Development of Earth Station Receiving Antenna and Digital Filter Design Analysis for C-Band VSAT

Su Mon Aye, Zaw Min Naing, Chaw Myat New, Hla Myo Tun

Abstract: This paper describes the performance improvement of C-band VSAT receiving antenna. In this work, the gain and efficiency of C-band VSAT have been evaluated and then the reflector design is developed with the help of ICARA and MATLAB environment. The proposed design meets the good result of antenna gain and efficiency. The typical gain of prime focus parabolic reflector antenna is 30 dB to 40dB. And the efficiency is 60% to 80% with the good antenna design. By comparing with the typical values, the proposed C-band VSAT antenna design is well optimized with gain of 38dB and efficiency of 78%. In this paper, the better design with compromise gain performance of VSAT receiving parabolic antenna using ICARA software tool and the calculation of C-band downlink path loss is also described. The particular prime focus parabolic reflector antenna is applied for this application and gain of antenna, radiation pattern with far field, near field and the optimized antenna efficiency is also developed. The objective of this paper is to design the downlink receiving antenna of VSAT satellite ground segment with excellent gain and overall antenna efficiency. The filter design analysis is base on Kaiser window method and the simulation results are also presented in this paper.

Index Terms: prime focus parabolic reflector antenna, satellite, efficiency, gain, path loss, VSAT.

1 Introduction

COMMUNICATION satellites especially in geostationary Earth orbit (GEO) provide an effective platform to relay radio signals between points on the ground. Benefits of satellite communications should be extended to users in all parts of the world through the use of smaller, inexpensive and less sophisticated Earth stations for two way (voice and data), and one way (video, data) use. VSAT evolution is a turning point in the history of the satellite industry. VSAT products exist with wide ranging service capabilities offering individual or integrated voice, data, and video services. VSAT technology is a powerful telecommunications tool with smaller antennas. The powerful C band VSAT can attenuate the losses of signal strength and rain effect in the space. Therefore, C band VSAT earth station terminal and the performance of link path loss calculation, gain, efficiency and frequency impairments are elegant with calculation. This technology could solve the communication problems of a large segment of industry and business, agriculture, construction, education, manufacturing, medical, transportation, etc. [2]. This paper is organized in the following sequence. Section II describes C band VSAT system with its block diagram .Section III is about the prime focus feed antenna used in this design. Design calculation and antenna parameters are presented in section IV. Simulation results exist in section V and the next section is followed by conclusion. A very small aperture terminal (VSAT) is a two-way satellite ground station or a stabilized VSAT antenna. The majority of VSAT antennas range from 75 cm to 4.5 m. VSATs access satellites in geosynchronous orbit to relay data from small remote earth stations to other terminals (in mesh topology) or master earth station "hubs" (in star topology). [4] VSATs are most commonly used to transmit narrowband data, or broadband data for the provision of satellite Internet access to remote locations, VoIP or video. VSATs are also used for transportable, on-the-move or mobile maritime communications. For small, low-cost VSATs, high satellite EIRP is needed to accommodate the higher bit-rate. The VSAT terminal is characterized primarily by its low cost and small size antenna. The maximum antenna gain of the earth station depends on the frequency, the antenna efficiency and the antenna diameter. C-band VSATs may be as large as 4 m (13 ft). The overall antenna efficiency is 50% to 80% for this VSAT application. [6] The hub station controls and monitors can communicate with a large number of dispersed VSATs. Since all VSATs communicate with the central hub station only, this network is more suitable for centralized data applications.

