AREA EFFICIENT & COST EFFECTIVE PULSE SHAPING FILTER FOR SOFTWARE RADIOS

Rajesh Mehra[1] and Swapna Devi[2]

[1,2]Department of Electronics & Communication Engineering, NITTTR, Chandigarh, India
[1]rajeshmehra@yahoo.com

ABSTRACT

In this paper area efficient and cost effective techniques for design of pulse shaping filter have been presented to improve the computational and implementation complexity. Pulse shaping filters have been designed and implemented by using Raised cosine filter, Nyquist filter and optimized half band filters for software defined radio (SDR) based wireless applications. The performance of different filters is compared in terms of BER and hardware requirements. The results show that the BER performance of the optimized designs is almost identical to the Raised cosine filter with significant reduction in hardware requirements. The hardware saving of 60% to 90% can be achieved by replacing the Raised cosine filter with proposed filters to provide cost effective solution for wireless communication applications.

KEYWORDS

HDTV, BER, RRC, SDR, ISI

1. INTRODUCTION

The wide diffusion of wireless terminals and particularly of cellular phones is opening new challenges in the field of mobile telecommunications. Besides, the possibility to transmit not only voice but even data between terminals and end users of many kinds has fostered the development of new technologies and new standards for cellular communications [1]-[2]. Recently, there is increasingly strong interest on implementing multi-mode terminals, which are able to process different types of signals, e.g. WCDMA, GPRS, WLAN and Bluetooth. These versatile mobile terminals favour simple receiver architectures because otherwise they'd be too costly and bulky for practical applications [3]. As digital technology ramps up for this century, an ever-increasing number of RF applications will involve the transmission of digital data from one point to another. The general scheme is to convert the data into a suitable baseband signal that is then modulated onto an RF carrier. Pulse shaping filters are used at the heart of many modern data transmission systems like mobile phones, HDTV, SDR to keep a signal in an allotted bandwidth, maximize its data transmission rate and minimize transmission errors. The ideal pulse shaping filter has two properties:

i. A high stop band attenuation to reduce the inter channel interference as much as possible.
ii. Minimized inter symbol interferences (ISI) to achieve a bit error rate as low as possible.

The RRC filters are required to avoid inter-symbol interference and constrain the amount of bandwidth required for transmission [4]. Root Raised Cosine (RRC) is a favorable filter to do pulse shaping as it transition band is shaped like a cosine curve and the response meets the Nyquist Criteria [5]. The first Nyquist criterion states that in order to achieve an ISI-free transmission, the impulse response of the shaping filter should have zero crossings at multiples of the symbol period. A time-domain sinc pulse meets these requirements since its frequency response is a brick wall but this filter is not realizable. We can however approximate it by

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sampling the impulse response of the ideal continuous filter. The sampling rate must be at least twice the symbol rate of the message to transmit. That is, the filter must interpolate the data by at least a factor of two and often more to simplify the analog circuitry. In its simplest system configuration, a pulse shaping interpolator at the transmitter is associated with a simple down sampler at the receiver. The FIR structure with linear phase technique is efficient as it takes advantage of symmetrical coefficients and uses half the required multiplications and additions [6].

2. Pulse Shaping Filter

Before delving into the details of pulse shaping, it is important to understand that pulses are sent by the transmitter and ultimately detected by the receiver in any data transmission system. At the receiver, the goal is to sample the received signal at an optimal point in the pulse interval to maximize the probability of an accurate binary decision. This implies that the fundamental shapes of the pulses be such that they do not interfere with one another at the optimal sampling point. There are two criteria that ensure non-interference. Criterion one is that the pulse shape exhibits a zero crossing at the sampling point of all pulse intervals except its own. Otherwise, the residual effect of other pulses will introduce errors into the decision making process. Criterion two is that the shape of the pulses be such that the amplitude decays rapidly outside of the pulse interval.

This is important because any real system will contain timing jitter, which means that the actual sampling point of the receiver will not always be optimal for each and every pulse. So, even if the pulse shape provides a zero crossing at the optimal sampling point of other pulse intervals, timing jitter in the receiver could cause the sampling instant to move, thereby missing the zero crossing point. This, too, introduces error into the decision making process. Thus, the quicker a pulse decays outside of its pulse interval, the less likely it is to allow timing jitter to introduce errors when sampling adjacent pulses. In addition to the non-interference criteria, there is the ever-present need to limit the pulse bandwidth, as explained earlier. The rectangular pulse, by definition, meets criterion number one because it is zero at all points outside of the present pulse interval. It clearly cannot cause interference during the sampling time of other pulses. The trouble with the rectangular pulse, however, is that it has significant energy over a fairly large bandwidth.

Due to this fact rectangular pulse is unsuitable for modern transmission systems. This is where pulse shaping filters come into play. If the rectangular pulse is not the best choice for band-limited data transmission, then what pulse shape will limit bandwidth, decay quickly, and provide zero crossings at the pulse sampling times? The raised cosine pulse is used to solve this problem in a wide variety of modern data transmission systems.

