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Design of Low Pass Fir Interpolator for Wireless Communication Application

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Abstract: The purpose of this paper is to design the Interpolator for WLAN 802.11n applications. The design of interpolator is based on Low Pass FIR filter. FIR filter show linear and stable performance if compare to the IIR filter. Equiripple technique and Kaiser Window are used here for the design simulation purpose which is done by using Matlab. The performance has been compared in the terms of stop band ripples, RMS EVM and PSD. It is concluded from the simulation results that Kaiser Window show better results when less transition width is required and Equiripple technique gives reduced amount of stop band ripples. The result also shows that performance of all the designs can be changed when filter order is increased.

Keywords: Equiripple technique, IEEE802.11n, Interpolator, Kaiser Window, Low Pass Filter, MATLAB, MIMO, OFDM.

I. INTRODUCTION

Multirate systems have earned popularity since 1980s and they are commonly used for communications systems, audio & video processing and also for transform analysis. In most of the applications multirate systems are used so as to improve the performance, or for the increased computational efficiency. Multirate signal processing refers to systems that allow sequences arising from different sampling rates that are to be processed together [1]. These days' IEEE 802.11 Wi-Fi standard based wireless network deployments, continue to increase rapidly. Started as single access point solution or simply called "hot spot", the 802.11 standard evolved dramatically, reaching speeds which are higher than those of wired Ethernet and also providing better infrastructure for those of crowded enterprise sites and organizations. To enhance 802.11for higher throughput operation, IEEE 802.11n amendment was created. Not only the new Physical Layer enhancements are standardized, but a new Medium Access Control (MAC) Layer mechanism is also defined [2]. Antenna arrays pay an important role and have been demonstrated as a very promising technique for the high-speed wireless networks, and are scheduled to be the indispensable Components in future wireless communication systems [3]. IEEE 802.11n is built by using multiple inputs multiple outputs (MIMO) technology, for physical layer has 40MHz channels and for that of the MAC layer frame aggregation. The MIMO design enables IEEE 802.11n to communicate in the presence from approximate 54 Mbps of high-power cross-technology interference [4]. For this the digital transmission has arisen more challenging. Orthogonal Frequency Division Multiplexing or simply "OFDM" is the most promising modulation technique [5]. Due to this reason, it is preferred by most of the wireless and wired communication standards.

The simple idea behind this is to use a number of carriers, which are spread in regular manner over a frequency band, in such a manner so as the available bandwidth (BW), is utilized to maximal efficiency. The transmission of bits is done in a fixed time period or interval, which is restricted by the bandwidth for a particular application. These days, the fingerprint-based approach for the positioning in WLAN has been drawing a great attention. However, this approach usually requires great time and efforts to collect the location fingerprints for those of the target areas [6].To meet the requirements of area and low power, various interpolator architectures have been designed. When the signal has to be up sampled without any aliasing effect for the transmission purpose, Interpolator plays an important. So these days, designing the best interpolator is a great challenge. Also the design constraints for interpolator circuits involves deep understanding of the tradeoffs and the complexity for linear-phase FIR filters that are dominated by the complexity of the coefficient multipliers. A novel linear-phase FIR interpolation and decimation and utilization of the Farrow structure with a very small distinct fractional delay. Therefore the interpolation or decimation structures can be only implemented by using one set of linear-phase FIR sub filters and also with one set of multipliers that correspond to distinct small delays i.e. fractional delays.

II. IEEE 802.11n WLAN

With the ratification of the IEEE 802.11n standard, new and latest technologies are used so as to increase the performance, capacity and coverage. To the client side, smart phones, laptops and other devices are there to be used in different or variety of applications. IEEE 802.11 is a set of standards for the wireless networking transmission

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methods. In the 802.11n WLAN, to enhancing data rata, high-order modulation like 64QAM followed by a 5/6 coding rate is used. Since the performance of high-order modulation can be affected by some non-linear Distortions, interpolations and decimations with the linear phase, high speed and small-ripple are required here to perform the rate of sampling conversions to the analog &digital interface [7].

802.11a/b/g and ac these are some other common versions or other standards that are commonly used today to provide wireless connectivity, shown in table.1 [8].