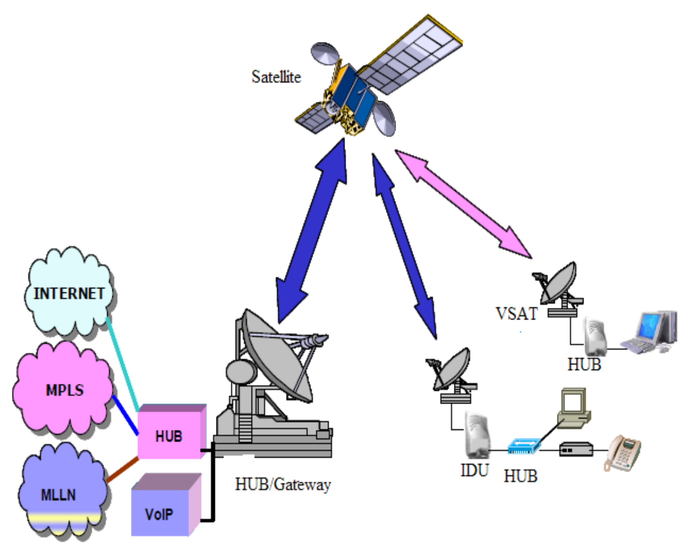

Fig.1. C band VSAT Architecture [12]

2 Overview of VSAT System

The essential parts of a VSAT configuration are:

- Antenna
- Block up converter (BUC)
- Low-noise block down converter (LNB)
- Interfacility link cable (IFL)
- Indoor unit (IDU)

The antenna, up and down converters and amplifiers are outdoor units and other remaining parts are indoor unit including modem. In a downlink receiving VSAT earth station, it is compromised of mainly four parts: VSAT antenna, filters, low noise amplifier and downconverter and it is shown in Fig.2.

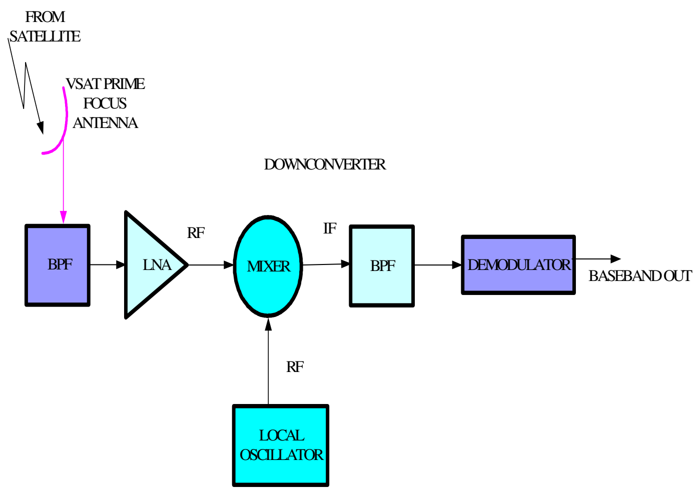

Fig.2. Block Diagram of VSAT downlink earth station system

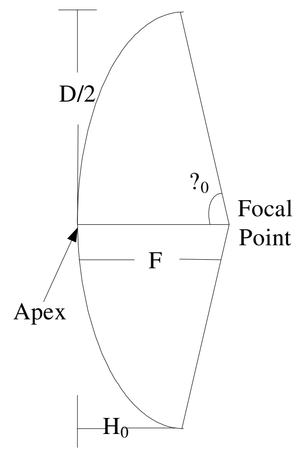

Fig.3. Geometry of the Prime Focus Parabolic Reflector Antenna

In the basic block diagram of a VSAT earth-station receiver, the signal from satellite transponder through the terrestrial network is received with the VSAT prime focus antenna and it is converted to downlink frequency by low noise amplifier and downconverter. Finally, it is demodulated by demodulator and the baseband signal is out to the remaining parts of VSAT unit. According to the international telecommunication frequency standard, the specific application and link design must be optimized. It needs to be taken into account the losses during passing through the space network and rain effects. Therefore, band selection is very important for the particular application and designing of antenna. In this work, C band is chosen because rain attenuation and sky noise is low at 4 GHz downlink frequency of C band to build a VSAT receiving antenna system.[5] Moreover, C band is the most well-liked frequency band for Asia and almost Asian countries use this frequency band satellite because of less rain attenuation.