3. Raised Cosine Filter

The magnitude spectrum, $P(\omega)$, of the raised cosine pulse is given by:

$$P(\omega) = \tau \qquad for\ 0 \le \omega \le \frac{\pi(1-\alpha)}{\tau} \tag{1}$$

$$P(\omega) = \frac{\tau}{2}\left[1-\sin\left[\left[\frac{\tau}{2\alpha}\right]\left[\omega-\frac{\pi}{\tau}\right]\right]\right] \qquad for\ \frac{\pi(1-\alpha)}{\tau} \le \omega \le \frac{\pi(1+\alpha)}{\tau} \tag{2}$$

$$P(\omega) = 0 \qquad for\ \omega \ge \frac{\pi(1+\alpha)}{\tau}$$

The inverse Fourier transform of $P(\omega)$ yields the time-domain response, $p(t)$, of the raised cosine pulse. This is also referred to as the impulse response and is given by:

$$P(t) = \frac{\left[\sin c\frac{t}{\tau}\right]\left[\cos\frac{\alpha\pi t}{\tau}\right]}{1-\left[\frac{2\alpha t}{\tau}\right]} \tag{3}$$

Unlike the rectangular pulse, the raised cosine pulse takes on the shape of a sinc pulse, as indicated by the leftmost term of $p(t)$. Unfortunately, the name "raised cosine" is misleading. It actually refers to the pulse's frequency spectrum, $P(\omega)$, not to its time domain shape, $p(t)$. The precise shape of the raised cosine spectrum is determined by the parameter, α, which lies between 0 and 1. Specifically, α governs the bandwidth occupied by the pulse and the rate at which the tails of the pulse decay. A value of $\alpha = 0$ offers the narrowest bandwidth, but the slowest rate of decay in the time domain. When $\alpha = 1$, the bandwidth is $1/\tau$, but the time domain tails decay rapidly. It is interesting to note that $\alpha = 1$ case offers a double-sided bandwidth of $2/\tau$. This exactly matches the bandwidth of the main lobe of a rectangular pulse, but with the added benefit of rapidly decaying time-domain tails. Conversely, inverse when $\alpha = 0$, the bandwidth is reduced to $1/\tau$, implying a factor-of-two increase in data rate for the same bandwidth occupied by a rectangular pulse. However, this comes at the cost of a much slower rate of decay in the tails of the pulse. Thus, the parameter α gives the system designer a trade-off between increased data rate and time-domain tail suppression [7]-[8]. The latter is of prime importance for systems with relatively high timing jitter at the receiver.

4. PROPOSED DESIGN IMPLEMENTATION

The raised-cosine filter is obtained by truncating the analytical impulse response and it is not optimal because it results in higher filter order. In this proposed work first Raised cosine filter has been designed using filter order 260, roll off factor 0.25 and stop band attenuation of 60 dB with Matlab [9]. Under certain conditions, a low pass filter can be designed to have a number of zero-valued coefficients.

Due to the presence of these zero-valued coefficients, these filters are computationally more efficient than other lowpass filters of same order. These filters are called the Nyquist filters or Lth-band filters [10]. Nyquist filter with equiripple response result in lower order as compared to Raised cosine filter. So the proposed design is based on Nyquist technique which provides same stop band attenuation and transition width with much lower order. The comparison of Raised cosine filter and Nyquist filter is shown in Figure1.

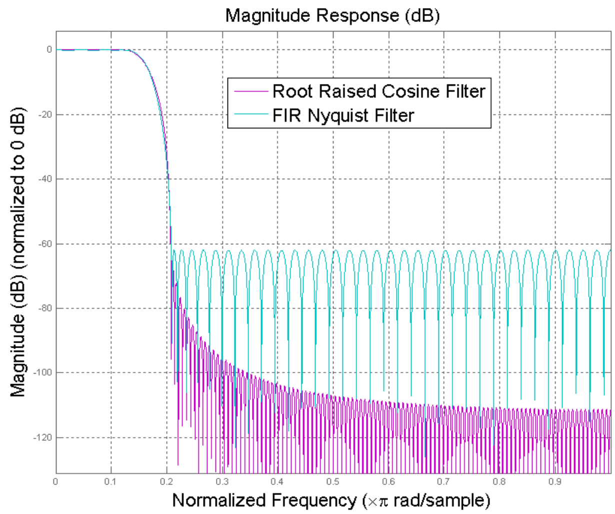

Figure1. Raised Cosine and Nyquist Filter

An even more efficient design in terms of implementation complexity may be obtained by cascading 3 half band filters. The main advantage of multistage over single stage designs is that longer filters are costly and can be operated at lower sample rates while shorter filters are operated at higher sample rates. An *L*th-band filter for $L = 2$ is called a half-band filter. The transfer function of a half-band filter may be expressed as:

$$H(z) = \alpha + z^{-1}E_1(z^2) \tag{4}$$

with its impulse response satisfying

$$h[2n] = \begin{cases} \alpha, & n = 0 \\ 0, & \text{otherwise} \end{cases} \tag{5}$$

