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Design and Performance Analysis of a C Band Micro-strip Patch Feed Reflector Antenna and Link Budget Optimization

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ABSTRACT : *This paper deals with the design and performance analysis of a very small size, low-cost, low-profile, high gain and high directivity C Band Micro strip Patch Feed Reflector Antenna considering the link budget optimization. The proposed antenna system has a gain of -4.45dB, directivity of 7.062dBi, return loss of -16.817327dB at 5.532 GHz and -15.998dB at 6.532GHz, Voltage Standing Wave Ratio (VSWR) of 1.338 at 5.5302GHz and 1.3766 at 6.5309 GHz, at C band it operates in two regions with bandwidth of 184MHz (5.4431 to 5.6275GHz) and 422MHz (6.3356 to 6.7576 GHz). The resonant frequencies of the antenna are 5.532GHzand 6.532GHz. The proposed antenna system can be used for C-band like satellite communications transmissions, VSAT, Wi-Fi, weather radar systems, medical applications and other wireless systems. The antenna system is designed and simulated in the CST Microwave Studio. Link budget optimization is performed in order to analyze the critical factors in the transmission chain and to optimize the performance characteristics. The link budget determines what size antenna is to use, power requirements and in general, the overall customer satisfaction.*

KEYWORDS *- Reflector antenna, C band, link budget optimization, gain, satellite communications, VSAT.*

I. INTRODUCTION

With the change of era new technologies are getting familiarity in satellite communications. Due to the drastic growth of modern satellite communication technology, the use of small antennas have increased due to their low-cost, low-profile, high gain and high directivity. Antennas for mobile communications are widely presented in books and papers in the last decade as presented in [1-3]. Global Mobile Satellite Communications: For Maritime, Land and Aeronautical Applications are illustrated in [4]. The satellite link is much like terrestrial microwave radio relay link with the advantage of not requiring as many re-transmitters as are required in the terrestrial link. Transmission of signals over a satellite communication link requires Line-of-Sight (LoS) communication. Link analysis basically relates the transmit power and the receive power [9]. The communication link between a satellite and the Earth Station (ES) is exposed to a lot of impairments such as free space path loss, rain loss, pointing loss and atmospheric attenuations etc. [10]. The organization of this paper is as follows – Section II conducts the antenna architecture. Section III illustrates the simulation results. Section IV reveals the result analysis. Section V conducts link budget analysis. Section VI resembles System Noise. Section VII shows link budget calculation. Section VIII conducts the cost calculation of the proposed antenna system. Finally, Section IX provides some concluding remarks.

II. ANTENNA ARCHITECTURE

The copper(annealed) lossy metal is used as substrate for the reflector. The relative permeability (μ_r) and electrical conductivity of the substrate material are 1.0 and 5.8e+007 (S/m) respectively. The reflector diameter is 100mm with 1mm thickness . A micro strip patch antenna is placed at distance of 9mm from the reflector surface without any electrical conduction. FR-4 lossy material is used for substrate and copper(annealed) as ground plane. The length of substrate is 41.33mm and width is 52.66mm.The patch length is 20.66mm and width is 26.33mm.The excitation signal is applied at the patch feed line. Fig 1 shows the structure of the C Band Micro strip Patch Feed Reflector Antenna.

