Development Of Digital Band Pass Filter And Antenna Design For C Band Small Satellite Uplink Model

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

Abstract: The paper deals with band pass filter which is located between up converter and modulator of uplink model for C band small satellite communication system that work digitally. In this paper, FIR equiripple method is used.The selection of FIR equiripple filter depends on the nature of the problem and specifications of the desired frequency response. The main theme of designing a digital FIR filter is to provide the better settlement solution, to improve an efficiency of the desired signal of the system and to allow adjustment of the compromise between the over shoot reduction and transition region width for practical application of the small satellite uplink system. The realization structure of this filter with a specific and symmetric filter coefficient is analysed and the symmetric coefficients of the filter structure is that this filter is stable, it is also linear and it has a constant group delay. And then the magnitude response and phase response of this filter are analysed and the simulation results are also described using FDA tool that is one of the Computer Aided Design tool available with MATLAB which enables design of the digital filter blocks faster and more accurate.With the performance evaluation of the equiripple filter design, the output results are completely suitable for the proposed small satellite uplink model and so Equiripple filter design is found to be the most suitable and optimized method to meet the desired specification. The second part of the paper is to analyze the antenna deign analysis. A multiple-feed system or a beam former is used to generate several beams from this common aperture. This results in a geometry, which has the typical advantages of a spacecraft-borne antenna i.e. a high order of functionality with a compact and lightweight structure. In this paper, the single offset parabolic multi beam reflector antenna is designed and implemented. Basic geometries for MBA are designed and implemented. Reflector antenna radiation analysis method will be used in the design of MBA.

Index Terms: uplink model,small satellite, C-band, FIR equiripplebandpass digital filter, MATLAB, spacecraft antennas, multi-beam, ffset, reflector antenna.

1 INTRODUCTION

SMALL satellites are becoming increasingly popular due to their low cost, minimized volume, reduced design and advance time and then digital filters are the essential part of microwave satellite communications, modern wireless communications and electronic system because it can eliminate the harmful constituent from signal. FIR equiripple filters have developed as a strong option for removing noise, shaping spectrum and minimizing inter-symbol nosiness in satellite communication architectures.Communication satellites can be classified into seven main categories. They are large satellite>1000kg, medium satellite 500-1000kg, mini satellite 100-500kg, micro satellite 10-100kg, nano satellite 1-10kg, pico satellite 0.1-1kg and femto satellite <100g. Small satellite system remains the same of classical communication satellite and that are both efficient and accurate when applied to communication paths. Low power consumption and small size are required for small satellite which stays an international project sharing among IRAN, CHINA, THAILAND and numerous Asian countries. Small satellite's dimensions and mass does not differ from large ones, including practically the same functions. Classical satellites are large, expensive and process of their building lasts for many years and therefore small satellites are playing a very important role in the field of remote sensing, navigation and surveillance and it necessities the use of commercial off the shelf (COTS) elements so they can be used in a lot of applications such as earth observation, education, military applications, distance learning, telemedicine, universal access, disaster recovery and television transmission in many tropical regions.[5]The frequency band used in this system is C band because they are mainly used for numerous Asian countries. This paper is organized in the following sequence. Section II describes C band small satellite uplink model with its block diagram and classification of frequency band. Section III is about digital filter and FIR. Design calculation and filter parameters are presented in section IV. Simulation results exist in section V and the next section is followed by conclusion.

