Inter-carrier Interference Mitigation in OFDM System Using a New Pulse Shaping Approach

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Abstract—In this paper, we suggest a new pulse shaping method namely scale alpha for orthogonal frequency-division multiplexing (OFDM) system. The proposed pulse shape is designed and simulated using Matlab software. Results and discussions are made to analyze the performance of the new pulse shape, particularly regarding two parameters that are inter-carrier interference (ICI) power reduction, and eye diagrams. It is shown that the new pulse is better in ICI power reduction performance than Franks, raised cosine, and double-jump pulses.

Keyword-OFDM, pulse shaping, scale alpha, Nyquist pulse, ICI

I. INTRODUCTION

The orthogonal frequency-division multiplexing (OFDM) technology is used by many latest communication services. It is especially suitable for high-speed and wide bandwidth wireless data transmission [1]. OFDM technology can conquer the frequency selected fading and inter-carrier interference (ICI) effectively, so it is the core technology in the future mobile communications. Further, OFDM has recently been applied widely in wireless communication systems owing to its high data rate transmission capability with high bandwidth efficiency and its robustness to multi-path fading and delay [2, 3]. It is a bandwidth efficient signalling scheme where the orthogonality among the subcarriers should be maintained to a high degree of precision [4]. The spectra of the sub-carriers are overlapping, and accurate frequency synchronization technique is needed. However, due to oscillator inaccuracies and non-ideal receiver synchronization, the orthogonality of subcarriers is compromised resulting in ICI which degrades the performance of OFDM system significantly. A special problem in OFDM is it vulnerability to frequency offset errors which limits the orthogonal property that resulting in ICI. ICI causes power leakage among subcarriers thus degrading the system performance. The mobility of the transmission results in loss of orthogonality among subcarriers which translates into ICI. ICI creates an off diagonal channel matrix which is not desired as it affect the accuracy of channel estimation and equalization. To solve this problem, some methods such as complexity reduction and the use of the basis expansion model (BEM) have been considered. However, a direct method would be the elimination of ICI through the use of pulse shaping to reduce out-of-band emissions and the sensitivity to interference and synchronization errors. Therefore, it is important to suggest a new transmit and receive pulse that is almost eigenfunctions of the channel and thus approximately diagonalizable the channel.

According to prior studies, there are some factors that cause ICI in OFDM system, the first one is due to time variations of the channel which leads to a loss of sub-channel orthogonality then results in ICI [5]. Local oscillator frequency mismatch between transmitter and receiver is also another factor that causes ICI. Another factor was, results show that when the carrier frequency offset exists, and there will be a leakage between subcarriers which results in ICI. However, in a Doppler spread channel, the channel time variation will limit the orthogonality among subcarriers leading to ICI which degrades the system's performance. Real world scenarios suffer from residual frequency offset, oscillator phase noise and Doppler spread causing ICI among subcarriers. The target in our approach is to design a pulse shaping filter that is better impulse response in both time and frequency domains than another pulses. One of the main advantages of OFDM is its ability to convert a frequency selective fading channel into several nearly flat fading channels [6]. Nevertheless, one of the main disadvantages of OFDM is it sensitivity against carrier frequency offset which causes attenuation and rotation of subcarriers, and ICI [7, 8]. The performance of OFDM system can be made better by using efficient pulse shaping techniques. If Nyquist filters that are better than raised cosine filters can be designed, robustness to noise and inter-symbol interference (ISI) distortions can be improved as well as the bit-error rate (BER) performance in data communications systems [9]. In this paper, ICI reduction using pulse shaping has been considered in detail. The remainder of this paper is organized as follows. Section II introduces the OFDM system model. Describing different pulse shaping functions including the proposed scale alpha pulse have been mentioned in Section III. Section IV shows the simulation results and discussions. Finally, Section V concludes the paper.

