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Intercarrier Interference of Various Pulse Shaping Functions Used in OFDM Systems with Carrier Frequency Offset

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***Abstract*- For orthogonal frequency-division multiplexing (OFDM) communication systems, the frequency offsets in mobile radio channels distort the orthogonality between subcarriers resulting in intercarrier interference (ICI). This paper is focused on the problem of reducing the intercarrier-interference (ICI), signal to noise ratio and improved performance in the transmission over OFDM using various pulse shaping methods. Here we have performed a detailed performance comparison of various pulse shaping functions used in OFDM Communication Systems with Carrier Frequency Offset. They appear to be suitable for transmission in OFDM systems with carrier frequency offset. The results obtained by analysis show that the performance improvement over conventional pulse shapes, are significant for reducing average intercarrier-interference (ICI) power and increased ratio of average signal power to average ICI power (SIR). BER performance comparison of all pulse shapes in OFDM system showing better performance by Improved sinc power pulse**

***Keywords*- OFDM; ICI; SIR; ISI;BER;SNR; Pulse shaping; Carrier frequency offset**

I. INTRODUCTION

The ORTHOGONAL Frequency Division Multiplexing (OFDM) is a bandwidth efficient signaling scheme where the orthogonality among the subcarriers should be maintained to a high degree of precision. Since the spectra of the sub-carriers are overlapping, an accurate frequency Synchronization technique is needed. Recently, orthogonal frequency division multiplexing (OFDM) has received considerable attention due to the need of high speed data transmission and been accepted as standard in several wire line and wireless applications [1]. One of the main advantages of OFDM is its ability to convert a frequency selective fading channel into several nearly flat fading channels[1].however, one of the main disadvantages of OFDM is its sensitivity against carrier frequency offset which causes attenuation and rotation of subcarriers, and intercarrier interference (ICI) [2,3]. The undesired ICI degrades the performance which is examined in [4]. Several methods have been presented to reduce ICI, including self-cancellation schemes [5], frequency domain equalization [6], windowing at the receiver [7-9], a number of methods have been developed to reduce the inter-carrier interference. New pulse shaping techniques have been introduced recently [1, 2, 4, 5, 6, 7, 8, and 9]. In this orthogonal frequency-division multiplexing (OFDM) is sensitive to carrier frequency offset which introduces intercarrier interference (ICI) in OFDM receivers. Frequency offset can be compensated by frequency offset estimation. However, estimation error is inevitable, and residue frequency offset usually exists in OFDM systems. Therefore, it is of interest to investigate schemes that are robust to frequency offset. ICI reduction techniques using coding were studied in References [11–14]. Transmitter pulse shaping can also realize ICI power reduction. As classified [15], three types of pulse shaping have been examined in the literature for ICI reduction. The first type, pulses of infinite time duration, was studied in References [16–21]. References [16–18] considered band-limited Nyquist pulses in multichannel data transmission systems. The pulse is chosen as g (t) = F-1{√G (f)} where G (f) is a band-limited Nyquist filter with roll-off factor 'a' and F−1 {·} denotes the inverse

Fourier transform. Other infinite duration pulses were designed in References [19–21] under the framework of the Weyl–Heisenberg system of functions. The second type comprises pulses of finite duration with length longer than one OFDM symbol interval. These pulses were developed for an OFDM system employing QAM in an AWGN environment based on an optimization criterion which maximizes the in-band energy under the constraint of zero inter-symbol interference (ISI) and ICI [15]. The third category also consists of pulses of finite duration. But different from the second category, the pulses have specified length of one OFDM symbol interval. These pulses are usually chosen as Nyquist pulses in the time domain, that is G(t). In this regard, Reference [22] used a raised-cosine pulse in their time-limited orthogonal multicarrier modulation schemes.

A. *Pulse Shaping Functions*

1. Rectangle Pulse

$$p_r(t) = \sin c(tT)$$

2. Raised Cosine Pulse

$$p_{rc}(t) = \frac{\sin c(tT)\cos(\pi atT)}{(1-(2atT)^2)}$$

3. Better Than Raised Cosine Pulse

$$p_{btrc}(t) = e^{(-a(tT)^2)} \sin c^n(\pi tT)$$

4. Square Root Raised Cosine Pulse

$$p_{srrc}(t) = \sin c(tT)((\frac{4a}{\pi\sqrt{t}}\cos((1+a)\frac{\pi t}{T})) + \frac{(\frac{T}{4at})\sin((1-a)\frac{\pi a}{T})}{(1-(\frac{4at}{T})^2)})$$

5. Polynomial Pulse

$$p_{poly}(t) = \sin c(tT)(1+\frac{b_3}{4}+\frac{b_4}{8})\sin c^2(\frac{at}{2T}) + \frac{\frac{3}{2}b_3(\sin c(atT)-1)}{(\pi atT)^2} + \frac{\frac{3}{8}b_4(\sin c^2(atT/2)-1)}{(\pi atT/2)^2}$$

