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PERFORMANCE ENHANCEMENT OF OPTICAL COMMUNICATION SYSTEM USING VARIOUS PULSE SHAPING FILTERS

SHARMA V.* AND KAUR G.
UCOE Punjabi University, Patiala-147002, Punjab, India.
*Corresponding Author: Email- vsharma091@gmail.com

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Abstract- Additive White Gaussian Noise (AWGN) and Timing Jitters are one of the most significant impairments in long distance fiber optical communication. In optical system communication system high data rates leads to some limitation like dispersion, noise, non-linearity and various jitters for example deterministic and random jitter. This paper reveals some of the drawbacks of the conventional techniques used for noise and jitter compensation. This paper brings out various pulse shaping filters which can be used to compensate noise and various timing jitters in optical communication. This paper also compares the performance of three pulse shaping filters on the basis of output Signal to Noise Ratio (SNR).

Keywords- Raised Cosine Filter, Square Root Raised Cosine Filter, Gaussian Filter, AWGN, Roll-off Factor, SNR.

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Introduction

In Optical Communication Wavelength Division Multiplexing (WDM) has come out as a method of acknowledgment for development of a system. As WDM system transmits multiple channels over a single fiber whereas the conventional optical communication system only transmits one channel over a single fiber [1]. The light signal required for communication is generated using the spontaneous and stimulated emission occurring in light emitting diodes (LEDs) and LASERs [2]. WDM facilitate to increase optical network capacity by squeezing multiple channels into a given bandwidth. Chromatic Dispersion is one of the most significant impairments in long distance fiber optical communication [3].Chromatic Dispersion occurs when signal components at different wavelengths experience different group delay which results in the broadening of transmitted optical pulse [1]. Chromatic dispersion can be compensated in either optical or electrical domain. Many dispersion compensating techniques has been reported in the literature [4-7] which includes dispersion compensating fibers (DCFs), Fiber Bragg gratings (FBGs), Electronic Dispersion compensation (EDC) each having its own advantages and disadvantages [4]. In WDM system where a number of frequencies are interleaved, dispersion is compensated using all pass filters [6]. The variable phase response of the APFs makes them to be used as the phase equalizers to compensate the chromatic dispersion.

The rest of the paper is organized as follows: In the next section simulation setup is explained. Section III shows the performance enhancement after filtering. Performance comparison of these filters concludes this paper in section IV.

Drawbacks of the Conventional Techniques

The traditional techniques like DCFs, FBGs, and EDC are not suitable for dispersion compensation in WDM system. DCFs give high insertion loss, large footprint, and non-linear distortions when the input signal is high etc. [1,2]. Also for the multiple channels in WDM system, the number of DCFs has to be installed making the system complex and costly. The same problem is with the FBGs which compensate the dispersion by the recompression of an optical signal. For different frequencies different architectures of the FBGs have to be introduced along the fiber link. EDC is rendered ineffective for WDM system since it is complex and also not a direct method of compensation as it involves the optical to electronic and electrical to optical conversions making the WDM communication slow which can't be tolerated in this growing world. Hence they can correct all order of dispersion but with highest complexity which increases the cost of WDM system making it less practical [8,9].

Simulation Setup

The block diagram for the simulation setup used to carry out enhanced optical communication system performance is shown in [Fig-1]. In order to carry out improved optical communication system performance using various pulse shaping filters, an optical system is build by writing suitable MATLAB code and run it in command window.

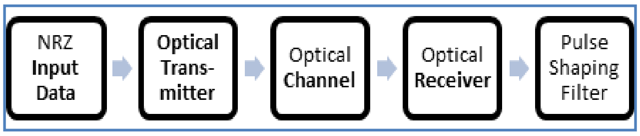

Fig. 1- Block Diagram of Simulation Setup

In [Fig-1] NRZ is the input data which gets corrupted during transmission. The message data gets corrupted with additive white gaussian noise, various jitters and dispersion effects as it travels along the optical fiber. The enhanced performance of optical communication system using various pulse shaping filters is evaluated using simulation results in the form of eye diagram. Simulation results are carried out at three major optical communication links:- Transmitter, Optical Channel and Receiver.