II. SYSTEM MODEL

Fig. 1 shows the structure of a typical OFDM communication system. In this system, quadrature phase shift keying (QPSK), quadrature amplitude modulation (16-QAM), and 64-QAM constellations may be utilized to map binary information. The high-speed serial data stream is split up into a set of low-speed sub streams and modulated onto the orthogonal carriers through inverse fast Fourier transform (IFFT). Signal x(t) which is represented in (1) is transmitted through the channel with various pulse shaping functions. The complex envelope of one radio frequency (RF) N-subcarrier OFDM symbol with pulse-shaping is expressed in (1) [2],

$$x(t) = \exp(j2\pi f_c t) \sum_{k=0}^{N-1} a_k\, p(t) \exp(j2\pi f_k t) \tag{1}$$

Where f_c is the carrier frequency, $f_k$is the kth subcarrier frequency, N is the number of subcarriers, $p(t)$ is the pulse shaping function, and $a_k(k = 0,1, \ldots, N-1)$is the data symbol transmitted on the kth subcarrier.

The data symbols are assumed to have zero mean and normalized average energy. They are also assumed to be uncorrelated and satisfy [10].

$$E[a_k a_m^*] = \begin{cases}1\\0\end{cases} f(x) = \begin{cases}-x, & k = m\\ \ \ x, & k \neq m\end{cases} \tag{2}$$

Where a_m^* is the complex conjugate of a_m ensure the subcarrier orthogonality, which is very important for OFDM systems the equation below has to be satisfied,

$$f_k\text{-}f_m = \frac{k-m}{T} \tag{3}$$

Where $\frac{1}{T}$ is the minimum subcarrier frequency spacing required to satisfy orthogonality between subcarriers. Hence, at the receiver the signal is expressed as

$$r'(t) = x(t) \otimes h(t) + n(t) \tag{4}$$

Where $n(t)$is the additive white Gaussian noise process with zero mean and variance $\frac{N_0}{2}$ per dimension and $\otimes$ denotes convolution, and $h(t)$is the channel impulse response. In this work, we assume that the channel is ideal, i.e., h(t)=∂(t) in order to investigate the effect of the frequency offset only on the ICI performance, where $\partial(t)$ is the same with $h(t)$ to shows the ideality. Doppler spread introduces a frequency offset $\Delta f \geq 0$.Then the signal received after multiplication by the carrier frequency $(f_c + \Delta f)$ is given by

$$r(t) = \exp\,(j2\pi\Delta f t)\sum_{k=0}^{N-1} a_k\, p(t) \exp(j2\pi f_k t) + n(t) \exp[j2\pi(-f_c + \Delta f)t] \tag{5}$$

Where $n(t)$is the additive white Gaussian noise.

Finally, the output of the mth subchannel correlation demodulator gives the decision variable for the transmitted symbol

$$a_m = a_m P(-\Delta f) + \sum_{\substack{k=0\\k\neq m}}^{N-1} a_k p\left(\frac{m-k}{T} - \Delta f\right) + n(m) \tag{6}$$

The first term contains the desired signal component, whereas the second term is the ICI. The ICI power depends on the number of subcarriers and the spectral magnitudes of the pulse shaping functions.The power of the desired signal can be calculated as

$$\sigma(m)^2 = E[a_m P(-\Delta f) a_m^* P(-\Delta f)^*] = E[a_m a_m^*]|P(\Delta f)|^2 = |P(\Delta f)|^2 \tag{7}$$

Then, the power of the ICI can be stated as

$$\sigma(ici)^2 = \sum_{k=0}^{N-1}\sum_{n=0}^{N-1}[a_n\, a_k^*][P\left(\frac{k-m}{T} + \Delta f\right) \times P\left(\frac{k-m}{T} + \Delta f\right)] \tag{8}$$

The average ICI power across different sequences can be calculated as

$$\sigma(ici)^2 = E[\sigma[ici))^2] = \sum_{\substack{k=0\\k\neq m}}^{N-1} \left|P(\frac{k-m}{T} + \Delta f)\right|^2 \tag{9}$$

As seen in (9) the average ICI power depends on the number of the subcarriers and $P(f)$ at frequencies $\left(\left(k - \frac{m}{T}\right) + \Delta f\right), k \neq m$. By using (7) and (9), the signal-to-interference ratio (SIR) can be defined as

$$\text{SIR} = \frac{|P(\Delta f)|^2}{\sum_{\substack{k=0\\k\neq m}}^{N-1} \left|P(\frac{k-m}{T} + \Delta f)\right|^2} \tag{10}$$

