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# Inter-Channel Interference (ICI) Removal based on MMSE and LMS Equalizer in Communication System

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***Abstract: In this paper, we present the effect of inter channel interference (ICI) on the performance of communication system. Different equalization techniques are employed to reduce the effect of inter-channel interference. Here, we use two equalization techniques to reduce the effect of inter-channel interference. Firstly, Minimum mean square error (MMSE) equalization technique is applied at the receiver to reduce the effect of ICI in channel by applying inverse filtering. Secondly, we use least mean square (LMS) equalization technique is apply at the receiver to reduce the effect of ICI in channel. These techniques are used to compensate the effect of inter-channel interference that is introduced in the system by impulse response of the channel. Experimental results are performed to evaluate the effectiveness of the proposed equalization techniques. Simulation result shows that the bit error rates versus EbNo with 3-taps MMSE and LMS equalization to reduce the effect of inter-channel interference. As the number of tap increases the performance of the equalizer improves. Results reveal that the LMS equalizer performed better than MMSE equalizer in terms of bit error rate.***

***Index Terms:*** **Inter channel interference (ICI), Minimum mean square error (MMSE) equalizer, least mean square (LMS) equalizer.**

## I. INTRODUCTION

Data communication speed is increasing rapidly over the years. Fiber optics has become one of the highest bandwidth communication channel types available in the current communication industry today. Transmission rate at hundreds of mega-bytes per second over thousands of kilometres are increasingly common and recent experiments have even shown that the high-bandwidth, ultra long-distance transmission of 2.56 terabits (trillion bits) of information per second over a distance of 4000 kilometers (2500 miles) is achievable [1].

From last few decades Optical Communication is gaining momentum in many signal processing applications [1] [2]. Light plays a vital role in our daily lives. It is used in compact disc (CD) players, in which a laser reflecting of a CD transforms the returning signal into music. It is used in grocery store checkout lines, where laser beams read bar codes for prices. It is used by laser printers to record images on paper. It is used in digital cameras that capture our world and allow pictures to be displayed on the Internet. It is the basis of the technology that allows computers and telephones to be connected to one another over fiber-optic cables.

The effect of filtering part of the transmitted signal by the channel on the quality of the received signal may be significant that a phenomenon called “Inter channel Interference (ICI)” occurs. ICI causes the transmitted pulses to get mixed together, meaning that a pulse that is transmitted between time instants will smear into adjacent pulses affecting the process of data detection and possibly causing errors not as a result of noise but as a result of symbols mixing together.

The equalizer attempts to extract the transmitted symbol sequence by counteracting the effects of ISI, thereby improving the probability of correct symbol detection. Its purpose is to reverse the effects that the channel has on the transmitted signal, with the aim of reproducing the original signal at the receiver end. As such, it would be an ideal choice for a typical optical channel, which often suffers from amplitude distortion. The inherent property behind linear equalizers is that they are optimum with respect to the criterion of minimum probability of symbol error when the channel does not suffer from amplitude distortion. However, in a practical optical communication channel, amplitude distortion is one of the major detrimental effects.

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Interference [3] [4] is a phenomenon in which two waves superimpose to form a resultant wave of greater or lower amplitude. Interference usually refers to the interaction of waves that are correlated or coherent with each other, either because they come from the same source or because they have the same or nearly the same frequency. Interference effects can be observed with all types of waves, for example, light, radio, acoustic, and surface water waves [5]-[7].

In this paper, we present the effect of inter channel interference (ICI) on the performance of communication system. Different equalization techniques are employed to reduce the effect of inter-channel interference. Here, we use two equalization techniques to reduce the effect of inter-channel interference. Firstly, Minimum mean square error (MMSE) equalization technique is applied at the receiver to reduce the effect of ICI in channel by applying inverse filtering. Secondly, we use least mean square (LMS) equalization technique is apply at the receiver to reduce the effect of ICI in channel. These techniques are used to compensate the effect of inter-channel interference that is introduced in the system by impulse response of the channel.

