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AN ALGORITHM TO ANALYZE IMPACT OF IMPLEMENTING PULSE SHAPING FILTER TECHNIQUES IN DIGITAL COMMUNICATION SYSTEMS

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Abstract- Simulation has been extensively utilized by researchers and engineers for design, development and realization of different constituents of advanced digital communication systems and networks. Electromagnetic signals carrying digital data are corrupted by intersymbol interference during propagation. A technical computing environment MATLAB is quite useful for analyzing and evaluating the error performance of digital communication systems. This paper presents a simplified algorithm to mitigate the effects of intersymbol interference (ISI) by introducing pulse shaping techniques at the transmitter end. Eye diagram is a useful tool to evaluate the error performance. In this paper, eye diagrams are created using MATLAB-code to illustrate the results. 16-QAM digital modulation method is considered here to demonstrate the results with pulse shaping by square-root raised cosine filter. Simulation algorithms for performance analysis presented here can be extended for various digital modulation schemes in different applications.

Keywords- **Digital Modulation, Eye Diagram, Intersymbol Interference (ISI), Pulse Shaping, Simulation.**

I. INTRODUCTION

In digital communications, the transmitted signal experiences various types of distortions including intersymbol interference. This causes rapid fluctuations in the received signal levels [1]. The performance of digital communication system can be analyzed through simulation prior to its realization. Simulation means appropriate modeling of mathematical description of communication channels. Additive White Gaussian Noise (AWGN) channel is used to develop the basic algorithm for simulation. Statistically independent Gaussian noise signals are then mixed with samples of information data [2]. Fig. 1 depicts a mathematical model of a typical baseband binary data transmission system.

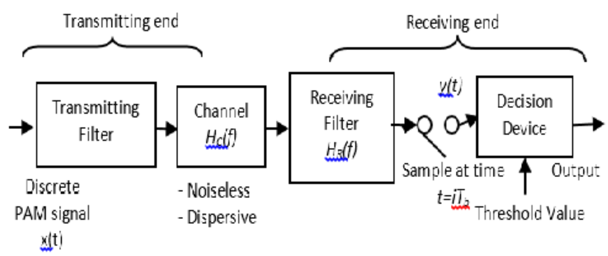

Fig. 1 Baseband Binary Data Transmission System

The discrete pulse-amplitude modulated (PAM) signal $x(t)$ is expressed mathematically as

$$x(t) = \sum_{k=-\infty}^{\infty} a_k v(t - kT_b) \quad (1)$$

The parameter a_k depends on the type of line coding and the input data; $v(t)$ represents the normalized waveform of the pulse with $v(0) = 1$, and T_b denotes the pulse duration.

The output of the filter at the receiver end, $y(t_i)$ sampled at $t_i = iT_b$ (i being an integer value), is given as

$$y(t_i) = \mu a_i + \mu \sum_{\substack{k=-\infty \\ k \neq i}}^{\infty} a_k p(iT_b - kT_b) \quad (2)$$

The first term (μa_i) on right hand side of this expression is generated by transmitting data bit, whereas the next term in this expression, called Intersymbol Interference (ISI), represents residual effect of all other transmitting data bits while decoding i^{th} bit.

When a short pulse signal propagates over band-limited channel, its frequency components get differentially attenuated. The arrival of the transmitted pulse is also delayed. The pulse waveform available at the system output is dispersed for a longer time period than that of the transmitted pulse, as shown in Fig. 2.

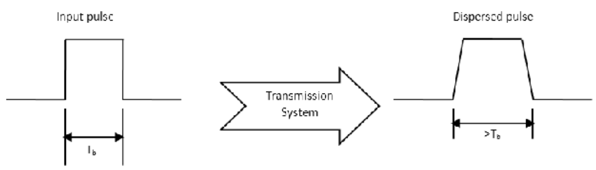

Fig. 2. Dispersed Pulse due to ISI

Each symbol (in case of high data rate) is most likely to interfere with adjacent symbols during transmission due to dispersion. This causes ISI which may introduce an error in decision-making device used to decode data at the output of the receiver. The receiver can make an error in deciding whether it has received a binary logic l or a binary logic 0.

This paper is organized in five sections. Section I defines intersymbol interference with the help of mathematical description of a basic model of baseband binary data transmission system. A glimpse of dispersed pulse as result of ISI is illustrated. Section II gives a brief account of Nyquist pulse shaping techniques followed by square root raised cosine type of filter used to mitigate the impact of ISI in digital transmissions.

Section III presents an algorithm using MATLAB library functions to design and implement a square-root raised cosine filter. A plot of its impulse response is presented for performance analysis. Section IV describes an eye diagram as a tool to analyze and evaluate the error performance of a digital communication link employing pulse shaping filter to mitigate the effects of ISI. This algorithm is implemented in MATLAB code using related library functions. The resultant eye diagrams are illustrated for 16-QAM digital modulation technique. For comparison purpose, eye diagrams with offset and without offset in filter attributes is presented.