2 C Band Small Satellite Uplink Model

There are many types of band services in communication. Among them, C band services are essentially important for developing countries as the supporting element is inexpensive and the signal cover large area. Such services are well improved to provide data services and internet connectivity. They facilitate global communications and deliver a wide range of services in developing countries. C band is most popular because of less propagation problem. Rain attenuation and sky noise exists low for C band that resists snow effects and might have a maximum output power. The standard C band frequency for uplink model is 5.925 to 6.425 GHz and that of the downlink model is 3.7 to 4.2 GHz.[5]. The system illustration using in this paper is described in Fig.1. It has five main portions such as Encoder, IF Modulator, Bandpass filter, Up-converter and High Power Amplifier. The input baseband signal comes into in the encoder system and passes through the modulator trail. The output of the modulator is the input of the bandpass filter. The output of this filter is entered to the next stage, up-converter. And then the desired signal is caught to the last stage, high power amplifier. This stage passes on the desired input baseband signal to the antenna system. Finally, the antenna transmits the wanted signal to the transponder system through the space. In the small satellite uplink system, digital bandpass filter is utilized to remove unwanted signal because the preferred baseband signal contains the unwanted factor called interference or noise. So, such noise or interference is prohibited by using digital bandpass filter. The advantages of digital bandpass filter (BPF) are that it is convenient in designing small in size and low in insertion loss. So, it is commonly used in satellite communication services. [6]

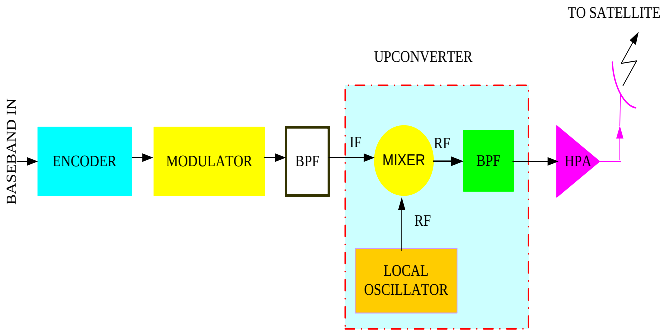

Fig.1. Block Diagram of C-Band Small Satellite Uplink System

3 Digital Filter

A filter is essentially a system or network that selectively changes the wave-shape, amplitude- frequency and phase-frequency characteristics of a signal in a desired satellite uplink model. The functions of filtering are; to improve the quality of a signal, to extract information from signal, to separate two or more signals previously combined.The requirements of filter design are that it should have specific phase shift or group delay, specific impulse response, specific frequency response, particular hardware or software and it should be stable and then the computational complexity of the filter should be low[1]. There are two types of filter and they are analog and digital filters. Digital filter is a mathematical algorithm implemented in hardware and software that operates on a digital input signal to produce a digital output signal.They are important class of Linear Time Invariant DSP systems designed to modify the frequency characteristics of the input signal to meet certain specific design requirements and have better signal to noise ratios than analog filter.[2] The advantages of digital filter are that it can have characteristics which are not possible with analog filters such as a truly linear phase response, the performance does not vary with environmental changes, the frequency response can be automatically adjusted if it is implemented using a programmable processor that use of adaptive filters, it can be used for filtering several input signals or channels without the need to replicate the hardware and are small in size, consume low power and less cost and it can be made to work over a wide range of frequencies.[3]Digital filters can be classified into Finite Impulse Response (FIR) and Infinite Impulse Response (IIR) filters. The selection of FIR or IIR digital filter depends on the nature of the problem and specifications of the desired frequency response.[7]