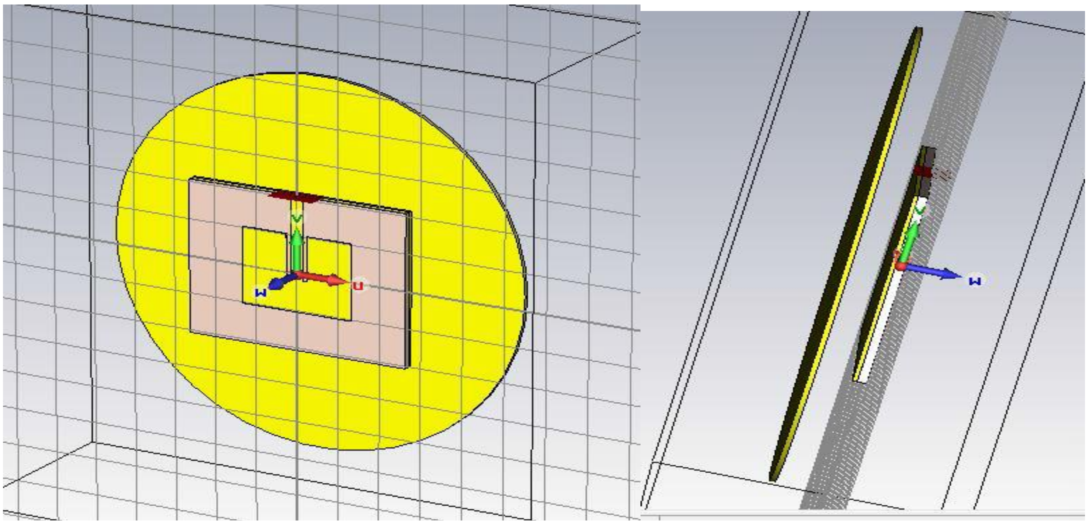

Fig. 1. Structure of C Band Micro-strip Patch Feed Reflector Antenna

III. SIMULATION RESULT

3.1 Electric & Magnetic Field Distribution

Electric & Magnetic field distribution of the C Band Micro-strip Patch Feed Reflector Antenna is given below:

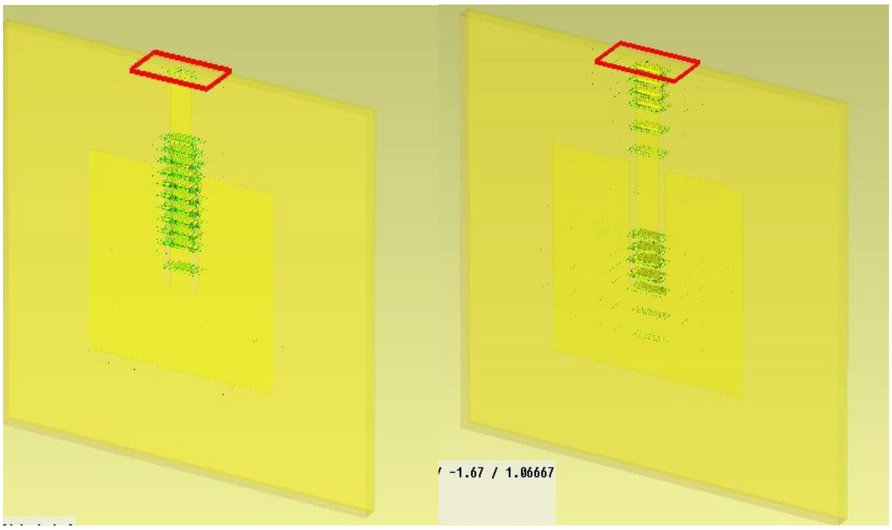

Fig. 2. Electric & Magnetic field distribution of the C Band Micro-strip Patch Feed Reflector Antenna

3.2 Voltage Standing Wave Ratio (VSWR) & Return Loss

Fig. 3 shows the graph of VSWR vs. Frequency. From this figure it can be seen that the VSWR value is very near to the unity which is mostly expected. The VSWR value of the antenna is 1.338 at 5.5302GHz and 1.3766 at 6.5309 GHz respectively.

