenna gain and effective antenna diameter is presented. The study considered only the 6 GHz C-band satellite link with depointing angle in the range of 0 to 1 degree. The results show that the composite gain of the parabolic antenna decreases nonlinearly with increase in depointing angle. Generally, there are quadratic and cubic nonlinear relationships between the depointing angle and the antenna depointing loss and percentage change in antenna diameter respectively.

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