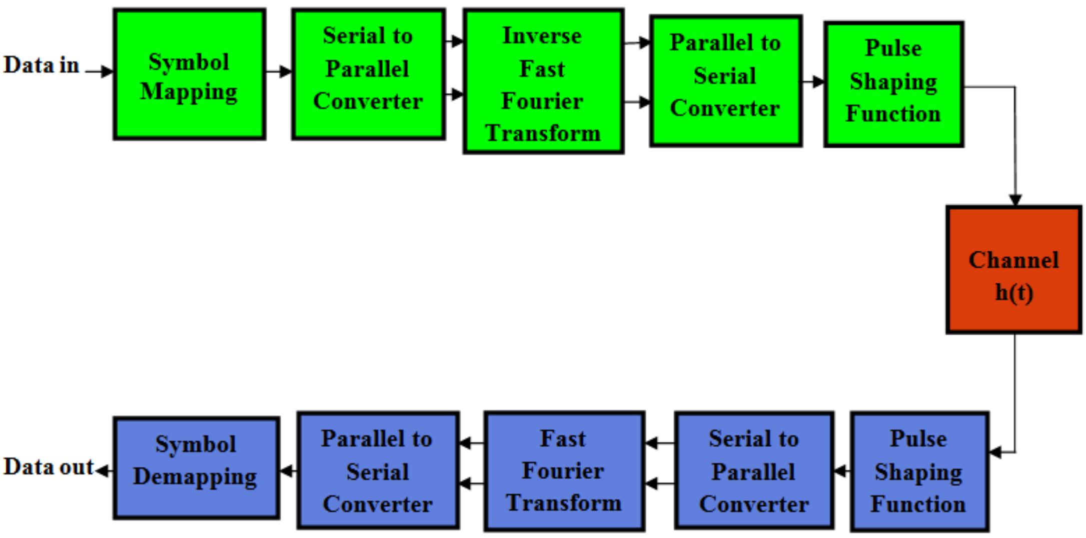


Fig. 1. Simulation block diagram of OFDM system.

III. PULSE SHAPING FUNCTION

Each carrier in the OFDM spectrum is represented by main lobe with a number of side lobes having lower amplitudes. Since peak power is associated with main lobe and ICI power is associated with side lobes, so the motive of pulse shaping function is to increase the width of main lobe and reduce the amplitude of sidelobes. Proper pulse shaping techniques makes a digital communication system possible to transmit data within a limited BW with minimum ISI [11]. OFDM remains a chosen modulation scheme for upcoming broadband radio area systems because of its inherent flexibility in power loading across the subcarriers and concerning adaptive modulation [12].

Here, we consider a double-jump pulse $p_{dj}(t)$, a raised cosine pulse $p_{rc}(t)$, a Franks pulse, $p_f(t)$ and scale alpha pulse, $p(t)_{s-\alpha}$. $P_{dj}(f)$, $P_{rc}(f)$, and $P_f(f)$are the Fourier transform of $p_{dj}(t)$,$p_{rc}(t)$, and $p_f(t)$, respectively. They are given as [13]

$$p_{dj}(f)=\text{sinc}(fT_u)\cos(\pi\alpha fT_u) \tag{11}$$

where,

$$\text{Sinc}(x)=\begin{cases} 1, & x=0 \\ \frac{\sin(\pi x)}{\pi x}, & x\neq 0 \end{cases} \tag{12}$$

$$p_{rc}(f)=\text{sinc}(fT_u)\frac{\cos(\pi\alpha t T_u)}{1-(2\alpha t T_u)^2} \tag{13}$$

$$p_f(f) = \text{sinc}(fT_u)[(1-\alpha)\cos(\pi\alpha fT_u + \alpha sinc(\alpha fT_u)] \tag{14}$$

where T_u is the time spacing and α is the roll-off factor ($0 \leq \alpha \geq 1$).

The time domain equation of the new scale alpha pulse can be written as:

$$p_{s-a}(t) = \text{phi} \times \text{Cos}\theta_p \times \text{Sinc}\theta_p \tag{15}$$

where,

$$\text{Phi} = (1-(t/2s)^2)\exp(-(t/2s)^2)/2 \tag{16}$$

$$\text{Cos}\theta_p = \frac{Cos\,(\alpha\pi t)}{1-(2\alpha t)^2} \tag{17}$$

$$\text{Sinc}\theta_p = \frac{Sin\pi t}{\pi t} \tag{18}$$

θ_p is the phase theta, and s is the number of scale.