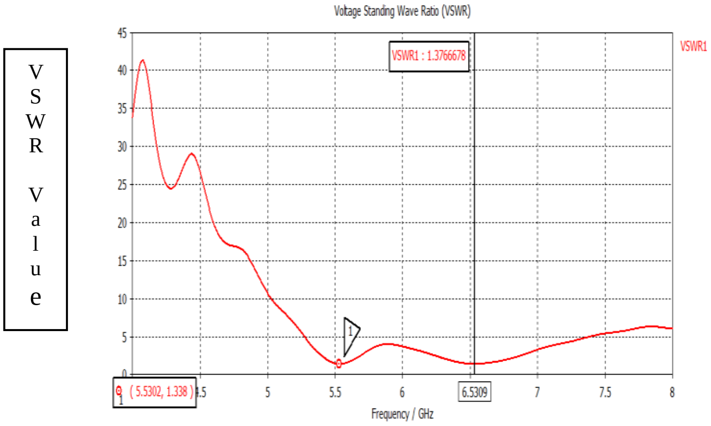

Fig. 3. VSWR vs. Frequency curve of the C Band Micro-strip Patch Feed Reflector Antenna

Fig. 4 shows the graph of return loss vs. frequency. From this figure we can observe the bandwidth of the antenna. The bandwidth of the antenna is 184MHz which operates in C band (5.4431 to 5.6275GHz) at 5.532GHz and 422MHzwhich operates in C band (6.3356 to 6.7576 GHz) at 6.532 GHz. The value of return loss is -16.817327dB at 5.532 GHz and -15.998dB at 6.532GHz.

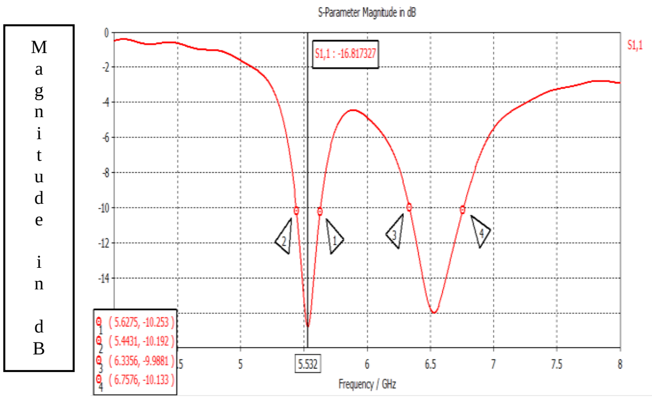

Fig. 4. Return loss of the C Band Micro-strip Patch Feed Reflector Antenna

3.3 Farfield Radiation Pattern (2D), Gain Pattern and Antenna Efficiency

Fig. 5 shows the far-field directivity pattern of the Proposed antenna. The radiation pattern of the antenna is bidirectional. From this figure it can be seen that the directivity and gain of the antenna is about 7.062 dBi and -4.45 dB respectively. The radiation efficiency is -11.52 dB

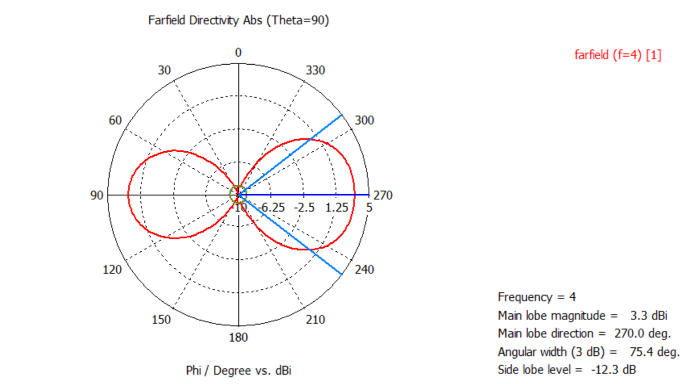

Fig. 5. Far-field directivity pattern of the C Band Micro-strip Patch Feed Reflector Antenna

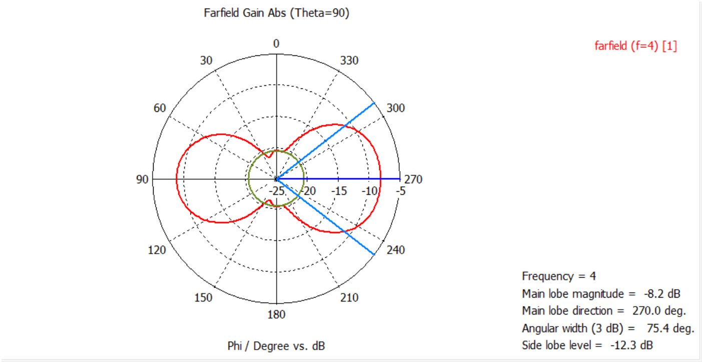

Fig. 6. Far-field gain pattern of the C Band Micros-trip Patch Feed Reflector Antenna