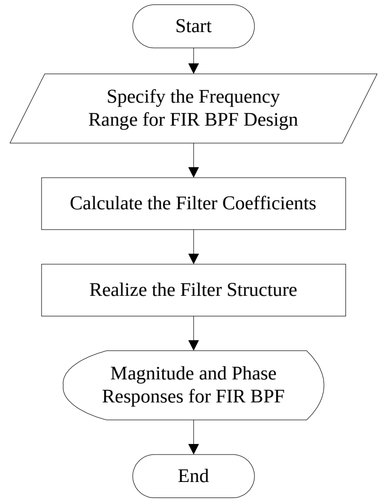

Fig.2. Steps in FIR filter design

FIR are particular useful for electronic applications where exact linear phase response is required. They are also known as non-recursive digital filters as they do not have the feedback even though recursive algorithms can be used for its realization and inherently stable. If thefilter coefficients are symmetrical, such a filter is linear phase. It is easier to design than IIR filters using different methods. The advantages of FIR filter are that the number of filter coefficients is not too large, little orno phase distortion is desired and digital signal processors are used. FIR filter design consistsof two parts such as approximation problem and realization problem. [8] There are essentially three well-known methods for FIR filter design: the window method, the frequency sampling method and optimal filter design method. All of the three methods, optimal filter design method is the best to find the optimal solution.The various optimal filter design methods are used to reject the interference containing the desired signal. They are least squared, equiripple, maximally flat, generalized equiripple and constrained band equiripple method. Among them, equiripple method is the most efficient way with minimum possible order and provides simplicity for designing a wide range of prototype filter bank. This technique have the advantages of high computational efficiency and suitable for hardware implementation aimed at the real time processing purpose. Using this method, maximun passband ripple and minimumstopband attenuation is attained. It has smaller peak error, smaller transitions width and smaller maximum deviation. In designing filters, it is usually desirable to have approximately frequency and magnitude using pass band and stop band. The design procedure for proposed filter is illustrated in Fig.2.[9]

4 Design Calculation

The required frequencies for calculating of FIR equiripplebandpass filter are passband frequency, passband ripple, stopband attenuation, sampling frequency and transition frequency. In this simulation, passband frequency, $F_p$is 70MHz-140MHz, passband ripple, A_p is 1dB, stopband attenuation, A_s is60dB, sampling frequency, F_s is 450MHz and transition frequency is 10MHz. From the above specifications, the filter has three bands: lower stopband (0-60MHz), a passband (70MHz-140MHz) and an upper stopband(150MHz-210MHz). According to the above frequencies, the three normalized bands are (0-0.133), (0.155-0.311) and (0.333-0.466).

Table I Filter Parameters

Parameter Name	Symbol	Value
Passband Frequency	Fp	70MHz-140MHz
Passband Ripple	Ap	1dB
Stopband Attenuation	As	60dB
Sampling Frequency	Fs	450MHz
Lower Stopband Frequency	Fs1	0-60MHz
Upper Stopband Frequency	Fs2	150MHz-210MHz

According to the above data,the deviation can be obtained from the given passband ripple and stopband attenuation.

Passband Ripple, A_p= 1 dB

A_p= 20log $(1+\delta_p)$

Passband Peak Deviation, δp= 0.2589

Stopband Attenuation, A_s= 60dB

A_s= $-20\log\delta_s$

Stopband Peak Deviation, δ_s= 0.464

The weights are dependent on the passband and stopband deviations. The ratio of δp to δs is 0.557 or 2:1.

$\delta_p/\ \delta_s$= stopband weight/passband weight =2:1

The filter length (N) is calculated by using the following equations.

$$N\approx\frac{C(\delta_p,\delta_s)}{\Delta F}+g(\delta_p,\delta_s)\Delta F+1 \quad (1)$$

Where,

$$C(\delta_p\ ,\ \delta_s)=\log_{10}\delta_s\ [\ b_1(\log_{10}\delta_p)^2+b_2\log_{10}\delta_p+\ b_3]$$
$$+[b_4(\log_{10}\delta_p)^2+b_5\log_{10}\delta_p+b_6 \quad (2)$$

And then,

$$g(\delta_p,\delta_s)=-14.6\ \log_{10}\left[{}^{\delta_p}/_{\delta_s}\right]-16.9 \quad (3)$$

b_1=0.01201; b_2=0.09664;
b_3=-0.51325; b_4=0.00203;
b_5=-0.5705; b_6=-0.44314;

The transfer function of FIR equiripplebandpass filter is defined as

$$H(z)=\sum_{k=0}^{N-1}h(k)z^{-k} \quad (4)$$

The output of the filter can be determined by using the following equation.