By inserting (16), (17), and (18) into (15), (15) can be rewritten as:

$$p(t)_{s-\alpha} = \{(1-(t/2s)^2)\exp(-(t/2s)^2)/2\} \times \{\frac{Sin(\pi t)Cos(\alpha\pi t)}{\pi t - 2\pi\alpha t^2}\} \quad (19)$$

Note that there are two brackets in (19) where the first one called phi.

IV. Simulation Results and Discussions

Fig. 2 below depicts the graph for phi and the time domain for new pulse against time when *s*=2. It can be seen that the new pulse for alpha, α= 0.25 has bigger side lobes compared to new pulse when α= 0.5.

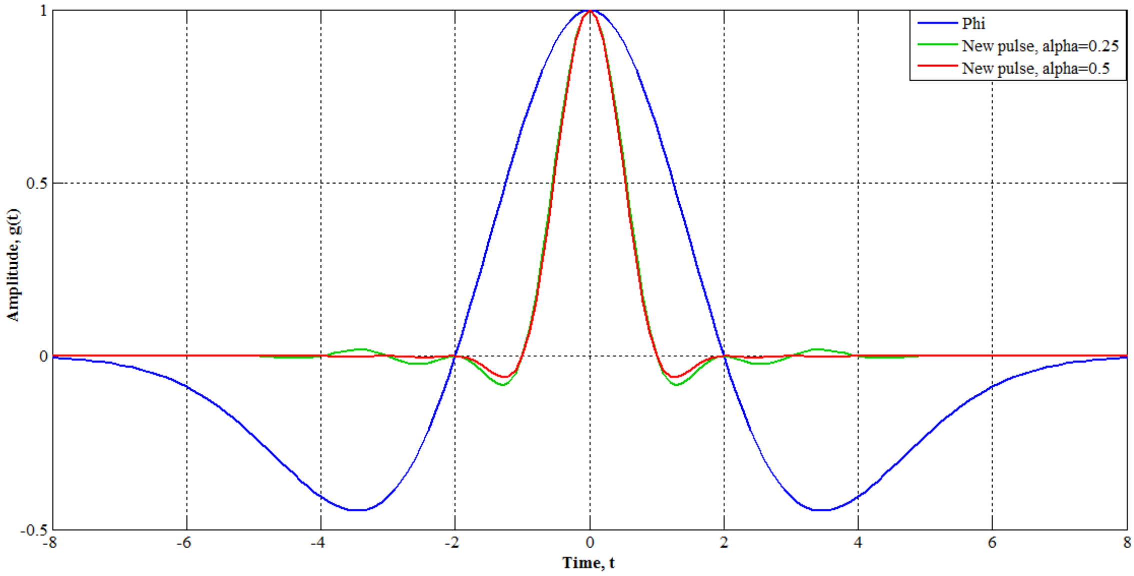


Fig. 2. Phi, and the new pulse against time.

Fig. 3 and Fig. 4 show the graph of impulse response for α = 0.25 in time and frequency domains, respectively. Fig. 3 compares the impulse response for different pulse shapes considered in this work, such as double-jump, raised cosine, Franks pulse, and new scale alpha pulse when α = 0.25. It is observed that the new scale alpha pulse shape has lesser side lobes amplitude compared to other existing pulses. So, our proposed scale alpha pulse shape has a reduced ICI power in comparison with other pulse shapes as the side lobes contain the ICI power. Fig. 5 and Fig. 6 show the impulse response for α = 0.5 in time and frequency domains, respectively. It can be clearly seen that when α increased from 0.25 to 0.5, the side lobes have lower amplitudes for all pulses under investigation, which results in better system performance in terms of ICI reduction.