TABLE I

	IEEE 802.11a	IEEE 802.11b	IEEE 802.11g	IEEE 802.11n
Frequency Band (GHz)	5.7	2.4	2.4	2.4/5
Average Theoretical Speed (Mbps)	54	11	54	600
Modulation	OFDM	CCK Modulation with QPSK	DSSS,CCK, OFDM	OFDM
Channel Bandwidth (MHz)	20	20	20	20/40
Coverage Radius (m)	35	38	38	75
Device Cost	Medium -Low	Low	Low	Medium
Security	Medium	Medium	Medium	High

Low Pass Filter
A low-pass filter is a type of filter that passes signals with frequency lower than a certain defined cutoff frequency and attenuates signals with frequencies higher than that of the cutoff frequency. The amount of attenuation done by the filter for each frequency is dependent on the filter design. The LPF is sometimes termed as a high-cut filter, or a treble cut filter in audio applications.

A low-pass filter or LPF is the opposite of a high-pass filter or HPF. A band-pass filter is combined form of a low-pass and a high-pass filter. In the microwave communication systems, low-pass filters (LPF) are often an important component. Low Pass filtering is also useful in EEG Systems [9]. Power gain is shown in decibels (i.e., a 3 dB decline reflects an additional half-power attenuation). Angular frequency is shown on a logarithmic scale in units of radians per second.

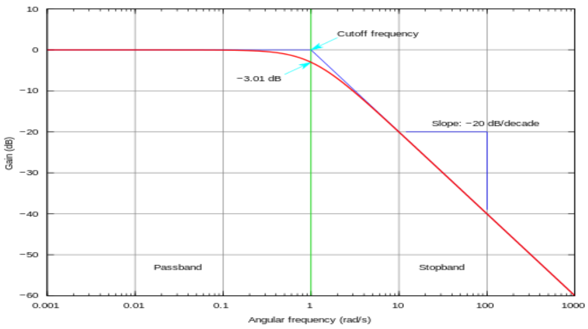

Fig.1 The gain-magnitude frequency response of a first-order (one-pole) low-pass filter

FIR Filter
FIR filter is Finite-impulse-response (FIR) filters can be built that approximate to sinc function for time-domain response of any ideal sharp-cutoff low-pass filter. In general, the time-domain response should be time truncated and is often in a simplified shape; in the simplest case, running average can be used, giving a square time response implementation for FIR filters is easy, but this is slower as compared to the IIR filters. Though IIR (Infinite Impulse Response) filters are generally our first choice because of the ease in design as well as the stability. By designing the filter taps that to be symmetrical about center tap position, the FIR filter can be guaranteed to have a linear phase [10]. When thehre is requirement of particular frequency response, different design methods are common for the designing of the FIR Filter.

1. Window design method
2. Frequency Sampling method
3. Weighted least squares design
4. Parks-McClellan method
5. Equiripple Technique

Here the designing is accomplished by using Equirriple method and Kaiser Window.

Equiripple Technique
Equiripple filter, as indicated by the name, has equal ripples in the pass band & stop band, this means the signal distortion that happens due to presence of a large ripple at the edge of the pass band is avoided in the Equiripple design but, the Equiripple design has a large transition band, thus this limiting the total pass band width.

Kaiser Window
The width of main lobe and attenuation of the side lobes depends only on length M, i.e., length of the window. The Kaiser window allows a separate control of width of the main lobe and attenuation of the side-lobe [18]. The simple approximation of the window by using Bessel functions, which is discovered by Jim Kaiser, can be given by the formula:

$$\omega_k(n) = \begin{pmatrix} \dfrac{I_0\left[\pi\alpha\sqrt{1-\left[\dfrac{2n}{N-1}\right]^2}\right]}{I_0(\pi\alpha)} & \text{for} \lfloor n \rfloor \le \dfrac{N-1}{2} \\ 0 & \text{otherwise} \end{pmatrix} \qquad (1)$$

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$$\propto = \begin{cases} 0 & ; \beta \le 21 \\ 0.5842(\beta - 21)^{0.4} + 0.07886(\beta - 1); & 21 < \beta \le 50 \\ 0.1102(\beta - 8.7) & ; \beta > 50 \end{cases}$$

Where I_0 is the zero order modified Bessel functions

Interpolator

In simple words, the process of up sampling together with or followed by filtering is the interpolation. (The filtering is to remove the undesired spectral images). Not to be confused, it is linear process, interpolation used here is different from that of the "math" sense of interpolation, but conceptually on the other side, the result is somehow similar or same as to create "in-between" samples from that of original samples. An interpolation factor is simply the ratio of output rate to that of input rate. It is generally symbolized by letter "L".