Finally, section V gives discussions about the results obtained. The analysis is concluded with the scope of exploring simulation further by using different pulse shaping and digital modulation techniques.

II. CREATION OF A PULSE SHAPING FILTER

The ISI occurs mainly because of imperfect frequency response of communication channel. The error performance improvement can be achieved by introducing pulse shaping devices at the transmitting end and specially-designed matched filter at the receiving end. By using Nyquist pulse, *[(sin x)/x]*, zero ISI condition can be obtained [3]. The amplitude characteristics of Nyquist filter can be expressed as

$$P(f) = \frac{1}{2B_0} rect\left(\frac{f}{2B_0}\right) \quad (3)$$

Where $B_0 = R_b/2$ is the bandwidth and R_b is the bit rate.

The impulse response of an ideal low pass filter can be represented by a function *p(t)* having its passband amplitude response as $1/(2B_0)$ is expressed as

$$p(t) = \frac{\sin(2\pi B_0 t)}{2\pi B_0 t} \sin c(2B_0 t) \quad (4)$$

The impulse response of Nyquist filter, as defined above, approaches infinity. This means that the impulse response of the Nyquist pulse will extend into impulse response of every subsequent pulses in the information data sequence, thereby causing interference. This situation is not acceptable at all because it is very much susceptible to degradation due to ISI induced by timing errors [4].

As a viable solution to mitigate the effects of ISI, a digital filter having square root raised cosine properties is implemented at the transmitter end to shape the input pulse data signal. Its transfer function is given by

$$H(f) = \begin{cases} 1 & \text{for } |f| < (2W_0 - W) \\ \cos^2\left(\frac{\pi}{4}\frac{|f| + W - 2W_0}{W - W_0}\right) & \text{for } (2W_0 - W) < |f| < W \\ 0 & \text{for } |f| > W \end{cases} \quad (5)$$

Where W represents the absolute bandwidth; $W_0 = T_b/2$ defines the -6 dB bandwidth (T_b is the pulse width) and; $(W - W_0)$ denotes the extra bandwidth more than the Nyquist bandwidth.

The corresponding impulse response for the above-specified transfer function is given by

$$h(t) = 2W_0\left[\sin c(2W_0 t)\right] \frac{\cos\left[2\pi(W - W_0)t\right]}{1 - \left[4(W - W_0)t\right]^2} \quad (6)$$

These type of filters are required to be used at both ends of the digital communication link [5-7].

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III. ALGORITHM TO DESIGN DIGITAL FILTER WITH SQUARE ROOT RAISED COSINE FUNCTION

An algorithm is proposed for design and implementation of a digital filter having square root raised cosine function. The related MATLAB library functions are used. A simplified flow-chart depicting this algorithm is shown in Fig. 3.

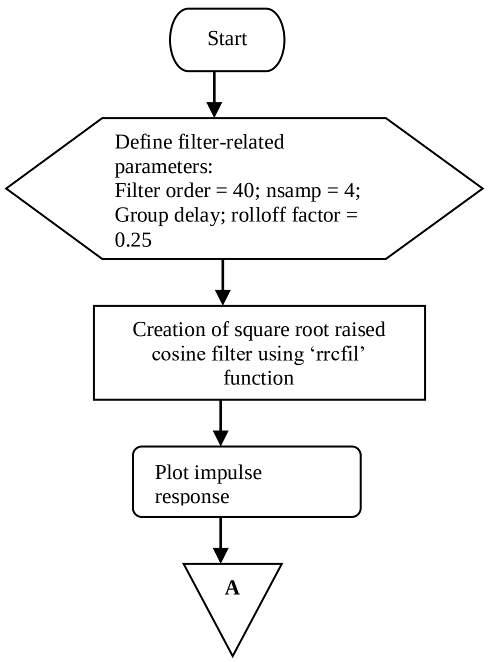

Fig. 3. An Algorithm to create a Digital Filter with Square Root Raised Cosine Function

Referring to this algorithm the relevant M-code is generated. Fig. 4 shows the plot of the impulse response as obtained from MATLAB simulation. [8].