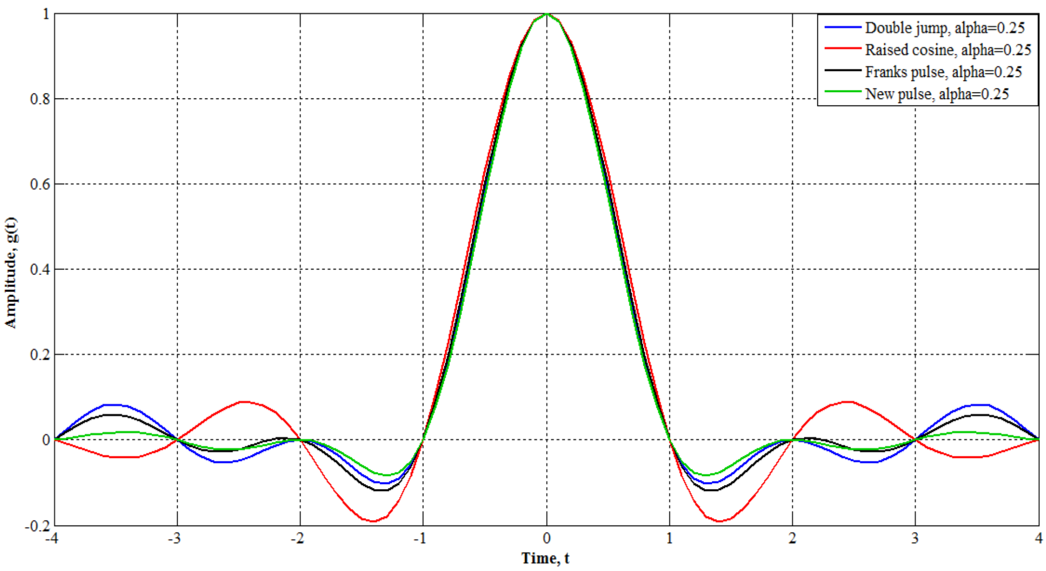


Fig. 3. Impulse response in time domain when α = 0.25.

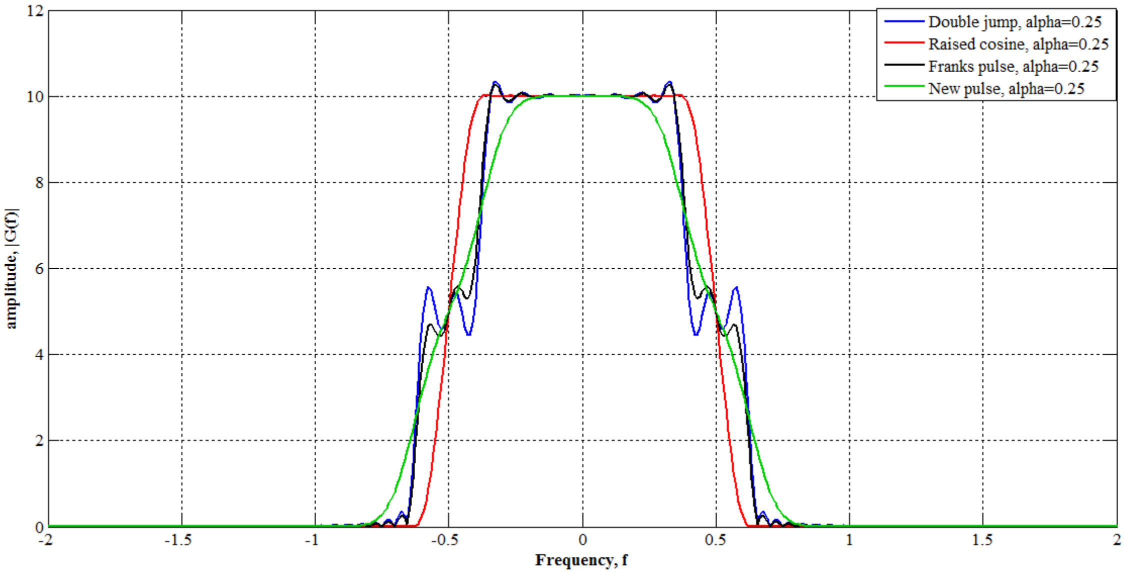


Fig. 4. Impulse response in frequency domain when α = 0.25.