6. Double Jump Pulse

$$p_{dj}(t) = \sin c(tT)\cos(\pi atT)$$

7. Second Order Continuous Window

$$p_{socw}(t) = \sin c(tT)\{2(1+b_1)\sin c(atT) - (1+2b_1)\sin c^2(atT/2)\}$$

$$where; b_1 = -0.5 \Rightarrow a = 1, b_1 = 0.4 \Rightarrow a = 0.25$$

8. Improved Sinc Power Pulse

$$p_{isp}(t) = e^{(-a(tT)^2)} \sin c^n(\pi tT)$$

9. Frank Pulse

$$P_f(t) = \sin c(tT)\{(1-a)\cos(\pi atT) + a\sin c(atT)\}$$

10. Sinc Power Pulse

$$p_{spp}(t) = \sin c(tT)\sin c(tT)$$

II. SYSTEM MODEL

The complex envelope of one radio frequency (RF) N-subcarrier OFDM symbol with pulse-shaping is expressed in [23],

$$x(t) = \exp(j2\Pi f_c t)\sum_{k=0}^{N-1} D_k P(t)\exp(j2\Pi f_k t) \quad (1)$$

Where 'f_c' is the carrier frequency system 'f_k' is the subcarrier frequency of the 'k_{th}' subcarrier where k = 0, 1… N-1, etc..., 'p (t)' is the time-limited pulse-shaping function and 'D_k' is the data symbol transmitted on the 'k_{th}' subcarrier. We assume that the transmitted symbol 'D_k' has mean zero and normalized average symbol energy. We further assume that the data symbols are uncorrelated.

$$E[D_k D_m^*] = \begin{cases} 1, k = m \\ 0, k \neq m \end{cases} \quad (2)$$

Where D^*_m' is the complex conjugate of 'D_m' ensure the subcarrier orthogonality, which is very important for OFDM systems the equation below has to be satisfied [10]

$$f_k - f_m = \frac{(k-m)}{T} \quad (3)$$

Where k,m = 1,2,..........,N-1, '1/T' is the minimum required subcarrier frequency spacing to satisfy orthogonality between subcarriers. Therefore, subcarrier frequencies should be defined as

$$f_k = \frac{k}{T} \quad (4)$$

Where k = 1,2,...........,N-1. To ensure the orthogonality [24] i.e.

$$\int_{-\infty}^{+\infty} P(t)\exp(j2\Pi(f_k - f_m)t)dt = \begin{cases} 1, k = m \\ 0, k \neq m \end{cases} \quad (5)$$

Equation (5) also indicates the important condition that the Fourier transform of the pulse ‘p (t)’ should have spectral nulls at the frequencies ±1/ (T), ±2/(T), to ensure subcarrier orthogonality. We consider here various time-limited Nyquist pulses in the time domain Time delayed version of p (t) is

$$P^d(t) = P(t - \frac{T}{2}(1+\alpha)), 0 \leq t \leq T(1+\alpha) \quad (6)$$

The Fourier transform of ‘p^d (t) ‘is

$$P^d(f) = P(f)\exp(-j\Pi\, fT(1+\alpha)) \quad (7)$$

In the receiver block, the received signal can be expressed as

$$r(t) = x(t) \otimes h(t) + n(t) \quad (8)$$

Where ⊗ denotes convolution and ‘h (t)’ is the channel impulse response. In (8), ‘n (t)’ is the additive complex Gaussian noise process with zero mean and variance ‘$N_0/2$’ per dimension. For this work we assume that the channel is ideal, i.e., ‘h (t) = δ (t)’ in order to investigate the effect of the frequency offset only on the ICI performance. At the receiver, the received signal ‘r (t)’ becomes

$$r'(t) = \exp(j2\Pi\Delta ft)\sum_{k=0}^{N-1} D_k\, P(t)\exp(j2\Pi f_k t) + n(t)\exp(j2\Pi(-f_c + \Delta f)t)) \quad (9)$$

Where Δf ($\Delta f \geq 0$) is the carrier frequency offset between transmitter and receiver oscillators. For the transmitted symbol ‘D_m’, the decision variable is given as [23]

$$D(t) = \int_{-\infty}^{+\infty} r'(t)\exp(-j2\Pi f_m t)dt \quad (10)$$

III. ICI, SIR AND BER ANALYSIS

To study the effect of different pulse-shaping’s on the ICI reduction of an OFDM system in the presence of frequency offset, we consider an imperfect receiver with frequency offset, $\Delta f(\Delta f \geq 0)$, operating on an ideal AWGN channel in the following analysis. The frequency offset may come from the receiver crystal oscillator inaccuracy, residual frequency offset after frequency offset estimation or Doppler shift introduced by the time variation in one OFDM symbol. ISI is not encountered in the AWGN channel model, so it is not necessary to employ a guard interval here. The received signal after multiplication by ‘exp (-j2π (f_c -Δf) t’ becomes. By using (3) and (10), the decision variable can be expressed as

$$D(m) = D_m P(-\Delta f) + \sum_{\substack{k=0 \\ k\neq m}}^{N-1} D_k P((k-m)/T + \Delta f) \times \exp((j\Pi(k-m) + \Delta fT)(1+\alpha)) + N_m \quad (11)$$