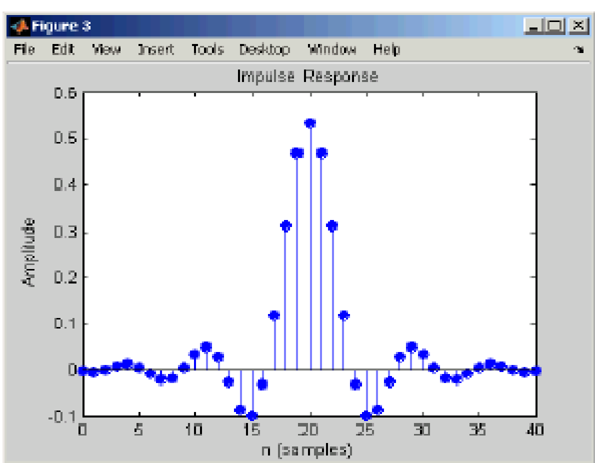

Fig. 4. Impulse Response

IV. AN EYE DIAGRAM ILLUSTRATING THE EFFECT OF PULSE SHAPING

An eye pattern, also called eye diagram, is a practical tool used to estimate the impact of the degradations contributed by ISI into the transmitted pulse signals as they travel through the transmitting medium to the receiver [9].

For analyzing the effects of ISI and other impairments arising due to non-ideal channel characteristics in digital transmissions, an eye diagram is a convenient tool. To create an eye diagram experimentally, the received and decoded digital signal waveform is plotted at fixed-interval time scale on digital storage oscilloscope in the laboratory. After the expiry of the pre-determined time period, the same signal is folded and brought to starting point on time scale. As depicted in Fig. 5, the resultant waveform comprises of number of overlapping waveforms, forming the shape of an eye, known as eye diagram.

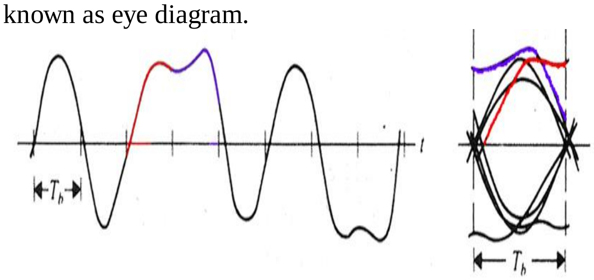

Fig. 5. The Concept of Eye Diagram

The best way to gather information from the eye diagram is to observe closely the instant at which the "eye" is widely open. At this particular instant of time, the demodulated signal is detected by the digital demodulator at the receiver so to obtain the desired digital information data [10].

Thus, an eye diagram is useful to determine the best decision point at that instance where the opening of the eye pattern is quite wide. As ISI increases, the opening of the eye decreases. In case the eye pattern is completely closed, it is not possible to mitigate the impact of data errors in received signal. This means that the reduction in the opening of an ideal eye pattern is due to degradation in the shape of the pulse. From a typical eye diagram, several aspects that determine the signal quality can be extracted. These include noise margin, timing jitter (minute variations of significant instants of a digital signal from its ideal position that may affect symbol clock recovery circuit) and level-crossing jitter (the difference between pre-defined threshold level and the ideal time of detecting the received pulse). [11].

Therefore, eye diagram serves the purpose of performing qualitative analysis of received data. This means that it determines the receiver's capability to recover digital data with synchronization. The received data can either be analyzed at the input or in any of the functional stage in the receiver but prior to decision-making device.

An algorithm for simulation as well as analysis of ISI using the square root raised cosine filter and creation of an eye diagram is proposed in Fig. 6.

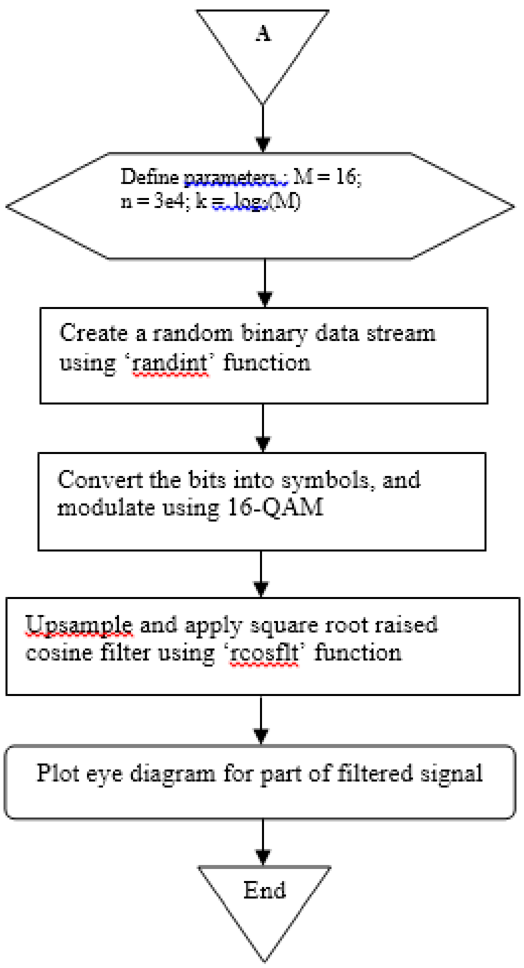

Fig. 6. An Algorithm for Performance Analysis including Filter

The *rcosflt* command internally performs various functions such as up-sampling of the modulated signal by *nsamp* times, padding the up-sampled signal with 0s at the end of filtering operation. A part of the filtered noiseless signal is taken to create an eye diagram using the specified function `*eyediagram'* in M-code.