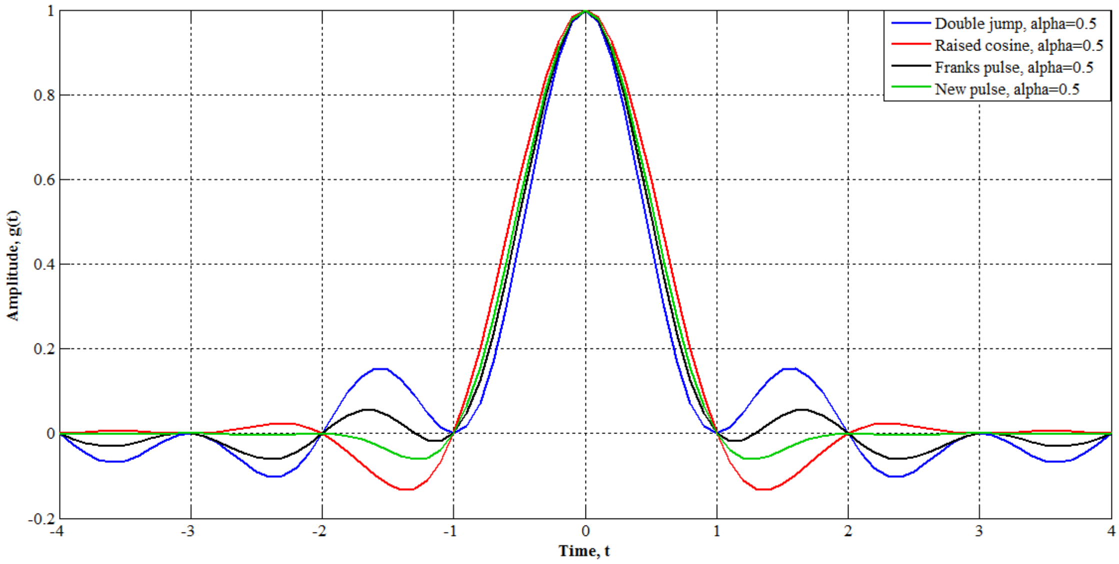


Fig. 5. Comparison of impulse response in time domain for all pulses when α = 0.5.

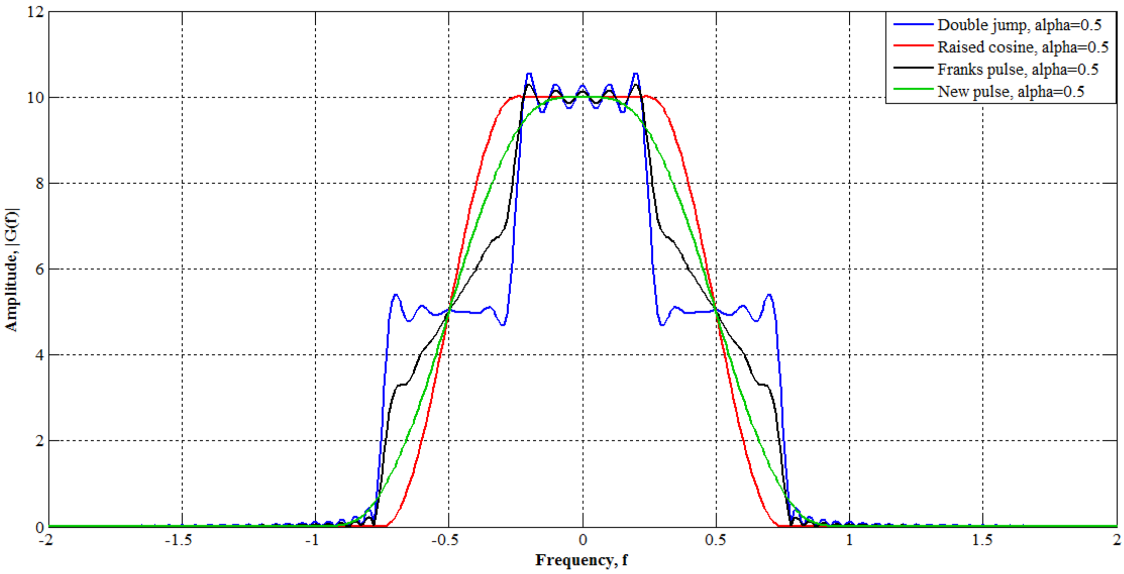
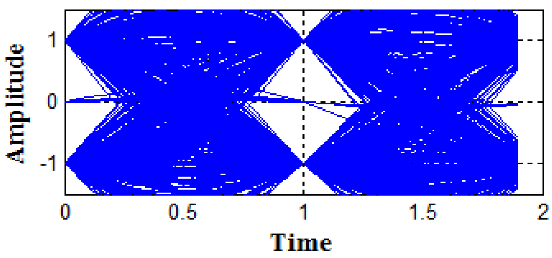
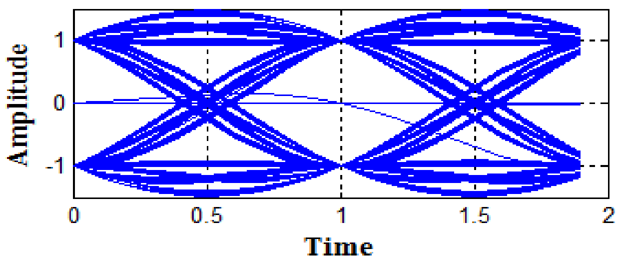