IV. RESULT ANALYSIS

VSWR, return loss, far-field radiation pattern, antenna gain, directivity and antenna efficiency of the proposed antenna system show reasonable characteristics. The performance of the antenna is quite good. This antenna can be used in C band applications for its effective performance.

Table I. Proposed C Band Microstrip Patch Feed Reflector Antenna parameters and their values at a glance

Designed Micro strip Patch Feed C Band Reflector Antenna Parameters	Simulation Results
VSWR	1.338
Return Loss (in dB)	-16.817327 dB
Gain (in dB)	4.45dB
Directivity (in dBi)	7.062 dBi
Bandwidth (MHz)	C Band : 184 MHz &422 MHz

The results in the Table I reveal that the proposed C Band Micro-strip Patch Feed Reflector Antenna system is useful for C band applications like VSAT Communication, satellite communications transmissions, Wi-Fi, cordless telephones, weather radar systems, medical applications and other wireless systems.

V. LINK BUDGET ANALYSIS

The Satellite link is much like the terrestrial microwave radio relay link with the advantage of not requiring as many re-transmitter as are required in the terrestrial link. Transmission of Signal over a satellite communication link requires Line-of-Sight (LoS) Communication. Line analysis basically relates the transmit power & receive power. Basic transmission parameters are – flux density, received power, antenna gain, noise power, figure of merit etc.A link consists three parts namely transmitter, receiver & media. The two main items that are associated with transmitter are flux density & EIRP. A measure of the amount of energy that is received at a distance *r* from a transmitter of gain G_t & transmitter power P_t watts is the flux density which is given by –

$$\phi = \frac{P_t G_t}{4 \pi R^2} \ [\mathrm{W/m^2}] \qquad (1)$$

Where P_tG_t is called the Effective Isotropic Radiated power or EIRP which is closely associated with a radiating source or a transmitter & a subset of flux density.

Fig. 7 shows that flux density decreases as square of the distance. The plot has been made between 400 ton40000 km for distance and the corresponding flux density lies between near about 10^{-9} to 10^{-13} W/ m^2 . The constant parameters are P_t = 20 W, G_t = 22 dB.

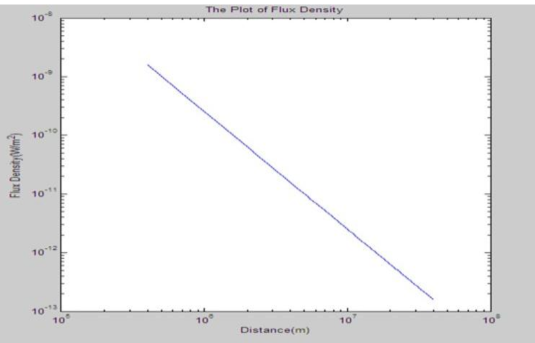

Fig. 7. Graphical representation of flux density

For an ideal receiver antenna of aperture area A, the total received power at the receiver is given by –

$$P_r = \phi \times A = \frac{P_t G_t A}{4\pi R^2} \text{ [W]} \qquad (2)$$

A practical antenna with physical aperture A will not deliver this power as some energy will be reflected and some will be absorbed by lossy elements. Thus the actual power received will be-

$$P_r = \eta A \times \phi \text{ [W]} \qquad (3)$$

where, η is the antenna efficiency and A is referred to as the effective collecting area of the antenna. The antenna
efficiency accounts for all losses between the incident wave-front and the antenna output port. An antenna of maximum gain G_r is related to its effective area by the following equation –

$$G_r = \frac{\eta 4\pi A}{\lambda^2} \qquad (4)$$

where, λ is the wavelength of the received signal.
Rearranging equation (4) and substituting in (3) we get –

$$P_r = \frac{P_t G_t G_r}{\left({4\pi R}/{\lambda} \right)^2} \text{ [W]} \qquad (5)$$