$$L = \text{Output rate/ input rate} \qquad (2)$$

Also a Decimator or simply digital down convertor (DDC) is an important part for SDR based 3G or 4G baseband receivers. Its main work is to shift the spectrum of interest from its intermediate frequency i.e. carrier frequency to the baseband [12]. Interpolations and Decimations with small ripple, linear phase and high speed are required to perform the sampling rate conversions at the (A/D) analog-digital interface [13]. In up-sampling L must only be an integer; it can't be a fractional part this is due to the fact that interpolation relies only on zero-stuffing. Interpolation factor L with an integer can be explained as a two-step process, with an equivalent implementation that is more efficient as compared. A sequence is created, xL (n) which contains the original samples, x (n) is separated by $L - 1$ zeros. The discontinuities are smooth out with a low pass filter (LPF) which then replaces the zeros. Here the filter is called as an interpolation filter. The interpolation filter is chosen as FIR type, this is due to the reason that its efficiency can be improved as here the zeros contribute nothing to its dot product calculations. FIR Filter can be designed or structured easily so as to keep it in linear-phase. Linear-phase filters put simply some delay to the input signal but do not disturb its phase. Also the FIR filters are simple and easy to implement. On most of the DSP microprocessors, the FIR calculation be done easily by simply putting in loop a single instruction. The FIR filters are more suitable for Multi-rate application [14].The calculation performed by an interpolating Finite Impulse Response (FIR) filter for every output sample is a dot product (scalar product). FIR Digital filters find its great applications in mobile communication systems to the functions like channelization, pulse shaping, channel equalization, and matched filtering due to the property of linear-phase and absolute stability [15].

$$y[j + nL] = \sum_{k=0}^{K} x[n - K].h[j + kL], \qquad (3)$$

Where j=0, 1… L-1
Where the h [•] sequence is impulse response, and K is the greatest value of k for which h [j + kL] is non-zero. Hence the interpolation (or decimation) structures can be implemented only by using one set of linear-phase FIR sub-Filters and also one set of multipliers that correspond the distinct small fractional delays [16]. The process is more efficient if the decimation or interpolation occurs in number of stages rather than in single step [17]. Block diagram of up sampler is shown in fig.1.

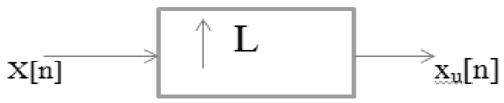

Fig.1 UP Sampler [18]

III. SIMULATIONS AND RESULTS

The magnitude response, Impulse response, Pole Zero plot, RMS EVM, PSD curves of the Low pass FIR filter using Kaiser Window and Equiripple technique are shown from fig.2 to fig. For filter order N = 38 and 66.