Fig. 6. Comparison of impulse response in frequency domain for all pulses when α = 0.5.

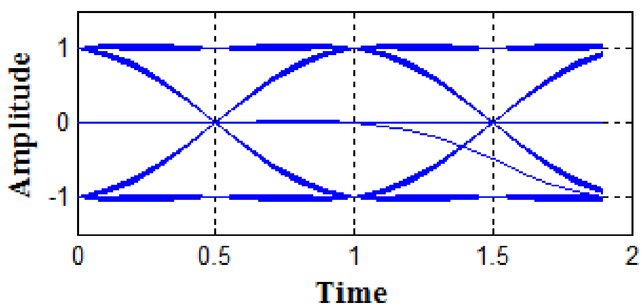
Fig. 7 shows the eye diagrams with various alpha from 0.25 to 1, so as we can see the eye diagram that have less noise is when alpha, α=1, so it means as alpha, α increase from 0.25 until 1, the noise also decrease. Fig. 8 shows the eye diagram for Franks pulse, as we can see the eye opener for Franks pulse is lower compared to new pulse. So it means that eye diagram for new pulse is better compared to Franks pulse in term of eye diagram.



(a)



(b)



(c)

Fig. 7. Eye diagram for various alpha,$\alpha$for new pulse (a) eye diagram for α=0.25, (b)ye diagram for α =0.5, (c) eye diagram for α=1.