From Fig. 8 it is seen that received power remains almost constant for GEO due to its longer distance which is above 35786 km above the earth surface. Here, the ranges of different orbits are taken as- LEO→500-1500km, MEO→5000-10000km, GEO→36000-41000km while the values of constant parameters of equation (5) are P_t = 20 W, G_t = 22dB, G_r 52.3 dB, f = 11 GHz.

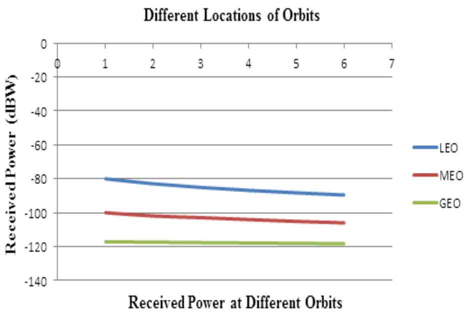

Fig. 8 Received Power at different orbits

For a parabolic antenna of diameter D, equation (4) can be rewritten as –

$$G_r = \eta \frac{\pi^2 D^2}{\lambda^2} \qquad (6)$$

The variation in antenna gain for a range of transmission frequencies that are employed in satellite communications is shown below assuming an efficiency of 60%.

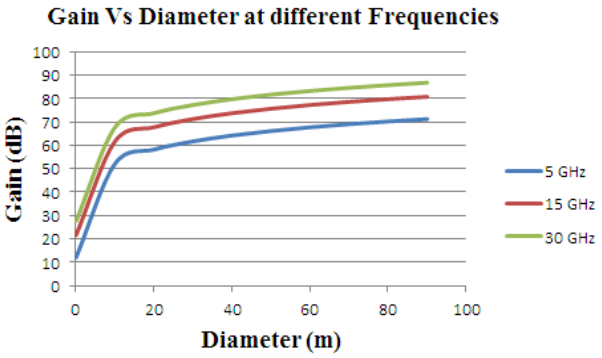

Fig. 9 Illustration of gain Vs diameter at different frequencies

The above figure resembles that highest frequency shows maximum gain while the lowest one illustrates the lowest gain as the gain is directly proportional to the square of the frequency.

VI. SYSTEM NOISE

6.1 Noise Power

The Thermal noise power P_n delivered to the optimam load by the thermal noise source of resistance R at temperature T is given by –

$$P_n = K T_p B_n \tag{7}$$

Where K – Boltzman Constant = 1.38 x 10^{-23} J/K, Tp – Noise temperature in Kelvin & B_n – Noise bandwidth in Hz.

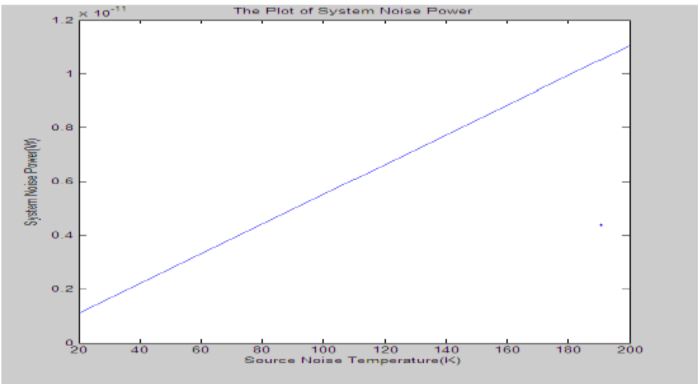

Fig. 10 Demonstration of system noise power

Since the system noise power is directly proportional to the system noise temperature so the noise power will increase as the temperature increases.