Input Data

The input light to be transmitted over optical fiber channel is converted into binary non return to zero (NRZ) format with amplitude varying from -1 to 1. The non return to zero has been the most predominant modulation format in optical fiber communication from past few years. NRZ format is mostly used because it is non-sensitive to laser phase noise and requires a relatively low electrical bandwidth at transmitter as well as receiver as compared to other modulation formats in optical communication and [Fig-2] shows the binary form of input NRZ signal launched into the optical fiber channel.

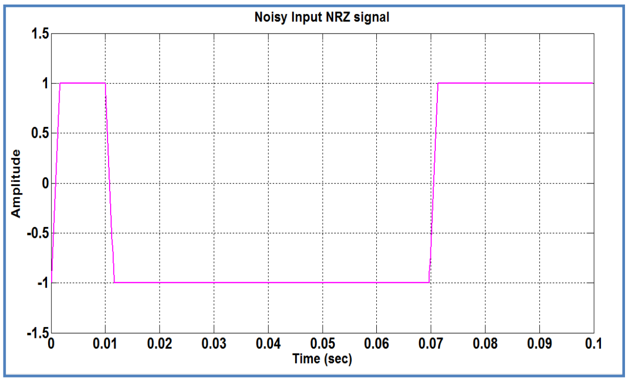

Fig. 2- Binary input NRZ signal

[Fig-2] shows the NRZ signal without any noise, jitter and dispersive effect.

Impact of Additive White Gaussian Noise (AWGN)

As the input signal travel through the optical fiber channel, additive white gaussian noise gets added to it. Additive White Gaussian Noise (AWGN) is a channel model in which the only impairment to communication is a linear addition of wideband or white noise with a constant spectral density and a gaussian distribution of amplitude. As the amplitude of the AWGN is increased, the signal-to-noise ratio decreases. [Fig-3] shows the NRZ input affected by additive white gaussian noise.

NRZ signal affected by AWGN can be seen in the form of distortion in [Fig-3]. AWGN does not account for fading, frequency selectivity, interference, nonlinearity or dispersion. Additive white Gaussian noise arises due to celestial sources such as the sun, many natural sources, such as the thermal vibrations of atoms in conductors.

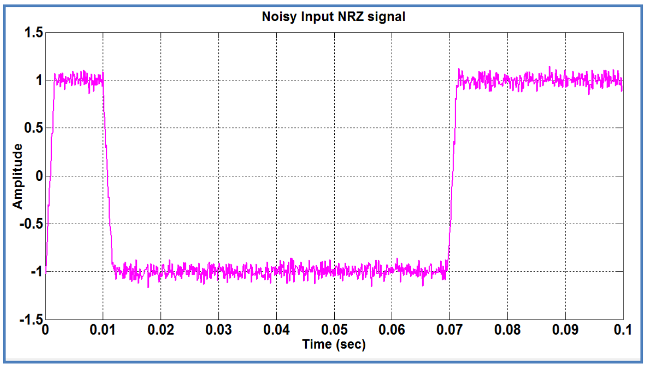

Fig. 3- Input NRZ signal affected by AWGN

[Fig-4] shows the eye diagram of input light signal in NRZ form affected by additive white gaussian noise. Impact of noise can be realized by reduction in signal quality as AWGN leads to decrease in signal to noise ratio.