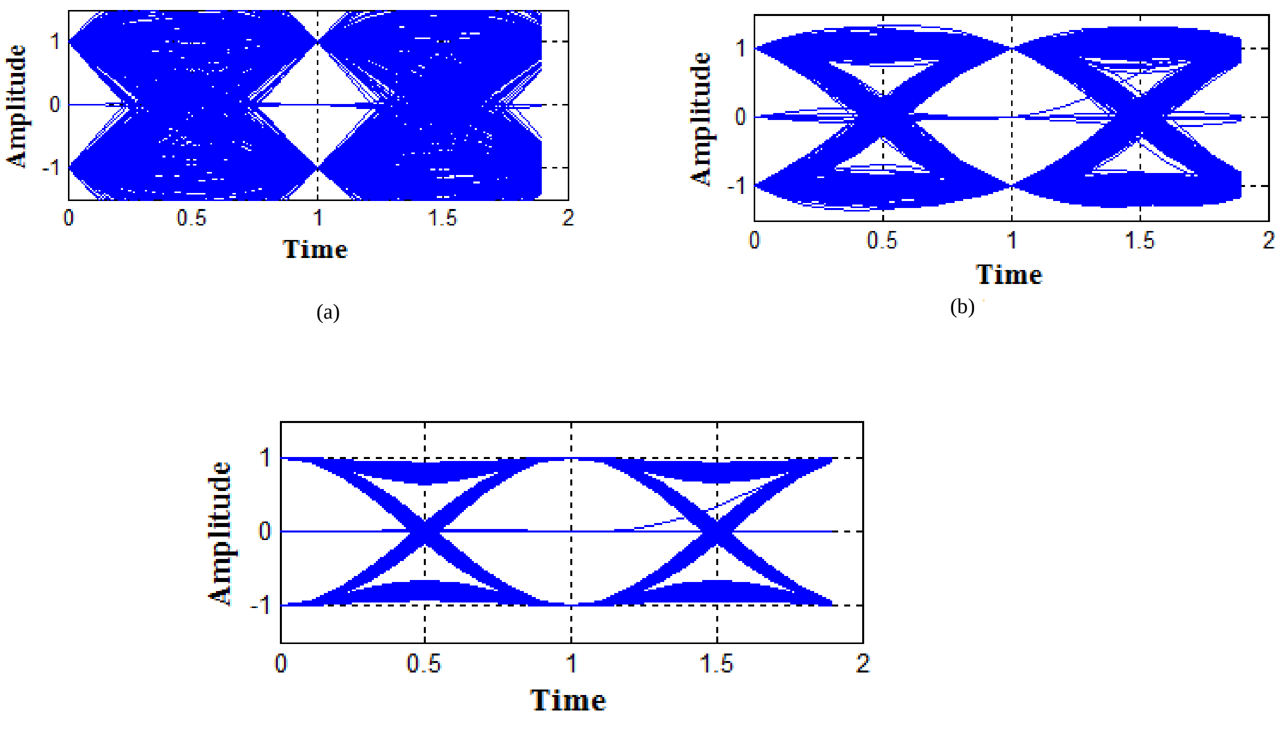


Fig. 8. Eye diagram for various alpha,$\alpha$for Franks pulsea) eye diagram for α=0.25, (b) eye diagram for α =0.5, (c) eye diagram for α=1.

Fig. 9 illustrates the comparison of without and with pulse shaping for Franks pulse and new pulse. For Franks pulse with pulse shaping, when the x-axis is 0.01, the value of ICI in y-axis is 1.994 × 10^{-8}dB. While the new pulse crosses lower ICI value of 1.095 × 10^{-15}dB at the same carrier frequency offset value. Whereas, for without pulse shaping, the value of y-axis for ICI was 1.114× 10^{-7} dB when carrier frequency offset is 0.01. This situation demonstrates that the ICI power is alleviated by 6.69% using our proposed pulse in comparison with Franks pulse.

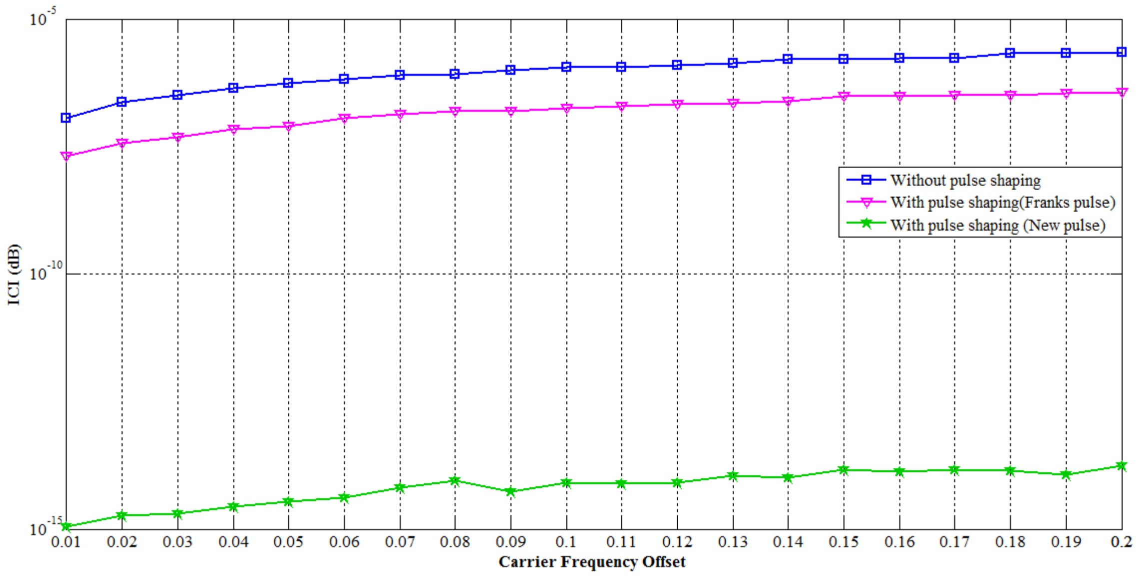


Fig. 9. Comparison of without and with pulse shaping using Franks and the newly proposed pulse.

V. CONCLUSIONS

In this work, simulation results have been presented to compare different shaping methods in OFDM system. It can be observed that our proposed scale alpha pulse has lesser side lobes amplitude compared to double-jump, raised cosine, and Franks shaping pulses. Further, the eye diagrams of the new scale alpha pulse show less noise when we increase the value of alpha from 0.25 to 1. Moreover, the new pulse achieves 6.69 % reduction of ICI power in comparison with Franks pulse.

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