$$y(n)=\sum_{k=0}^{N-1}h(k)x(n-k) \quad (5)$$

The impulse response of the filter can be written as

$$h(n)=\frac{1}{N}\sum_{k=0}^{N-1}H(k)e^{j2\pi nk/N} \quad (6)$$

The impulse response (or) the inverse Z- transform of a transfer function H (Z) is

$$h(n)=z^{-1}[H(z)] \qquad n=0,1,2,3.... \quad (7)$$

$$H(z)=\frac{1}{1-z^{-1}} \quad (8)$$

$$H((z)=\frac{b_0+b_1z^{-1}+b_2z^{-2}+\ldots b_Nz^{-N}}{a_0+a_1z^{-1}+a_2z^{-2}+\ldots a_Mz^{-M}} \quad (9)$$

From the above equation,

b_0=1, a_0=1, a_1=-1;

Table II Filter Coefficients

h(0) =	0.0015 = h(89)	h(23) =	-0.0201 =h(66)
h(1) =	0.0021 = h(88)	h(24) =	-0.0201 = h(65)
h(2) =	0.0060 = h(87)	h(25) =	-0.0051 = h(64)
h(3) =	-0.0036 = h(86)	h(26) =	0.0219 = h(63)
h(4) =	-0.0120 = h(85)	h(27)	0.0055 = h(62)
h(5) =	0.0027 = h(84)	h(28) =	0.0010 = h(61)
h(6) =	0.0142 = h(83)	h(29) =	0.0107 = h(60)
h(7) =	0.0019 = h(82)	h(30) =	-0.0242 = h(59)
h(8) =	0.0077 = h(81)	h(31) =	-0.0291 = h(58)
h(9) =	-0.0005 =h(80)	h(32) =	0.0207 = h(57)
h(10) =	0.0040 = h(79)	h(33) =	0.0167 = h(56)
h(11) =	-0.0037 = h(78)	h(34) =	0.0023 = h(55)
h(12) =	0.0107 = h(77)	h(35) =	0.0328 = h(54)
h(13) =	0.0069 = h(76)	h(36) =	-0.0123 = h(53)
h(14) =	-0.0059 = h(75)	h(37) =	-0.0709 = h(52)
h(15) =	0.0009 = h(74)	h(38) =	0.0001 = h(51)
h(16) =	-0.0038 = h(73)	h(39) =	0.0324 = h(50)
h(17) =	-0.0114 = h(72)	h(40) =	0.0044 = h(49)
h(18) =	0.0069 = h(71)	h(41) =	0.8837 = h(48)
h(19) =	0.0152 = h(70)	h(42) =	0.0699 = h(47)
h(20) =	-0.0021 = h(69)	h(43) =	-0.2141 = h(46)
h(21) =	-0.0005 = h(68)	h(44) =	0.1796 = h(45)
h(22) =	-0.0001 =h(67)		

The value of the impulse response h (n),

$$h(n)={}^{1}/_{a_0}\left[b_n-\sum_{i=1}^{n}h(n-i)a_i\right] \qquad , n=1,2,3,\ \ldots \quad (10)$$

Where, $h(0)={}^{b_0}/_{a_0}$

From the calculation results,
Filter length or filter coefficients, N = 90
Filter structure,Direct form FIR Type (II)
Filter weight, 2, 1, 2

Filter order, 90
Number of stages, 89
Input sample,90

Edge frequencies, 0.133, 0.155, 0.311, 0.333 and 0.46

From the above table, the filters coefficients are described. They are symmetric and so this filter is stable and it is also linear. The filter order is 90 which are the same of the filter coefficients.

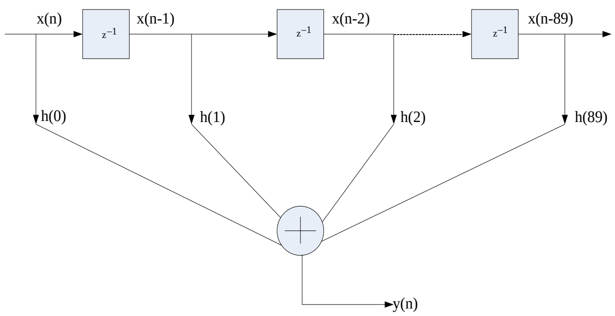

Fig.3. Block diagram of FIR Equiripple Transversal Structure or Direct Form Type (II)

There are three realization structures for FIR filters such as transversal structure or direct form, frequency sampling structure and fast convolution structure. The most widely used for FIR is the direct form or transversal structure because it is particularly simple to implement and this block diagram is shown in Fig.3.