Equiripple FIR Interpolator

Order of the Interpolator, N=38

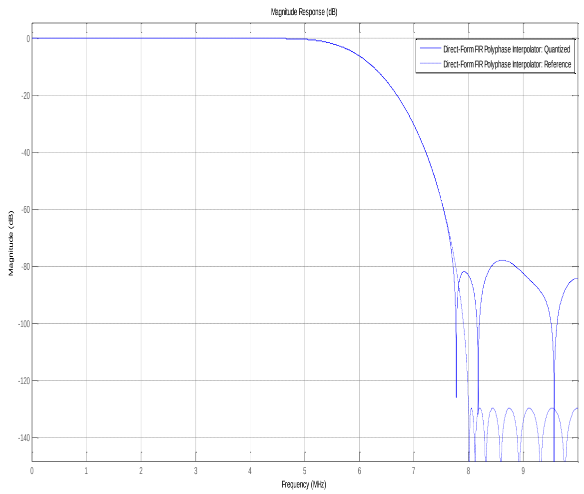

Fig.3 Magnitude Response

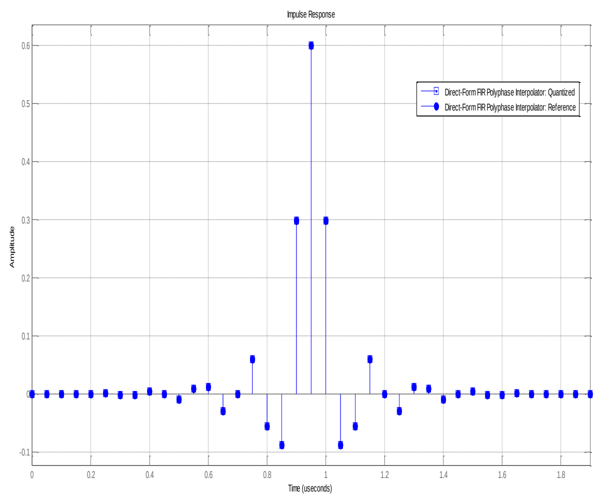

Fig.4 Impulse Response

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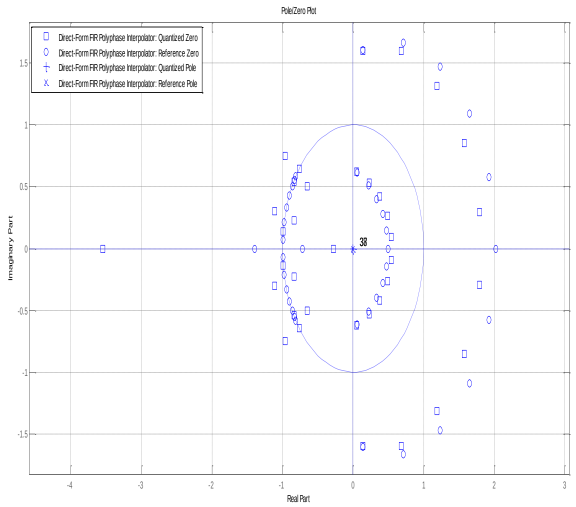