The rest of thr paper is organized as follows: Section II presents the basic of optical communication system. Section III gives the brief introduction of inter channel interference both for single side interference and double side interference. Minimum mean square error (MMSE) equalization is presented in section IV. Mathematical analysis is presented in this section. Section V, present the basic of least mean square (LMS) equalization. Section VI, simulation results are presented with bit error rate as the performance criteria to remove the effect of ICI. Finally, conclusions are put forward.

## II. OPTICAL COMMUNICATION SYSTEM

Fiber optics [1][2] is a medium for carrying information from one point to another in the form of light. Unlike the copper form of transmission, fiber optics is not electrical in nature. A basic fiber optic system consists of a transmitting device that converts an electrical signal into a light signal, an optical fiber cable that carries the light, and a receiver that accepts the light signal and converts it back into an electrical signal. The complexity of a fiber optic system can range from very simple (i.e., local area network) to extremely sophisticated and expensive (i.e., long distance telephone or cable television trunking).

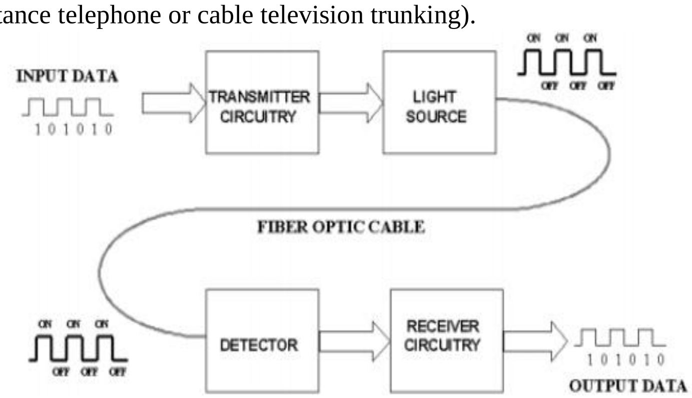


**Fig. 1 Optical Communication System**

## III. INTER CHANNEL INTERFERENCE (ICI)

The effects of inter channel interference on the performance of the receiver. There are two type of inter channel interference are

1. Single-Sided Interference
2. Double-Sided Interference

### *A. Single-Sided Interference*

Interference is a central phenomenon in wireless communication when multiple uncoordinated links share a common communication medium.

1. orthogonalize the communication links in time or frequency, so that they do not interfere with each other at all;

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2. Allow the communication links to share the same degrees of freedom, but treat each others interference as adding to the noise floor.

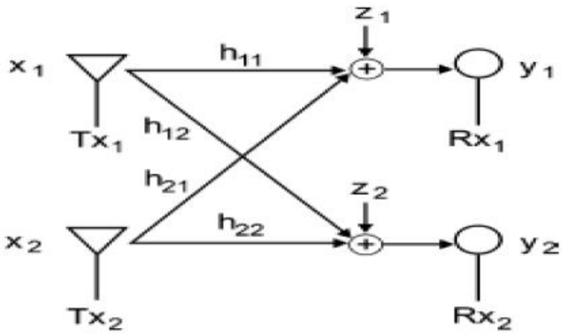


**Fig. 2 Gaussian interference channel**

It is clear that both approaches can be suboptimal. The First approach entails an a priori loss of degrees of freedom in both links, no matter how weak the potential interference is. The second approach treats interference as pure noise while it actually carries information and has structure that can potentially be exploited in mitigating its effect. These considerations lead to the natural question of what is the best performance one can achieve without making any a priori assumptions on how the common resource is shared. A basic information theory model to study this question is the two user Gaussian interference channel, where two point-to-point links with additive white Gaussian noise (AWGN) interfere with each other [10].