3 Prime Focus Feed Antenna

The most important part is an antenna and it has to be superior gain and efficiency for achieving the best performance of VSAT terminal. There are three geometries of parabolic antenna types: Prime Focus Feed antenna, Caseegrain and Gregorian antenna.[7] Among them, the firstly Prime focus feed antenna system is the most useful one for VSAT application as it has uniformly distributed illumination radiation and its efficiency is superior. The geometry of the prime-focus parabolic reflector antenna is shown in Fig.3. It has parameters such as main reflector diameter, the focal length (F) and the subtended half-angle (θ_o), defined as the maximum semi angle. It is subtended by the reflector antenna and actually gets radiation into free space rather than lost as heat on the antenna's structure or reflected back into the source. η is the percentage antenna overall aperture efficiency and (60-80) % is typical. [8].

The most common basic geometry for a reflector antenna is based on a paraboloid surface. A paraboloid collimates the radiation coming from a focal point. Because of this geometrical property, paraboloidal reflector antennas are widely used for high gain antennas in telecommunication applications. The paraboloid can be fed directly from the focal point or a sub reflector antenna can be used whose focal point coincides with the focal point of the paraboloid. The main design parameter of the prime-focus systems is the optics angle. Typically, this angle is in the range of 51–80◦ and equivalent to acceptable range in F/D of 0.25–0.65.[9] Therefore, in this paper, the maximum gain and efficiency are well-performed with the most suitable F/D curvature rate 0.45.With the various F/D ratios, the antenna aperture gains and overall efficiencies are premeditated.

4 Design Calculation

According to the input parameters and design calculation, the antenna gain and efficiency of the chosen prime focus antenna are considered by six steps. Firstly, C band downlink frequency in GHz is selected. And input parameters for antenna such as Main dish diameter, D and Feed diameter, d are chosen. Then, the subtended angle is calculated with the most suitable focal length to main dish diameter ratio. In the next step, the overall aperture efficiency with various efficiencies such as spillover, taper and blockage efficiency is calculated. Finally, antenna gain in dB can be calculated. If it is not a good design to meet with high gain efficiency, the main dish diameter and subtended angle of reflector can be changed and the design has to calculate again.

4.1 Efficiency Calculation

An antenna's efficiency is a measure of how much power is radiated by the antenna relative to the antenna input power. The efficiency is a function of where the feed antenna is placed (in terms of F and D) and the feed antenna's radiation pattern. Antenna efficiency is in terms of spillover, taper, illumination, phase and blockage efficiency. This efficiency term will often be on the order of 0.6-0.7 for a well designed dish antenna. [11]

4.2 Gain Calculation

Parabolic reflectors typically have a very high gain (30-40 dB is common) and low cross polarization. They also have a reasonable bandwidth, with the fractional bandwidth. The maximum possible gain of the antenna can be expressed in terms of the physical area of the aperture. The actual gain is in terms of the effective aperture, which is related to the physical area by the efficiency.

$$\lambda=\frac{c}{f} \quad (1)$$

θ_0 (angle from the feed (focal pt) to the reflector's rim),

$$\theta_0=2\tan^{-1}\left[\frac{1}{4\left(\frac{F}{D}\right)}\right] \quad (2)$$

Focal distance (focal length),

$$F=\frac{D^2}{16H_0} \quad (3)$$

$$\text{Aperture area, } A_p=\frac{\pi D^2}{4} \quad (4)$$

$$\text{Effective area, } A_e=\eta A_p \quad (5)$$

$$\text{Gain,} G=\frac{4\pi A_e}{\lambda^2} \quad (6)$$

$$\text{Beamwidth,} \theta_{3dB}=70\frac{\lambda}{D} \quad (7)$$

$$\text{Aperture Efficiency} = \eta_{taper}\times \eta_{spillover}\times \eta_{blockage} \quad (8)$$