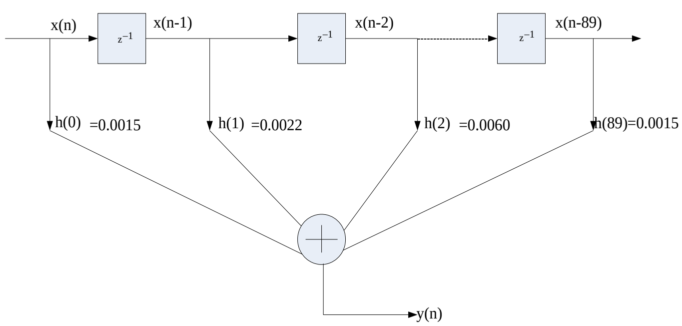

Fig.4. Block diagram of FIR Equiripple Transversal Structure or Direct Form Type (II) with symmetric filter coefficients

From the above filter coefficients, the realization structure of the FIR filter is drawn in Fig.4. It involves converting a given transfer function H (z), into a suitable filter. The magnitude response of equiripple band pass filter used in normalized frequency is shown in Fig.5.

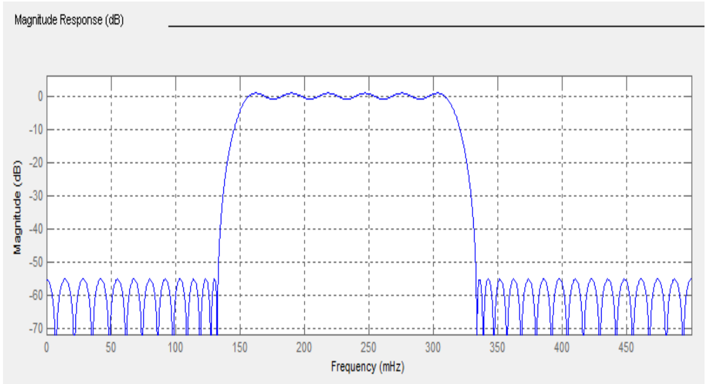

Fig.5. Magnitude Response of Equiripple Bandpass Filter used in normalized frequency

5 Simulation Results

Simulated results applying MATLAB software are displayed in the following figures.The magnitude response of FIR equiripplebandpass filter is shown in Fig.6