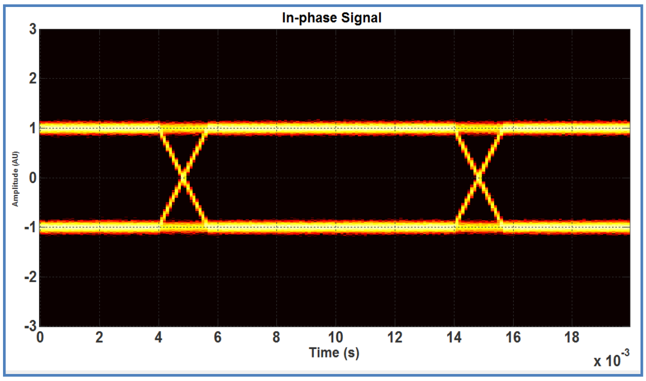

Fig. 4- Eye Diagram Input NRZ signal affected by AWGN

Impact of Timing Jitter

In high speed communication system jitter is the undesired deviation from true periodicity of an assumed periodic signal. Jitter is the deviation of timing edges from their intended locations.. Timing jitter is defined as the deviation of a signal's timing clock from the ideal clock. Timing variations are conventionally split into two categories: jitter and wander, timing variations that occur slowly are known as wander; jitter refers to variations that occur more rapidly. Timing jitter can be divided into two main subcategories: - Deterministic and Random jitter.

Deterministic Jitter

It is a type of clock timing jitter or data signal jitter that is predictable and reproducible. The peak-to-peak value of this jitter is bounded, and the bounds can easily be observed and predicted, two examples of deterministic jitter are periodic jitter and inter-symbol interference (ISI). This deterministic jitter is modeled by writing MATLAB code.

Random Jitter is unpredictable timing noise. Random jitter typically follows a gaussian distribution or normal distribution. It is believed to follow this pattern because most noise or jitter in a electrical circuit is caused by thermal noise, which has a gaussian distribution. The jitter encountered in a communication system can be any combination of these components functions. [Fig-5] Eye Diagram of input signal affected by Random Jitter.

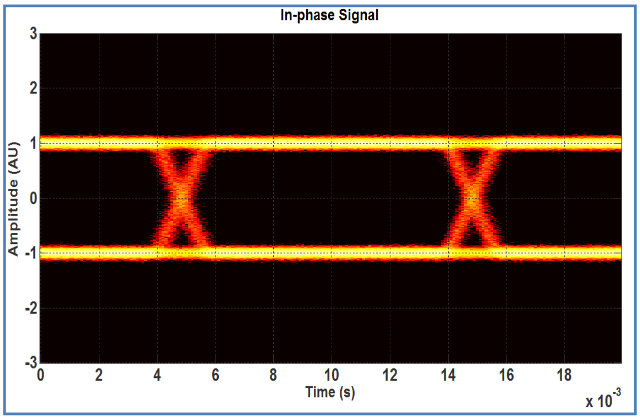

Fig. 5- Eye Diagram of input signal affected by Random Jitter

A commonly used combination is the dual-Dirac model, where ISI and random jitter are combined, two equal amplitude dirac functions to model inter symbol interference. The random effect of jitter is better illustrated by the eye diagram of the signal. [Fig-5] displays the eye diagram of NRZ signal degraded by random noise**.**

Received Signal

At the receiver end, the time dispersed signal is received due to timing jitter occurred while travelling through the optical fiber channel. Received optical signal is also affected by AWGN. The effect of jitter is better illustrated by the eye diagram of the signal. This jitter degrades the system efficiency in the way that it limits the information capacity and transmission distance in the fiber-optic channel due to pulse broadening. The light signal carrying required information received is spread into various components and each component travel differently along the optical fiber with different velocity and hence received at different times which distorted the information and the original signal can't be interpreted in the right manner.

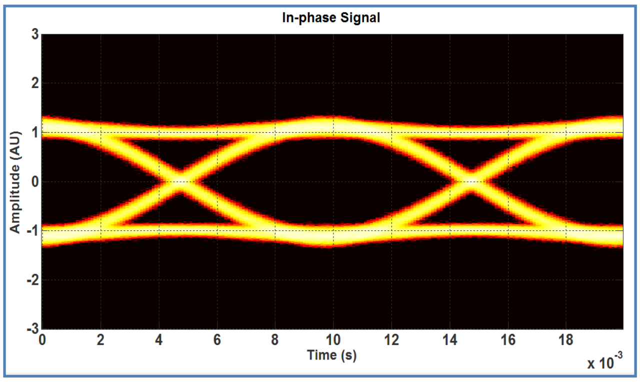

Fig. 6- Eye Diagram of NRZ data Degraded by Noise and Jitters

[Fig-6] displays the eye diagram of NRZ data degraded by noise and jitters.