$$\eta_{spillover}=1-u^2(N+1) \quad (9)$$

$$N=\frac{\log 0.1}{2\log(\cos\left(\frac{\theta_0}{2}\right))} \quad (10)$$

$$u=\cos\left(\frac{\theta_0}{2}\right) \quad (11)$$

$$\eta_{taper}=\frac{4(N+1)(1-u^N)^2}{N^2(1-u^{2(N+1)})}\cot^2\left(\frac{\theta_0}{2}\right) \quad (12)$$

$$\eta_{illumination}=\eta_{spillover}\times\eta_{taper} \quad (13)$$

$$\eta_{blockage}=1-\frac{A_b}{A_g} \quad (14)$$

$$A_b=\frac{\pi d^2}{4} \quad (15)$$

$$A_g=\frac{\pi D^2}{4} \quad (16)$$

Link path loss = 32.4+20logR+20logf

Where, R = 37000m and f = 4.7215GHz

Therefore,

Link path loss = 217.2447 dB.

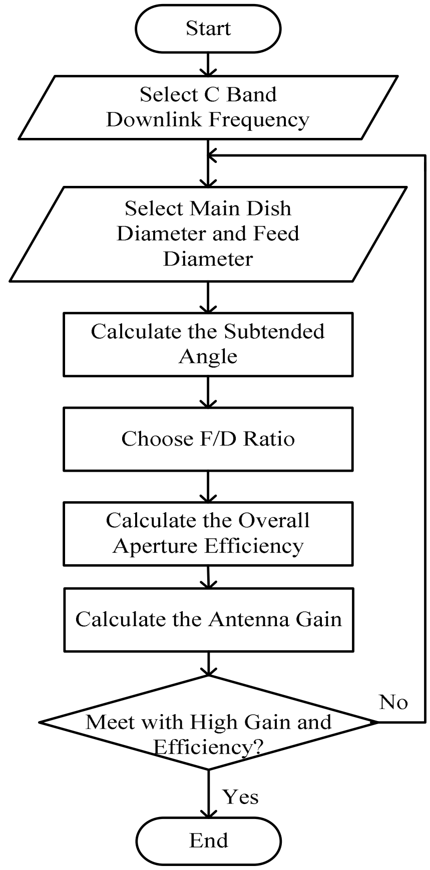

Fig.4. Flowchart of antenna gain and efficiency calculation

TABLE I

GEOMETRICAL PARAMETERS FOR SELECTED PRIME FOCUS FEED ANTENNA

Type	Prime Focus Feed
Aperture Diameter	1.800 m
Feed Diameter	0.1800 m
Focal length	0.8100 m
Angle from the feed (focal pt) to the reflector's rim	53.1301M

5 SIMULATION RESULTS

Calculated parameters are simulated by using ICARA (Induced Current Analysis of Reflector Antenna) software tool. The behaviour of reflector antenna is prepared using Physic Optics method. [1] The maximum VSAT antenna gain for downlink and the maximum efficiency are found by taking the most appropriate F/D ratio as shown in the following figures.

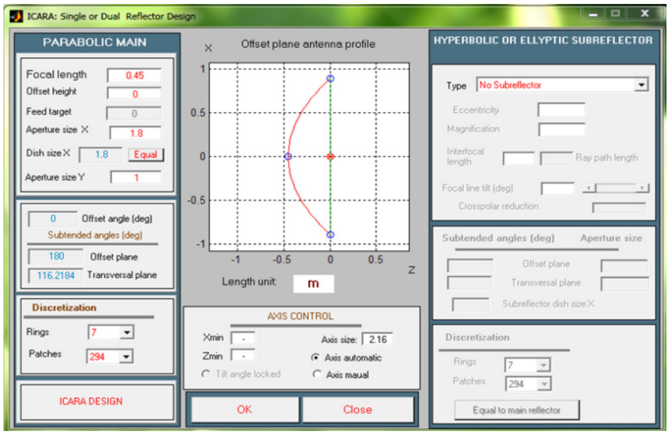

Fig.5. Reflector Configuration

In Fig.5, the reflector configuration of the proposed antenna is shown and the input parameters are placed as main dish diameter and focal length.