Where ‘P (f)’ is the Fourier transform of ‘p (t)’ and N_m, m = 0. . . N − 1 is the independent complex Gaussian noise component in (11). First term contains the desired signal component and the second term represents the ICI component. With respect to (3), ‘P (f)’ should have spectral nulls at the frequencies ± (1/T), ± (2/T) to ensure subcarrier orthogonality. Then, there exists no ICI term if f and θ are zero. The power of the desired signal can be calculated as [12]

$$\sigma(m)^2 = E[D_m P(-\Delta f) D_m^* P(-\Delta f)^*] = E[D_m D_m^*]\,|P(\Delta f)|^2 = |P(\Delta f)|^2 \quad (12)$$

The power of the ICI can be stated as [13]

$$\sigma(ici)^2 = \sum_{k=0}^{N-1}\sum_{n=0}^{N-1}[D_n D_k^*][P((k-m)/T + \Delta f) \times P((k-m)/T + \Delta f)] \quad (13)$$

The average ICI power across different sequences can be calculated as (13)

$$\sigma(ici)^2 = E[\sigma[ici))^2] = \sum_{\substack{k=0 \\ k\neq m}}^{N-1} |P((k-m)/T + \Delta f)|^2 \quad (14)$$

As seen in (14) the average ICI power depends on the number of the subcarriers and ‘P (f)’ at frequencies ((k-m)/T) + Δf), $k \neq m$. By using (12) and (14), the signal-to-interference ratio (SIR) can be defined as

$$\mathrm{SIR} = \frac{|P(\Delta f)|^2}{\sum_{\substack{k=0\\k\neq m}}^{N-1} |P(\frac{(k-m)}{T} + \Delta f)|^2} \qquad (15)$$

IV. SIMULATION RESULTS

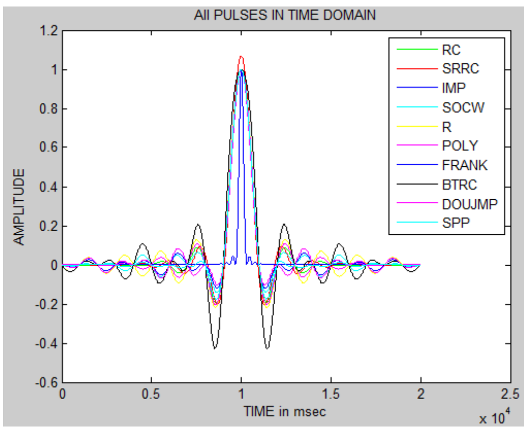

Figure 1. Time Domain Response for all pulses (for a=0.25, where' a' is the roll off factor)

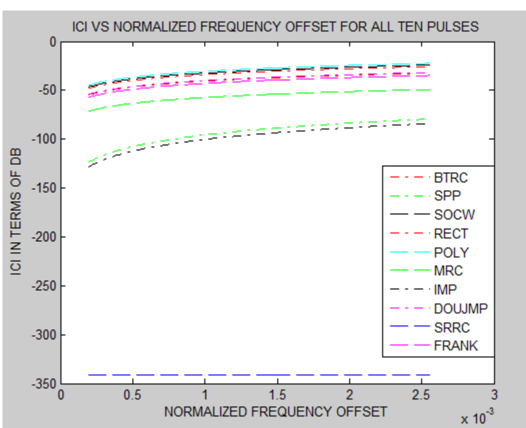

Figure 2. Normalized Frequency Offset (vs.). Intermarries Interference Ratio for ten pulses out of those improved sinc power pulse and Square root raised cosine pulse gives the better performance than remaining pulses (a=0.25, where' a' is the roll off factor)

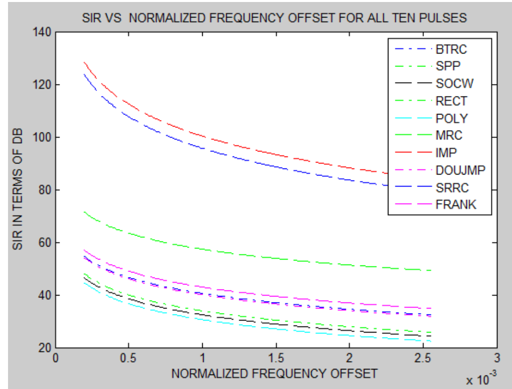

Figure 3. Normalized Frequency Offset (vs.). Signal to Interference Ratio for ten pulses out of those improved sinc power pulse and Square root raised cosine pulse gives the better performance than remaining pulses (a=0.25, where 'a' is the roll off factor.

V. CONCLUSION

In this paper, the effect of several Nyquist pulses for ICI reduction and SIR enhancement of OFDM systems in the presence of frequency offset was examined. It was found that the improved sinc power pulse and square root raised cosine pulse exhibits best performance among the Nyquist pulses.

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