Performance Analysis Using Pulse Shaping Filters

Pulse Shaping Filters are used to neutralize the effects of various jitters and additive white gaussian noise at the receiver end by writing suitable MATLAB code. When the signal's bandwidth becomes larger than the channel bandwidth, the channel starts to introduce distortion to the signal.

Pulse Shaping Filters Under Analysis

Pulse shaping filters need to be used so that the filter itself does not introduce any noise or jitter. Pulse Shaping Filters under analysis are:

- Raised Cosine Filter
- Square Raised Root Cosine Filter
- Gaussian Filter

Performance Analysis Using Raised Cosine Filter

A raised cosine filter is one of the most common pulse-shaping filters in optical communication system. The raised cosine filter is pulse shaping filters used in digital due to its ability to compensate chromatic dispersion which cause inter symbol interference (ISI). The ISI caused by chromatic and intermodal dispersion is compensated by the proper pattern of impulse response of raised cosine filter. Its name is derived from the fact that the non-zero portion of the frequency spectrum of its simplest form (β = 1) is a cosine function raised up to sit above the horizontal i.e. frequency axis. The main parameter of a raised cosine filter is its roll-off factor beta which indirectly specifies the bandwidth of the filter. [Fig-7] shows the impulse response of raised-cosine filter with various roll-off factors.

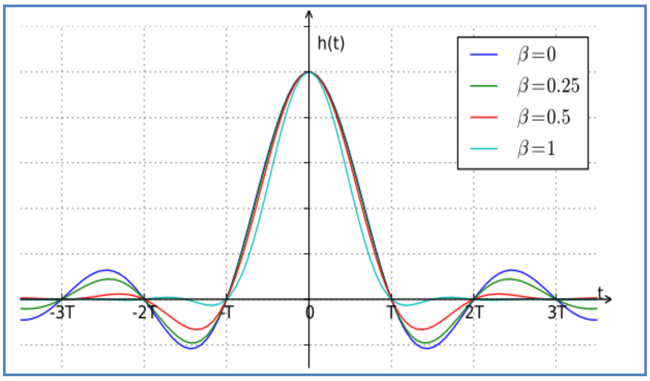

Fig. 7- Impulse response of raised-cosine filter with various roll-off factors

In order to carry out improved signal output raised cosine filter is used at the receiver end so as to compensate for various jitters and noise added during transmission. [Fig-8] shows the eye diagram using Raised Cosine Filter.

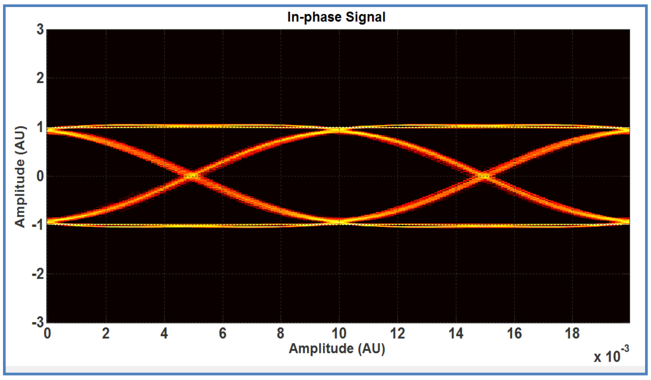

Fig. 8- Eye Diagram Using Raised Cosine Filter

Improved performance can be seen in [Fig-8] in terms of small crossing amplitude, wide vertical and horizontal opening after filtering.