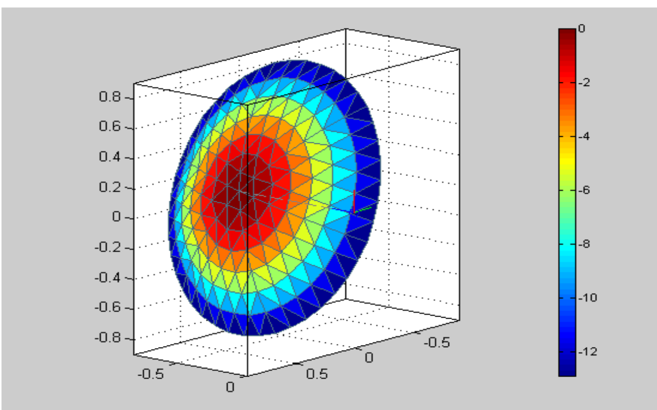

Fig.6. Sketch of Reflector

Fig.6 shows 3D sketch of the prime focus-fed reflector configuration. In this sketch, the signal strength is the best compromise with the red period. The ellipse major diameter D of the reflector has been chosen as 1.8 m and the minor diameter d has been chosen as 0.18 m. The focal length can be calculated from the following equations.

F/D = 0.45, where D = 1.8 m
Therefore,
F = 0.81 m

The best value for the parameter, based on the simulation results, was used when the next parameters were optimized. In this way it was possible to study separately how each parameter affected the radiation of the prime focus feed antenna. The design process was repeated many times to find the maximum gain with low side lobes.

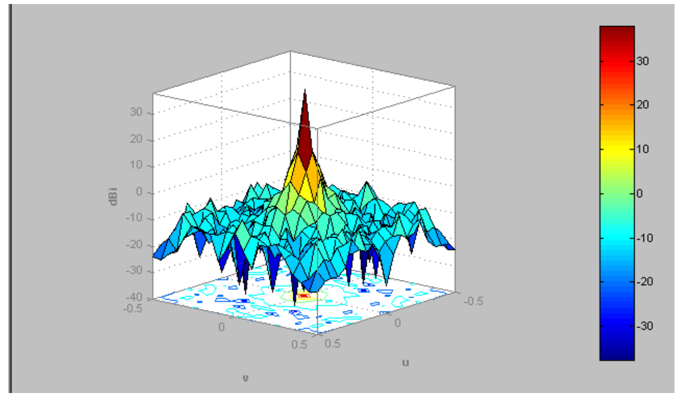

Fig.7. Far Field at 4.7215 GHz

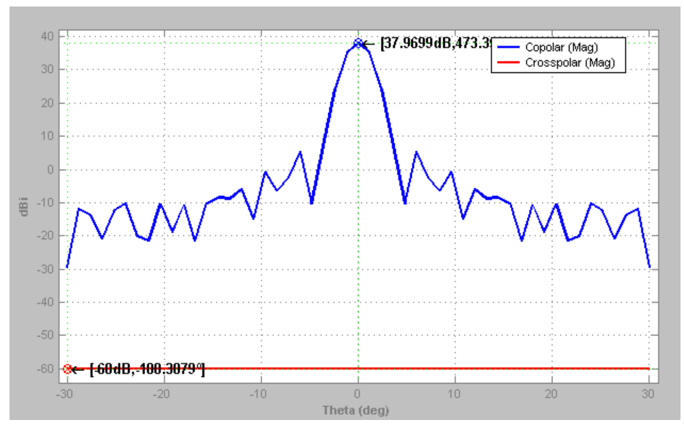

Fig.8. Far Field Phi Constant at 4.7215GHz

The far field analysis of the proposed parabolic single feed system is shown in Fig 7 and Fig 8. With these figures, the maximize gain can be occur in 37.98dBi. The radiation pattern is defined in the θ, direction from-_30°to30° as shown in Fig.7. And Fig.8 shows the radiation patterns of the prime focus –fed reflector antenna with far field at downlink frequency 4.7215 GHz.