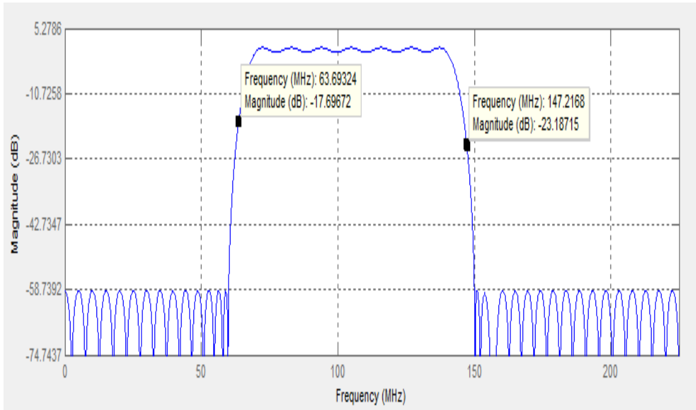

Fig.6. Magnitude Response forFIREquiripple Method

The IF modulator frequency usedfor small satellite uplink system is 70MHz to 1GH. In this simulation, the passband frequency is 70MHz to 140MHz so the maximum frequency is 140MHz and the sampling frequency is at least twice of the maximum frequency. The larger the sampling frequency, the smaller the Gibbs or ripple between the passband range. The first stopband frequency is 60MHz and that of the end is 150MHz. The first passband frequency is 70MHZ and that of the second is 140MHz. The attenuation in the first and second stopband is 60dB.The amount of ripple allowed in the passband is 1dB.The transition width between the passband and stopband is 10MHz. The filter order is minimize because equiripple filter design produces the desired signal consists of less error with minimum possible order. From the simulation results, it is minimum ripple and so the desired signal contains less distortion and the result is upright using this method.The phase response applying FIR equiripple filter method is shown in Fig.7. In this figure, getting the smooth slope line between the passband ranges is the best result. If it has symmetric coefficients, it is also linear, it has a constant group delay and vise vasa.

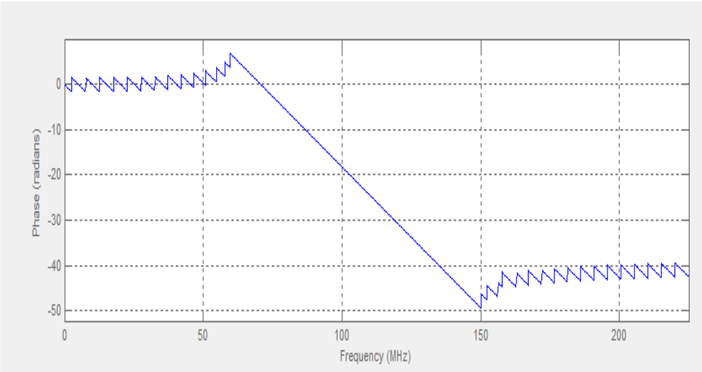

Fig.7. Phase Response for FIR Equiripple Method

When the transfer function has a zero on the unit circle in the z-plane, its phase response displays a jump discontinuity at the corresponding frequency.If there are no jump discontinuities, and there are no zeros on the unit circle. The filter has group delay and it is dependent on the number coefficients of the filter and it is a very close approximation to a constant in the passband which means that it must have symmetric coefficients and it is linear phase.

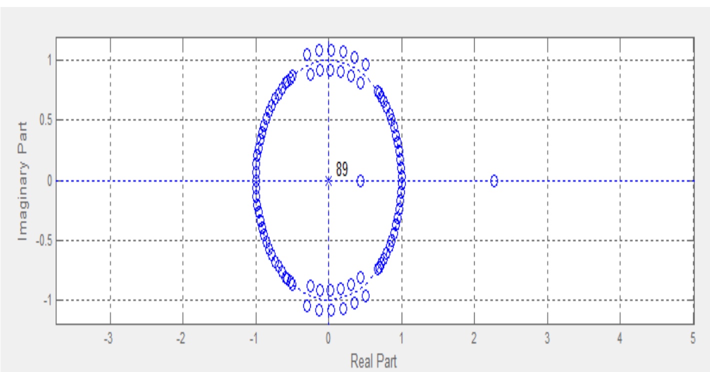

Fig.8. Pole Zero Response for FIR Equiripple Method

The group delay is the average delay of the filter as a function of frequency that is reduced by half while the phase response remains in the region of linear in the passband. The normalized frequency is displayed in X-axis and the continuous phase is presented in Y-axis.The transfer function can be expressed as its poles-zeros location and it can infer the frequency response of the system and its degree of stability. For a stable system, all the poles must lie inside the unit circle. In FIR system design, the impulse response is required to implement the system. It may be viewed as the response of a discrete time systemto a unit sample which has a value of 1 at n=0 and a value of 0 at all other values of n. It is because the system input is equal to the unit impulse and the system output is equal to the system's impulse response

5 Design Calculation of Antenna

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.

5.1 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]

5.2 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.