Fig.5 Pole Zero Plot

Order of the Interpolator N=66

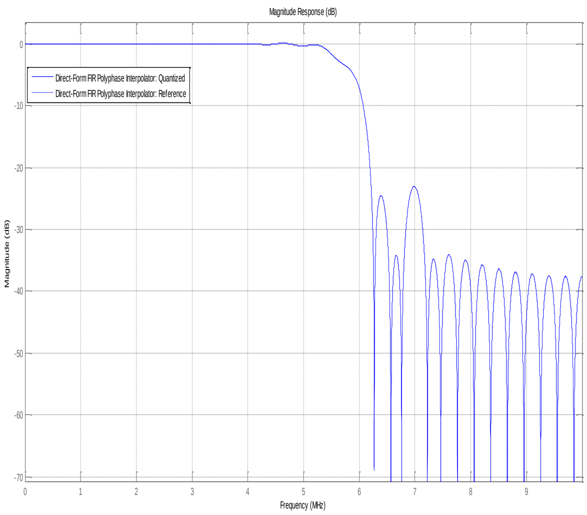

Fig.6 Magnitude Response

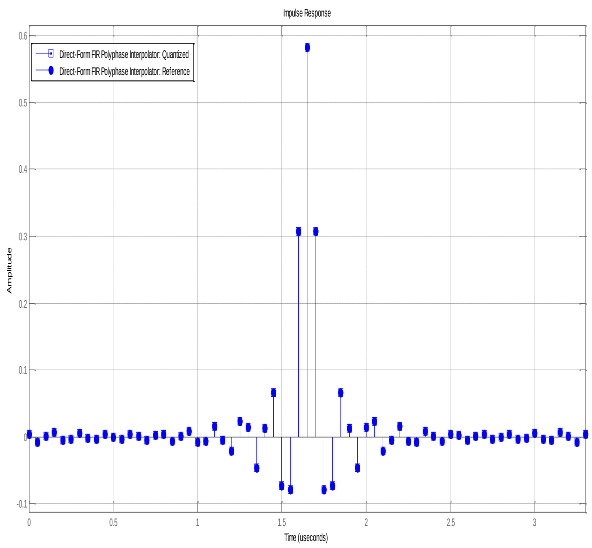

Fig.7 Impulse Response

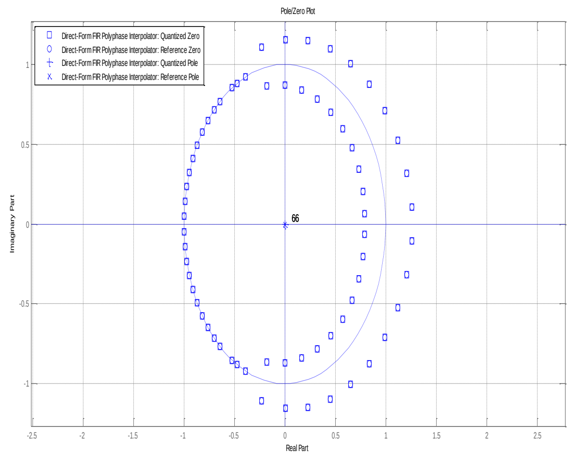

Fig.8 Pole Zero Plot

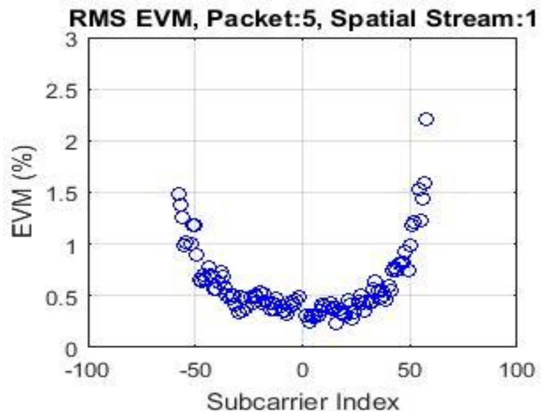

Fig.9 RMS EVM of 1st Spatial Stream

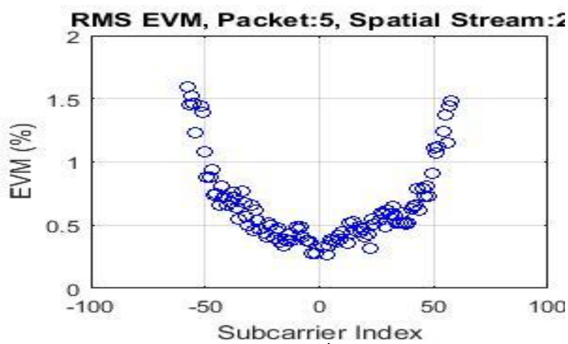

Fig.10 RMS EVM of 2nd Spatial Stream

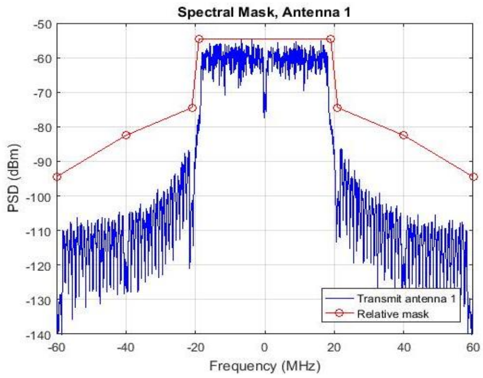

Fig.11 PSD Curve of antenna 1

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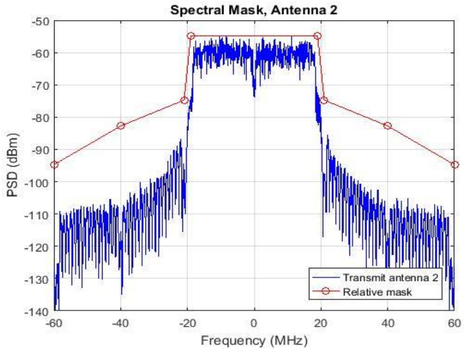