6.2 Figure of Merit

The figure of merit is introduced to describe the capability of an earth station or satellite to receive the signal. Since the C/N is the ratio of Signal Power to noise power, we have that –

$$C/N = \frac{P_r}{P_n} = \frac{P_t G_t G_r}{\left(4\pi/\lambda\right)^2} \tag{8}$$

i.e. $$\frac{C}{N} = f\left(\frac{G_r}{T_s}\right)$$

The ratio G_r/T_s is known as figure of merit which indicates the quality of receiving satellite earth station & it is measured in dB/K.

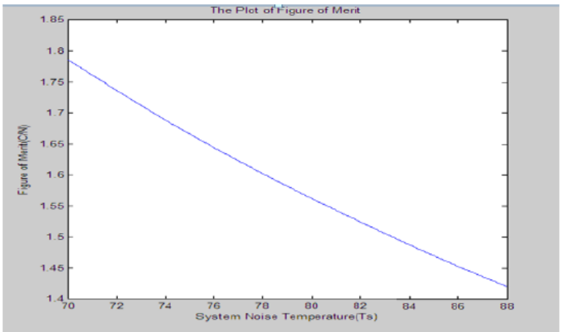

Fig. 11 Realization of Figure of Merit

Since the figure of merit is inversely proportional to the system noise temperature, so the figure of merit will decrease as the system noise increases. Here P_t = 20 W, G_t = 22 dB, R = 39000 Km, f = 4.15 GHz, B = 4 GHz, G_r = 10,000 – 100,000.

VII. LINK BUDGET CALCULATION

The results obtained from the link budget calculator are shown below [11]-

7.1 Uplink Budget

Uplink frequency GHz	5.5
Uplink antenna diameter m	0.1
Uplink antenna aperture efficiency e.g. 0.65	0.65
Uplink antenna transmit gain dBi	13.3369523
Uplink antenna, power at the feed W	200
Uplink EIRP dBW	36.3472523
Range (35778 - 41679) km	1000
Uplink path loss dB	167.257253
Uplink pfd at satellite dBW/m^2	-94.653082
Bandwidth Hz	184000000
Satellite uplink G/T dB/K	-5.3
Uplink C/N dB	9.7418203

7.2 Downlink Budget

Downlink frequency GHz	4
Downlink receive antenna diameter m	.1
Downlink receive antenna aperture efficiency e.g. 0.65	0.65
Downlink system noise temperature (antenna+LNA) K	270.43
Downlink receive antenna gain dBi	10.5708984
Downlink receive antenna G/T dB/K	-13.749650
Downlink satellite EIRP dBW	55.59
Downlink path loss dB	164.491199
Downlink C/N dB	23.3009716

VIII. COST CALCULATION

Large antennas are expensive to construct and install, with costs exceeding $1M for 30-m diameter fully steerable antennas [12]. The cost of large fully steerable antennas has been quoted as [13]-

$$\text{Cost} = \$\ y(D)^{2.7} \tag{9}$$

Where, D is the diameter of the antenna aperture in feet. The constant y in equation (1) depends on the currency used and inflation, but might typically be around five U.S. dollars in the early 1980s. The diameter of the proposed Micro-strip Patch Feed C Band Reflector Antenna aperture is 100 mm i.e.; 0.32808 feet which in turn gives-

$$\begin{aligned} \text{Cost} &= \$\ y(D)^{2.7} \\ &= \$\ \{5 \times (0.32808)^{2.7}\} \\ &= \$\ 0.2467 \end{aligned}$$

IX. CONCLUSION

The design of a C Band Micro-strip Patch Feed Reflector Antenna and its performance analysis for C band along with the link budget optimization has been demonstrated in this paper. The simulation results of the proposed antenna system resemble very good performance. Also the cost calculation reveals that our proposed antenna system is cost effective. In this paper, CST Microwave Studio software has been used for all the simulations which provide effective and satisfactory results. The proposed antenna system provides high gain, directivity, efficiency and bandwidth. It also shows very low value in case of VSWR which is near about unity that satisfies the antenna specification.

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