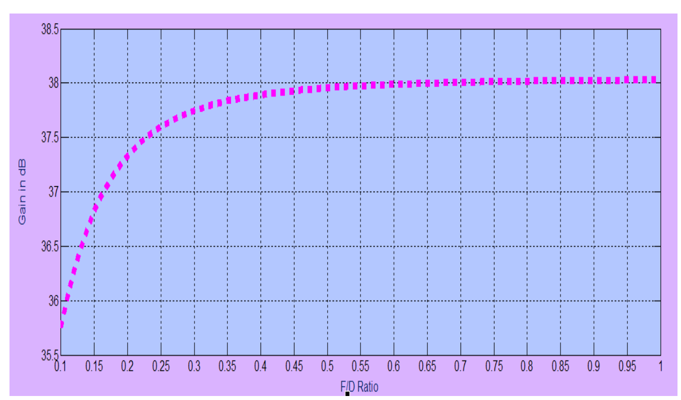

Fig.9. Plot of Gain as a function of F/D ratio

In Fig.9, this response curve illustrates gain with respect to F/D ratio. The maximum VSAT antenna gain for downlink and the maximum efficiency are found by taking the most appropriate F/D ratio as shown in the above figures.

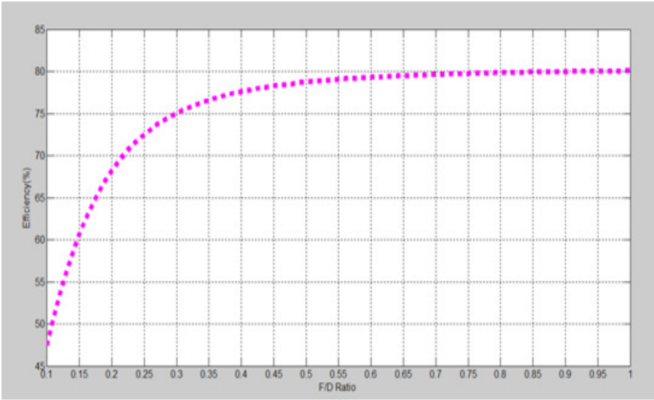

Fig.10. Plot of Efficiency as a function of F/D

In Fig.9 and Fig.10, the maximum gain and efficiency is superimposed in F/D value of 0.45 and then these values are constant when F/D is increased as 0.5, 0.55 and so on.

TABLE II
COMPARISON FOR SELECTED PRIME FOCUS FEED ANTENNA AND EXISTING VSAT ANTENNA IN INDIA

	Proposed System	Karnataka, India
Antenna diameter	1.8 m	1.8 m
C band Downlink Frequency	4.72GHz	4.72GHz
Gain	37.98 dB	36.8dB
Efficiency	78.76%	63%
Path Loss	217.24 dB	217dB

Figure 7 and 8 show the antenna radiation pattern in Cartesian coordinate system representation with side lobes. The main lobe of an antenna radiation pattern has larger field strength than the others and the side lobe represents unwanted radiation in undesired directions. The main lobe of an antenna radiation pattern is the lobe containing the maximum power. It has the greatest field strength. The efficiency of a parabolic antenna is in terms of spillover, taper, blockage, illumination and phase efficiency. In this work, spillover, taper and blockage efficiency are considered. The illumination efficiency is the multiplication of taper and spillover efficiency. And the phase efficiency is also unity in high frequency application. In gain and efficiency calculation, the appropriate and the most reliable F/D parameter is also considered. Therefore, the better gain and efficiency is higher than that of the existing system.