Performance Analysis Using Square Root Raised Cosine Filter

A Square Root Raised cosine filter (SRRC) sometimes known as Root Raised Cosine filter (RRC) is frequently used as transmit or receive filter in a digital communication system. Roll-off factor (β) and T the reciprocal of the symbol-rate are main parameters that can be varied to carry out better performance. Filtering the received degraded signal travelling through the optical channel with a square root raised cosine filter provides a much more amount of increase in signal to noise ratio at receiver than raised cosine filter. Square root raised cosine filter remove almost same amount of timing jitter but with slight improvement in signal to noise ratio. [Fig-9] shows the eye diagram using square root Raised Cosine Filter at receiving end of the simulation setup.

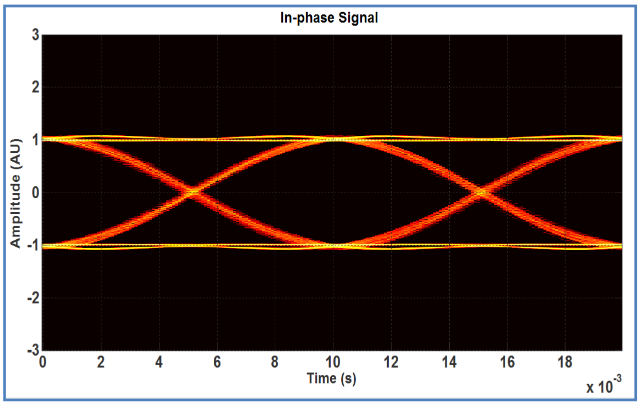

Fig. 9- Eye Diagram Using Square Root Raised Cosine Filter

Improved performance can be seen in [Fig-9] in terms of small crossing amplitude, wide vertical and horizontal opening after filtering.

Performance Analysis Using Gaussian Filter

Gaussian pulse shaping filter is useful for those modulations which are well suited for power efficient non-linear amplifiers. The Gaussian filter has a smooth transfer function with no zero-crossings [10]. The impulse response of the gaussian filter leads to a transfer function, which is highly dependent upon 3-dB bandwidth [10]. The Gaussian filter has a narrow absolute bandwidth and has sharp cut -off, low overshoot and pulse area preservation properties which make it very attractive for use in modulation techniques that use nonlinear RF amplifiers.

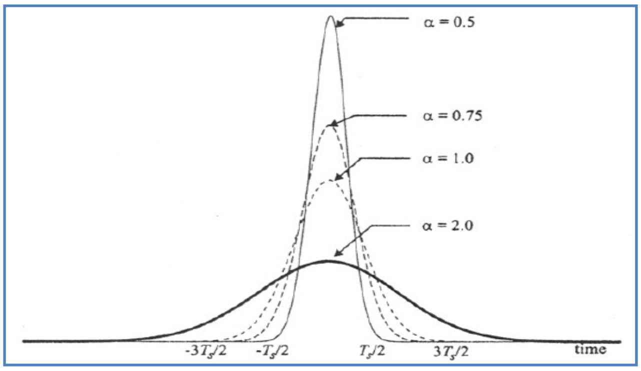

Fig. 10- Impulse response of a Gaussian pulse-shaping filter [10]

Trade off is made between the desired RF bandwidth and the irreducible error due to ISI of adjacent symbols when gaussian pulse shaping is used [11]. The gaussian pulse is neither a nyquist pulse nor an orthogonal pulse [12]. For sufficiently small *σ*, if high proportion of the pulse energy is included in one symbol time, this pulse can be approximately considered as both nyquist and orthogonal pulse. [Fig-10] showing impulse response of a gaussian pulse-shaping filter.

The improvement in the signal quality lies in the fact that more the improvement in the signal to noise ratio more would be reduction in additive white gaussian noise. [Fig-11] shows the improved eye diagram using gaussian filter at receiving end of the simulation setup.