Fig. 7 depicts the resultant eye diagram with effect of the pulse shaping.

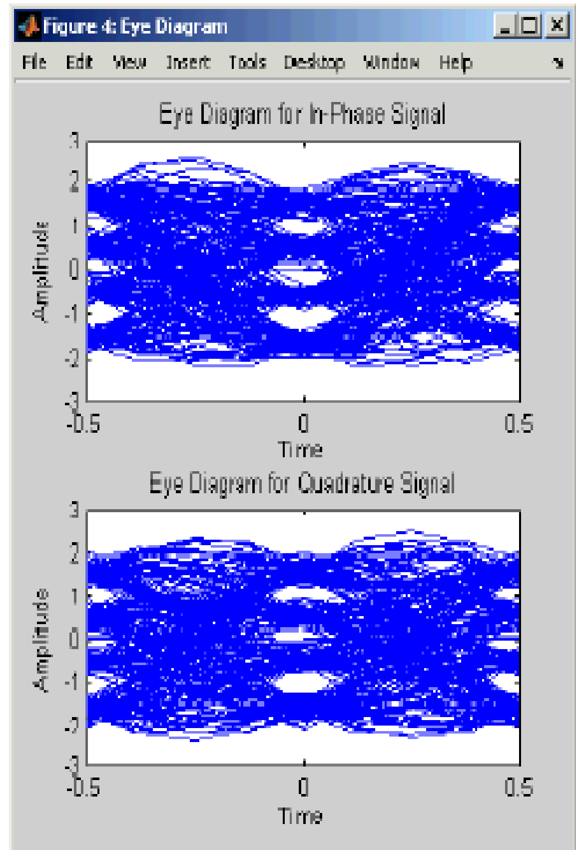

Fig. 7. Eye Diagram with Pulse Shaping

It is observed that the received signal possesses considerable amount of intersymbol interference. This is due to use of a simple square root raised cosine filter without any offset.

When a randomized digital data signal waveform is mapped over a 16-QAM digitally modulated signal waveform, a noisy radio channel is simulated using a raised cosine filter.

Several M-functions are employed to manipulate the filtered signal so as to isolate its behaviour in steady-state condition.

The resulting *eyediagram* function creates an eye diagram in M-code and displayed with no offset, as shown in Fig. 8.

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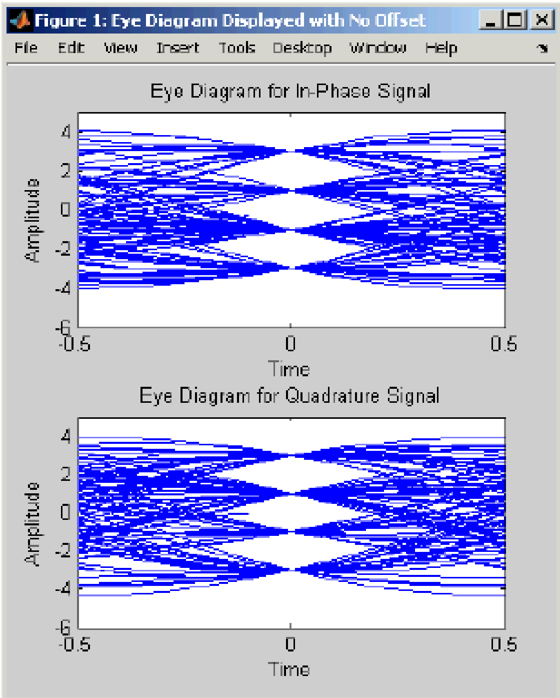

Fig. 8. Eye Diagram having no offset

It is observed that when a vertical line is drawn around the center of the eye diagram, it crosses the "eye" where it is maximum open. If the *eyediagram* command used a different offset value, then this line would not cross the eye at its widely open point. Thus, an eye diagram is useful to provide an estimate about possible bit error rate (BER) in a digital communication system.

V. Discussions And Conclusion

In digital communication systems, intersymbol interference poses a serious problem in achieving the desired performance at high data rate applications. To mitigate the effects of ISI, pulse shaping filters are implemented at the transmitting end. In this paper, an algorithm has been evolved for simulation of square-root raised cosine filter with 16-QAM digital modulation scheme. The resultant plots of eye diagram are illustrated using MATLAB tool. It is proposed to use square-root raised cosine filters at either end of the digital communication link which improves the error performance of the system. This simulation analysis can be extended to other types of digital modulation techniques with different filter characteristics.

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