6 DESIGN OF DIGITAL FILTER

The window method

The various window methods for FIR filter design are the following. They are

(1) Blackman
(2) Blackman-Harris
(3) Bohman
(4) Chebyshew
(5) Flat top
(6) Gaussian
(7) Hamming
(8) Hann
(9) Nutall
(10) Parzen
(11) Rectangular
(12)Kaiser

All of the above filtering methods, Kaiser window is the best windowing method because it offers very low order to meet the desired specification and adjusts the compromise between the overshoot reduction and transition region width spreading. But when Kaiser Window is compared with optimal filter design method, equiripple filter design found to be most suitable and optimized method to meet the desired condition.

$$w(n) = \frac{I_o\left\{\beta\left[1-\left(\frac{2n}{N-1}\right)^2\right]^{1/2}\right\}}{I_0(\beta)-(N-1)/2} \le n \le (N-1)/2$$

$$w[n] = \begin{cases} I_o\left[\beta\left(1-[(n-\alpha)/\alpha]^2\right)^{1/2}\right] \\ 0, \end{cases}$$

$$\beta = 0 \qquad \text{if} A \le 21\text{dB}$$

$$\beta = 0.5842(A-21)^{0.4} + 0.07886(A-21) \qquad \text{if} 21\text{dB} < A < 50\text{dB}$$

$$\beta = 0.1102(A-8.7) \qquad \text{if} A \ge 50\text{dB}$$

$$N \ge \frac{A-7.95}{14.36\Delta f}$$

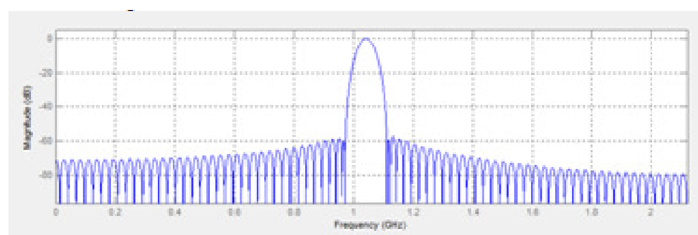

Fig.11. Magnitude Response

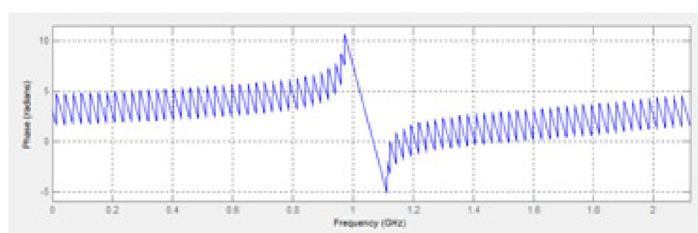

Fig.12. Phase Response

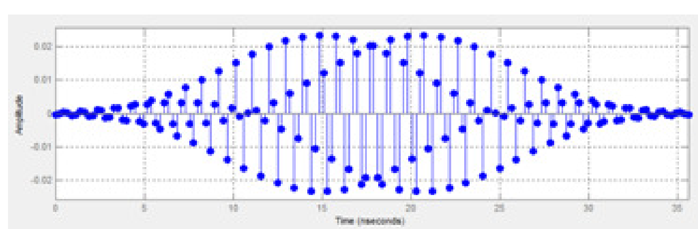

Fig.13. Impulse Response

According to the design of digital filter analysis, we got the magnitude response, phase response and impulse response for proposed VSAT model. Fig. 11 shows the magnitude response. Fig. 12 shows the phase response. Fig. 13 shows the impulse response.

4 Conclusion

The simulations are completed with ICARA (Induced Current Analysis of Reflector Antenna) software by the Antenna Group at the University of Virgo using physical optics (PO). Fig.3 shows the geometric of the prime focus VSAT antenna. The latter demonstration shows how the gain and efficiency from this geometry is analyzed with MATLAB. Path loss calculation for C band VSAT satellite is also presented. As a comparison, with the same aperture diameter and same downlink frequency, the previous research antenna design of VSATs in Karnataka, INDIA, is accomplished with gain 36.85dB and efficiency is 63%. In this paper, the preferred antenna design is well-organized with gain 37.98dB and efficiency of 78.76%. The paper has designated the various techniques complicated in the design of FIR filters. Every method has its own benefits and drawbacks. In windowing method, Kaiser Window is the greatest than any others windowing method.

Acknowledgment

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