Fig.12 PSD Curve of antenna 2

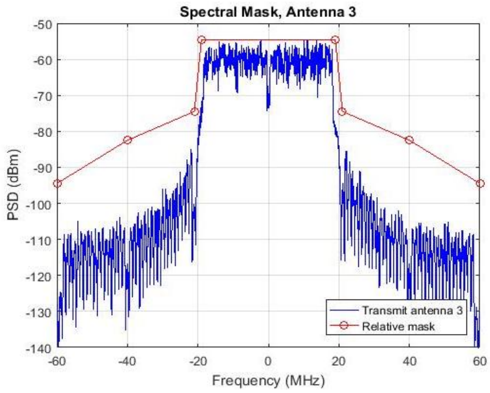

Fig.13 PSD Curve of antenna 3

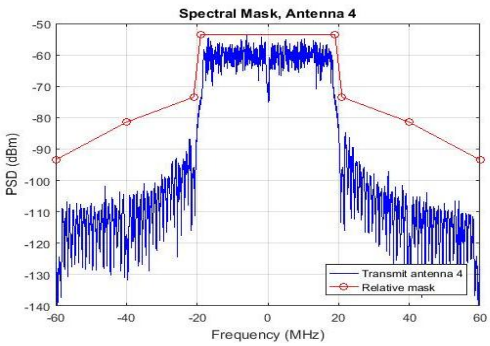

Fig.14 PSD Curve of antenna 4

Kaiser Window based Interpolator

Order of the Interpolator, N=38

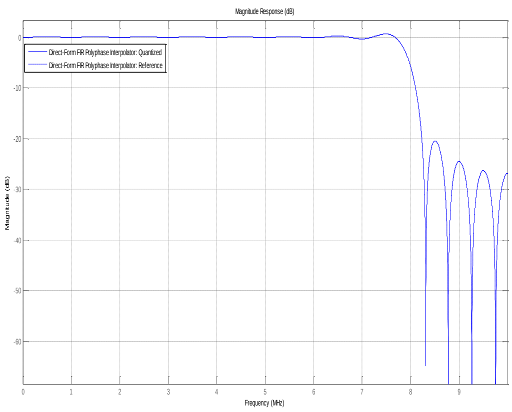

Fig.15 Magnitude Response

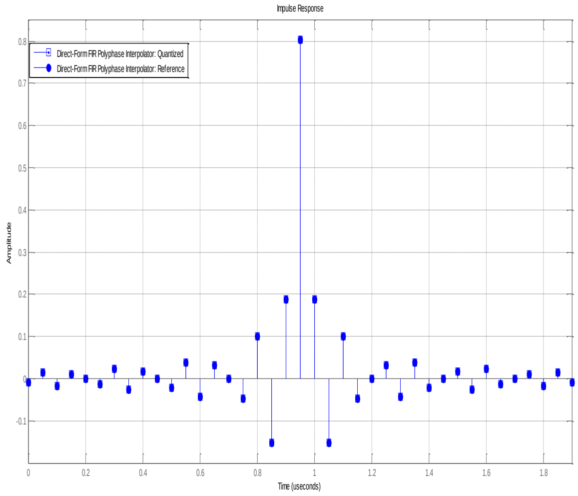

Fig.16 Impulse Response

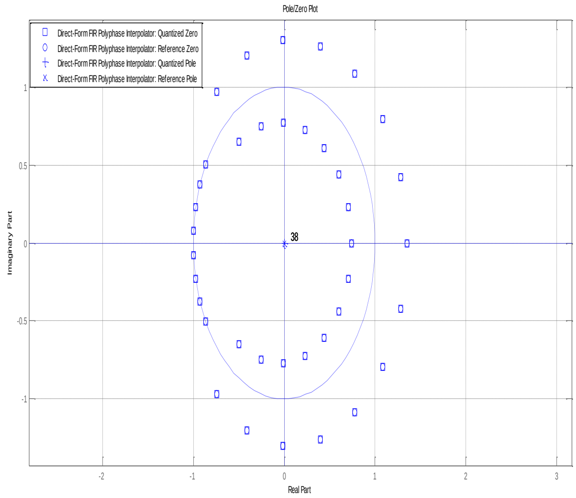

Fig.17 Pole Zero Plot

Order of the Interpolator N=66

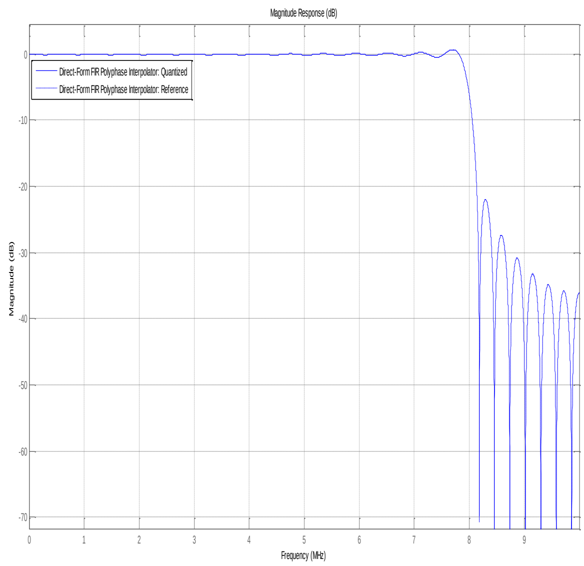

Fig.18 Magnitude Response

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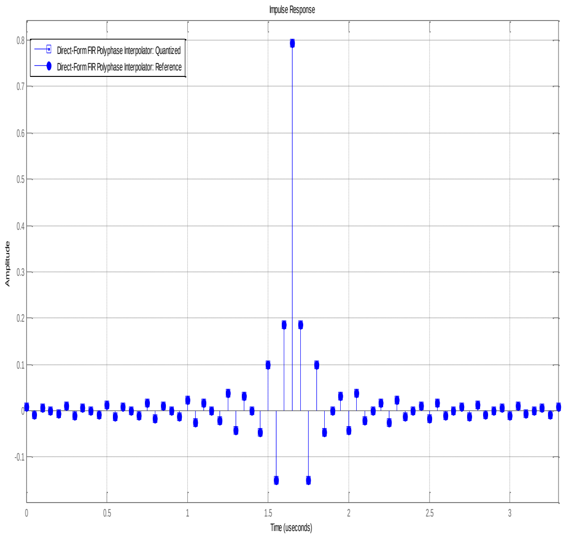