Initially, $z(t)$ is assumed to be the received signal. $z(t)$ is a zero mean Gaussian process. This signal has two possibilities
1 = data signal + noise + interchannel interference
0 = noise + interchannel interference
$z(t)$ can be divided in two parts:

$$z(t) = z_a(t) + z_b(t) \tag{1}$$

with $z_a(t)$ a having a rectangular bandwidth $B_0$ , and $z_b(t)$ b having a rectangular bandwidth $kB_0$ . The parameter $k$ is referred to as the channel overlap parameter; it represents the overlapping percentage of an adjacent channel. It varies between 0 and 1, with 0 corresponding to no overlap and 1 corresponding to complete overlap [11][12].

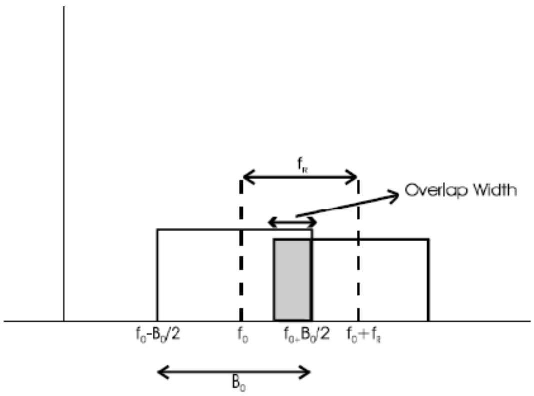


**Fig. 3 Inter Channel Interference**

Fig. 3 illustrates a scenario where one channel is interfering with another. With the aid of this figure we can obtain the mathematical definition of $k$. In fig. 3 $B_0$ is the optical bandwidth and $f_R$ is the channel spacing. The overlap width is defined as

$$\text{Overlap Bandwidth} = B_0 - f_R \tag{2}$$

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The moment generating function of the received signal $z(t)$ in the ON state can be represented as:

$$M_{ON}(s) = \left[1-2(\sigma_s^2-\sigma_n^2)ks\right]^{-2mk}\left[1-2(\sigma_s^2-\sigma_n^2)(1-k)s\right]^{-2m(1-k)} \tag{3}$$

For the OFF case the MGF is obtained in a similar fashion and is given by

$$M_{OFF}(s) = \left[1-2(\sigma_s^2-\sigma_n^2)ks\right]^{-2mk}\left[1-2\sigma_n^2 2m(1-k)s\right]^{-2m(1-k)} \tag{4}$$

### *B. Double-Sided Interference*

Single-sided interchannel interference is only valid for a system which has two channels or for the extreme channels of a system. Thus, for practical systems we have to consider the effect of the interference of both adjacent channels. The difference from the single-sided case is that instead of including only one interfering signal in our calculations, we have to include now two, both having the same variance.
The MGF of the received signal in the ON-state is given by

$$M_{ON}(s) = \left[1-2(3\sigma_s^2-\sigma_n^2)2mks\right]^{-2mk}\left[1-2(\sigma_s^2-\sigma_n^2)2m(1-k)s\right]^{-2m(1-k)} \tag{5}$$

The MGF for the OFF-state is obtain as

$$M_{OFF}(s) = \left[1-2(2\sigma_s^2-\sigma_n^2)2mks\right]^{-2mk}\left[1-2\sigma_n^2 2m(1-k)s\right]^{-2m(1-k)} \tag{6}$$

## IV. MINIMUM MEAN SQUARE ERROR (MMSE) EQUALIZER

Zero-forcing equalizer, although removes ICI and ISI, may not give the best error performance for the communication system because it does not take into account noises in the system. A different equalizer that takes noises into account is the minimum mean square error (MMSE) equalizer [7][8]. It is based on the mean square error (MSE) criterion [5]. Without knowing the values of the information symbols $I_k$ beforehand, we model each symbol $I_k$ as a random variable. Assume that the information sequence is WSS. We choose a linear equalizer $H_E(z)$ to minimize the MSE between the original information symbols $I_k$ and the output of the equalizer.