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

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

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

Focal distance (focal length),

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

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

Effective area, $A_e= \eta A_p$ (5)

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

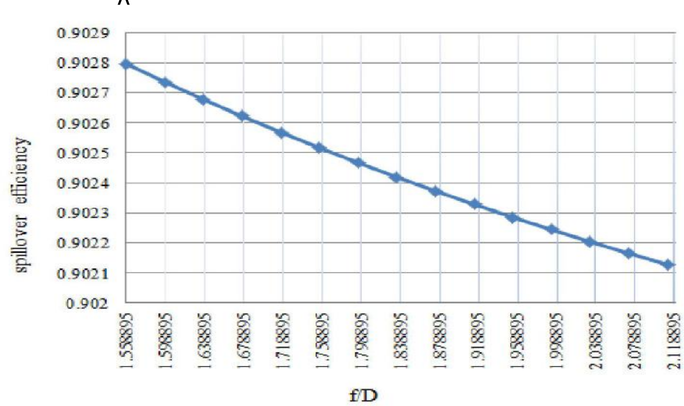

Fig.9. Spillover Efficiency vs f/D

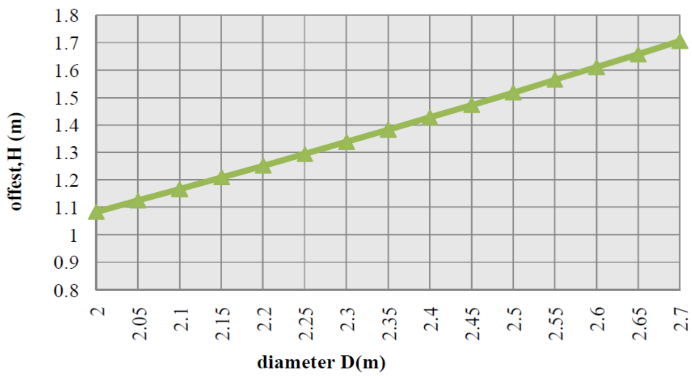

Fig.10. Offset vs Diameter (m)