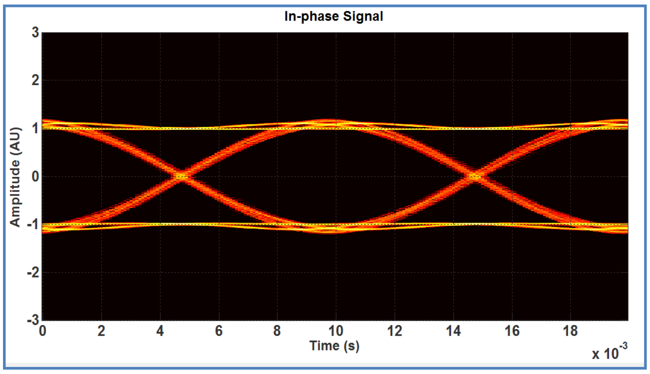

Fig. 11- Eye Diagram Using Gaussian Filter

Improved performance can be seen in [Fig-11] in terms of small crossing amplitude, wide vertical and horizontal opening after filtering.

Result and Discussion

Different pulse shaping filters used are compared on the basis SNR with the variation of roll off factor from value 0.2 to 1. [Table-1] shows the values of SNR after varying the values roll off factor.

Table 1- Comparison between pulse shaping filters on the basis of SNR

Roll-off Factor(β)	PULSE SHAPING FILTERS SNR (db)		
	RC	SRRC	Gaussian
0.2	8.9	9.63	4.5
0.3	9.99	11.3	8.41
0.4	13	13	12.5
0.5	14.1	14.5	13.5
0.6	15.1	16	15
0.7	16.1	17	15.6
0.8	15.1	17.1	14.9
0.9	14	17.5	13.9
1	14.1	17.8	14.2

The message data gets corrupted with additive white Gaussian noise, various jitters and dispersion effects as it travels along the optical fiber. The results have been simulated for the non-return to zero data with sampling frequency of 10050 Hz and symbol rate of 150 symbols per second launched into an optical fiber. A performance improvement has been analyzed after using three pulse shaping filters at receiver end in an optical communication system. Hence the noise and jitter effects are compensated with pulse shape filtering to get increased signal to noise ratio (SNR).

[Fig-12] shows the comparison between pulse shaping filters in terms of output SNR.

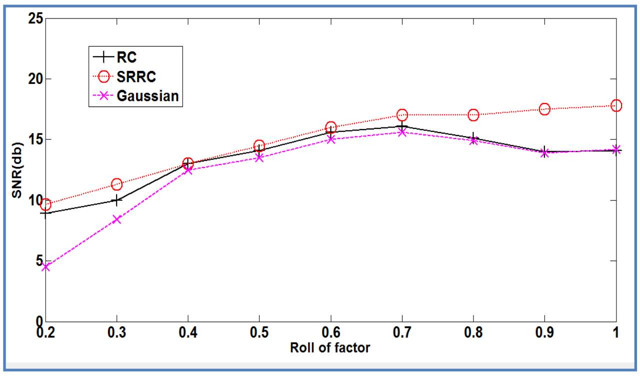

Fig. 12- SNR (db) v/s Roll-off Factor (β)

In [Fig-12] SRRC filter maintains the highest value of SNR, RC filter have SNR values slightly lower than SRRC filter and gaussian filter provides the lowest value. Output SNR values of gaussian filter catches the RC filter SNR at β = 0.80 and as the roll off factor is further increased gaussian filter maintain value of SNR nearly equal to RC filter. Since SNR relates the average symbol power of the transmitted wave to the noise power, which has caused the symbol to vary from its ideal position due to additive noise, distortion, jitters and ISI. Gaussian filter does not offer a good performance in terms of performance parameter SNR as compared to RC and SRRC filter.

Conclusion

It has been concluded from this paper that traditional techniques corrects all order of dispersion but with highest complexity which increases the cost of WDM system making it less practical. Dispersive effects are compensated by using pulse shaping filters. The type of pulse-shaping filter and its roll-off factor (β) affects the performance of an optical communication system. The values of SNR with variation of filter roll-off factor (β) over 0.20 to 1.0 are analyzed. In this paper it has been concluded that SRRC filter gives the highest value of SNR, RC filter follows next and gaussian filter provides the lowest value. Output SNR values of gaussian filter catches the RC filter SNR at β = 0.80 and thus Gaussian filter presents a moderate value of SNR for high value of filter β.

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