Fig.19 Impulse Response

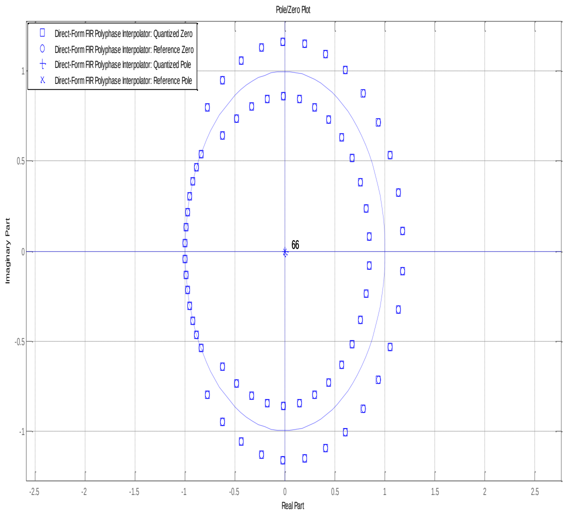

Fig.20 Pole Zero Plot

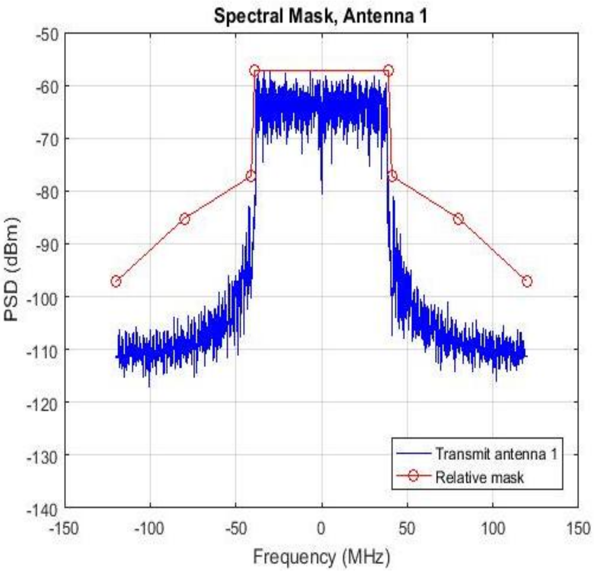

Fig.21 PSD Curve of antenna 1

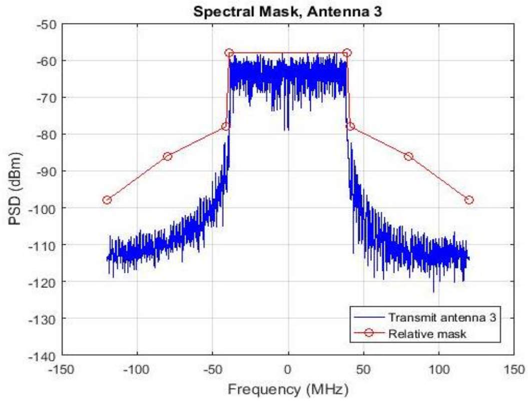

Fig.22 PSD Curve of antenna 3

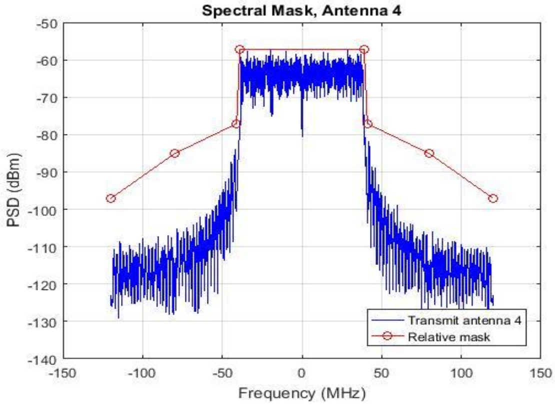

Fig.23 PSD Curve of antenna 4

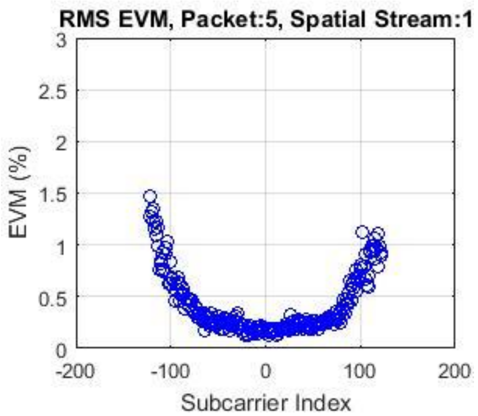

Fig.24 RMS EVM of 1st Spatial Stream

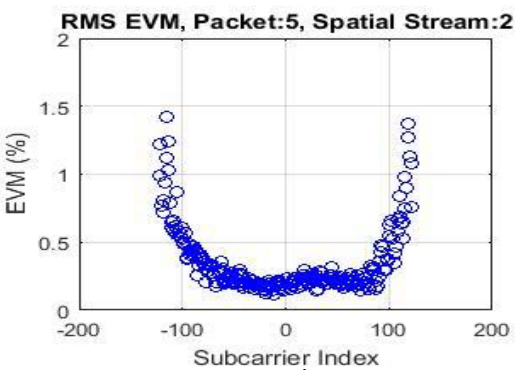

Fig.25 RMS EVM of 2nd Spatial Stream

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IV. RESULT ANALYSIS

Comparison of different techniques in terms of FIR filter parameters with different order is observed from the different magnitude response, impulse response and pole zero plot of the FIR Interpolator is shown in table.2.

Table2. Comparison of different Techniques

Order of Interpolator	Technique Used	Transition Width (MHz)	Stop Band Ripple (dB)
N=38	Equiripple	2.092	-77.88
	Kaiser Window	0.964	-20.45
N=66	Equiripple	.875	-23.04
	Kaiser Window	.435	-21.99

Four transmitting antennas with two spatial streams are used with five packets for WLAN applications. Power Spectral Density (PSD) of each packet, Root Mean Square Error Vector Magnitude (RMS EVM), is also getting calculated for both Equiripple and Kaiser Techniques, as shown in table.3 and table.4.

Table.3. PSD Comparison

Technique Used	Antenna	PSD (dBm)
Equiripple	1st	-55
	2nd	-54
	3rd	-52
	4th	-51
Kaiser Window	1st	-56
	2nd	-57
	3rd	-58
	4th	-59

Table.4. Different Spatial Stream Comparison

Technique Used	Spatial Stream	RMS EVM (%)
Equipripple	Ist	0.7
	2nd	0.8
Kaiser Window	Ist	0.3
	2nd	0.4

V. CONCLUSION

Interpolator based on FIR Band Pass Filter using Kaiser Window and Equiripple technique is designed here. Kaiser Window technique shows improved transition width in comparison to equiripple technique and Equiripple technique shows better stop band ripples in comparison to Kaiser window for the order of N=66. PSD of Kaiser window based interpolator is -59dBm within the bandwidth range of -50 MHz to 50 Mhz. RMS EVM is also reduced resulted as 0.4 % in Kaiser Window and 0.8% in Equiripple technique. Also it is concluded from the results that the pass band ripples are increasing with the increase in order of the filter.

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BIOGRAPHIES

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