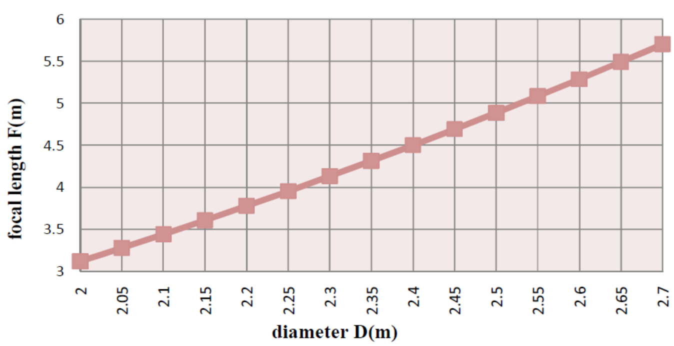

Fig.11. Focal Length vs f/D

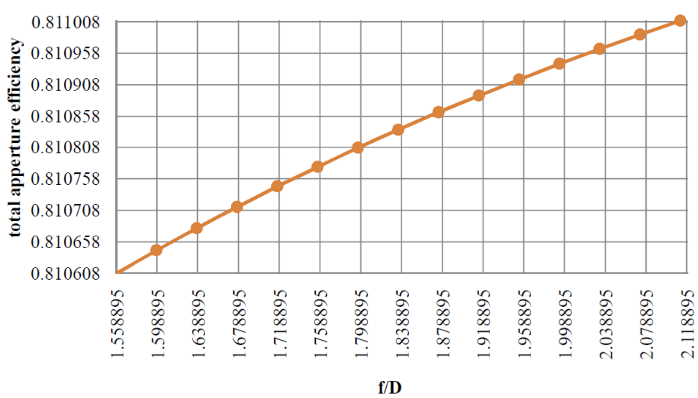

Fig.12. Total Aperature Efficiency vs f/D

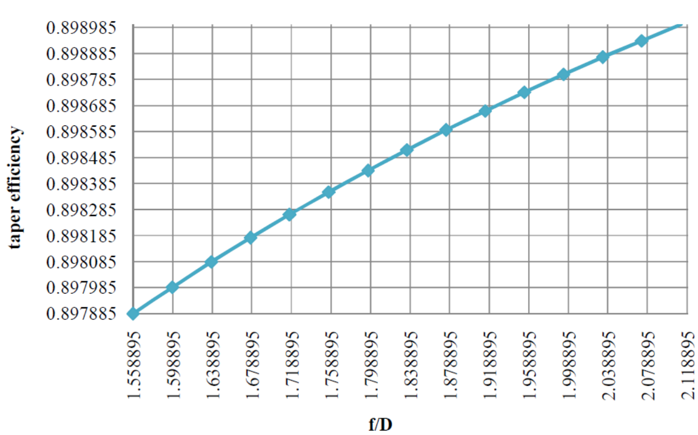

Fig.13. Taper Efficiency vs f/D

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

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

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

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

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

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

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

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

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

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

$$\text{Link path loss} = 32.4+20\log R+20\log f$$

After designing the appropriate antenna design, we got the simulation results on antenna design analysis. Fig 9 shows the spillover efficiency vs f/D. Fig.10 demonstrates the Offset vs Diameter (m). Fig.11 illustrates the Focal Length vs f/D. Fig.12 mentions the Total Aperature Efficiency vs f/D and Fig.13 gives the Taper Efficiency vs f/D.

6 Conclusion

The design of FIR filters for this uplink model is developed in this paper. In windowing method, Kaiser Window is the greater than any other windowing methods. But when Kaiser Window is compared with optimal filter design method, equiripple filter design is found to be the most suitable and optimized method to meet given requirement. Equiripple filters have the smallest maximum deviancy when compared to all other linear-phase FIR filters of the same order. They are well-matched for applications in which a specific tolerance must be met. They have maximumstopband attenuation or minimum passband ripple. They have smaller peak error and smaller transitions width, and smaller maximum deviationThis filter design method is suited for electronic communication applications and the best result is acquired by using it that compared with other design techniques and it allows adjustment of the compromise between the overshoot reduction and transition region width spreading.The performance of FIR equipplebandpass filter used in satellite transmitting earth station is well-designed with FDA tool and Signal Processing (SP) tool in MATLAB. We also described the design analysis on single offset configuration for multibeam applications. The numerical analyses are also developed to meet the required specification of real world antenna design.

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REFERENCES
[1] Magdy T. Hanna,"Design of Linear Phase FIR Filters with MaximallyFlat Passband", IEEE Trans. Circuits Syst. II, 1996.

[2] Keshab.K.Parhi, VLSI Digital Signal Processing Systems Design and Implementation. A Wiley-Interscience Publication,1999

[3] J.G. Proakis, D.G. Manolakis,"Digital Signal processing Principles", Algorithms and Applications New Delhi: Prentice-Hall, 2000.

[4] Arojitroychaudhary,"FIR filter design tech." M.Tech. credit seminar report,Electronicn Systems Group, EE Dept, IIT Bombay, submitted November2002

[5] F. Bernelli-Zazzera, A. ErcoliFinzi, M. Molina, and M. Cattaneo,"In-orbit technology validation for a university microsatellite", inProc. 4th IAA Symp. Small Satell. Earth Observ., Berlin, Germany, 2003

[6] T. Vladimirova and M. Sweeting, "System-on-a-chip development for small satellite onboard data handling", J. Aerosp.Comput., Inform. Commun., vol. 1, no. 1, pp. 36–43, 2004.

[7] Shanthala S, S.Y.Kulkarni"High Speed and Low Power FPGA Implementation of FIR Filter for DSP Applications, "European Journal of Scientific Research, ISSN 1450-216X Vol.31 No.1 (2009), pp. 19-28.

[8] Prof. GopalS.Gawande, "Performance analysis of FIR Digital Filter Design Techniques", International Journal of Computing and Corporate Research, Vol. 2, Issue 1 January 2012.

[9] T. Pratt, C. Bostian ,J.Allnutt, "Satellite Communication" John Wiley and Sons, 2nd Edition