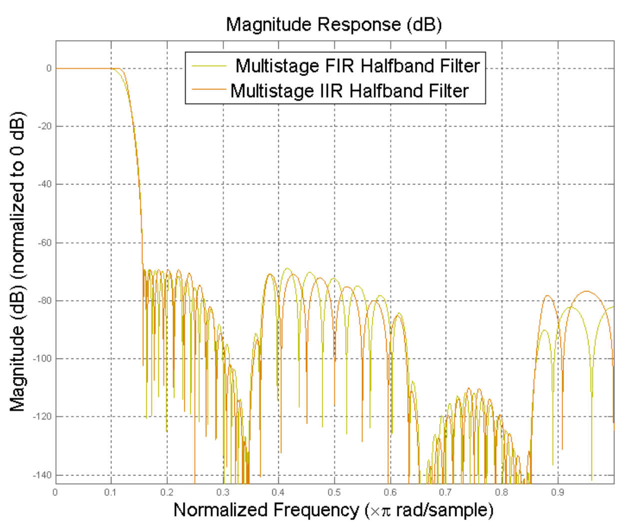

Figure2. Half band FIR and IIR

The performance comparison of all the four designs is shown in Figure3.

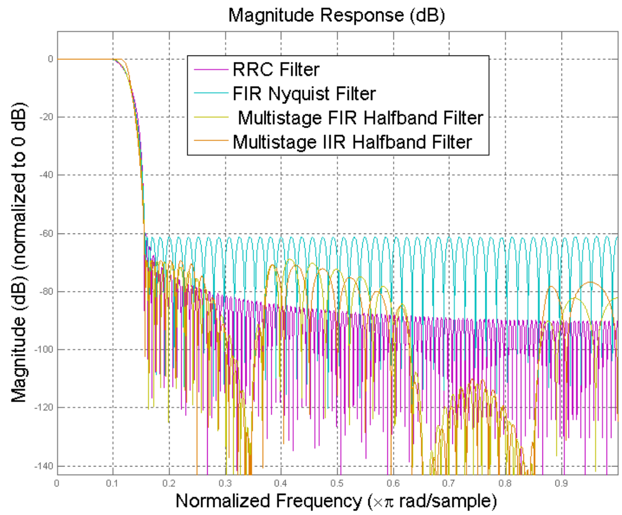

Figure3. Performance comparison of all designs

5. Results & Discussion

The performance and cost of all the four designs have been analyzed and compared. The bit error rate of all the four designs is calculated with 16 QAM modulation scheme and an additive white Gaussian noise channel. The results show that the bit error rate (BER) introduced by the four design is very similar.

Table1. BER Comparison of Four Designs

Technique	Bit Error Rate		
	10-dB SNR	15-dB SNR	20-dB SNR
Raised Cosine	0.0686	0.0041	0
Nyquist FIR	0.0705	0.0046	0
FIR Half Band	0.0702	0.0046	0
IIR Half Band	0.0734	0.0055	0

The performance of the four designs is almost identical as shown in table 1 but their implementation cost varies greatly, as shown in the table 2. The other 3 designs provide significant savings both in terms of hardware and operations per sample as compared to Raised cosine design. The FIR Nyquist design results in 60% saving, FIR Half band results in 80% saving and IIR Half band results in 90% saving of hardware as compared to Raised cosine filter.

Table2. Implementation Cost Comparison

	Implementation Cost Comparison			
	Mult	**Add**	**Mult/Samp**	**Add/Samp**
Raised Cosine	260	253	260	253
Nyquist FIR	94	87	94	87
FIR Half Band	32	29	60	53
IIR Half Band	12	24	22	44

6. CONCLUSION

In this paper, three optimized alternatives to Raised cosine filter are presented. The performance of the four designs is almost identical in terms of bit error rate but their implementation cost varies greatly in terms of hardware requirements. The Nyquist FIR, FIR Half Band and IIR Half band results in 60 to 90% saving in terms of hardware requirement. So proposed alternative designs may be used to provide cost effective solution for SDR based wireless communication applications.

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Authors

Rajesh Mehra: *Mr. Rajesh Mehra is currently Assistant Professor at National Institute of Technical Teachers' Training & Research, Chandigarh, India. He is pursuing his PhD from Panjab University, Chandigarh, India. He has completed his M.E. from NITTTR, Chandigarh, India, B.Tech. from NIT, Jalandhar, India. Mr. Mehra has 14 years academic experience. He has authored more than 25 research papers in national, international conferences and reputed journals. Mr. Mehra's interest areas are VLSI Design, Embedded System Design, Advanced Digital Signal Processing and Wireless & Mobile Communication. Mr. Mehra is life member of ISTE.*

Swapna Devi: *Ph.D in Engineering from Tezpur University, Assam, (2008), she did her M.E. degree from Regional Engineering College (presently NIT), Rourkela, Orissa, in 1997 and B. Tech degree in Electronics & Communication Engineering, NERIST, Arunachal Pradesh, in 1994. Dr. Swapna Devi is currently Associate Professor at National Institute of Technical Teachers' Training & Research, Chandigarh, India. Dr. Swapna has 11 years academic experience. She has authored more than 100 research papers in national, international conferences and reputed journals. Dr. Swapna's interest areas are Medical Image Processing, Soft Computing and Neural Networks. Dr. Swapna Devi is a lif member of IEEE and*