$$MSE = E\left[e_k^2\right] = E\left[(I_k - \widehat{I}_k)^2\right] \tag{7}$$

Let us employ the FIR filter of order $2L$+1 shown in Fig. 4 as the equalizer. A delay of $L$ symbols is incurred at the output of the FIR filter. Then

$$\begin{aligned} MSE &= E\left[\left(I_k - \sum_{j=-L}^{L} \widehat{I}_{k-j} h_{E,j}\right)^2\right] \\ &= E\left[\left(I_k - \widehat{I}_k^T h_E\right)^2\right] \end{aligned} \tag{8}$$

Where

$$\widehat{I}_k = \left[\widehat{I}_{k+L}, \cdots, \widehat{I}_{k-L}\right]^T$$
$$h_E = \left[h_{E,-L}, \cdots, h_{E,L}\right]^T$$

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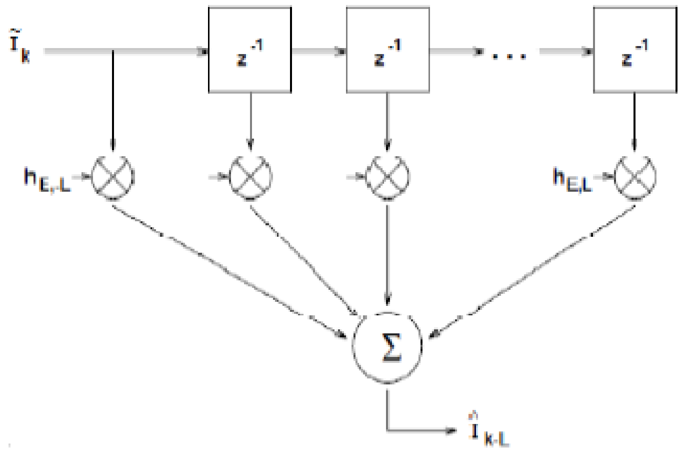


**Fig. 4 MMSE equalizer with FIR filter**

Differentiating with respect to each $h_{E;j}$ and setting the result to zero, we get

$$E\left[\left(I_k - \tilde{I}_k^T h_E\right)\right] = 0 \tag{9}$$

$$\mathbf{R}\mathbf{h}_\mathbf{E} = \mathbf{d} \tag{10}$$

The linear MMSE equalizer can also be found iteratively. First, notice that the MSE is a quadratic function of $h_E$. The gradient of the MSE with respect to $h_E$ gives the direction to change $h_E$ for the largest increase of the MSE. In our notation, the gradient is (d- $Rh_E$). To decrease the MSE, we can update $h_E$ in the direction opposite to the gradient.

## V. LEAST MEAN SQUARE (LMS) EQUALIZER

The LMS algorithm [9] is a type of adaptive filter known as stochastic gradient-based algorithms as it utilizes the gradient vector of the filter tap weights to converge on the optimal wiener solution. It is well known and widely used due to its computational simplicity. It is this simplicity that has made it the benchmark against which all other adaptive filtering algorithms are judged. With each iteration of the LMS algorithm [10], the filter tap weights of the adaptive filter are updated according to the following formula.

$$\mathbf{w}(n+1) = \mathbf{w}(n) + 2\mu e(n)\mathbf{x}(n) \tag{11}$$

Here $\mathbf{x}(n)$ is the input vector of time delayed input values, $\mathbf{x}(n) = [x(n)\ x(n-1)\ x(n-2) \ldots\ldots\ldots\ldots\ x(n-N+1)]^T$. The vector $\mathbf{w}(n) = [w_0(n)\ w_1(n)\ w_2(n)\ \ldots\ w_{n-1}(n)]^T$ represents the coefficients of the adaptive FIR filter tap weight vector at time n. The parameter μ is known as the step size parameter and is a small positive constant. This step size parameter controls the influence of the updating factor. Selection of a suitable value for μ is imperative to the performance of the LMS algorithm, if the value is too small, the time adaptive filter takes to converge on the optimal solution will be too long; if μ is too large the adaptive filter becomes unstable and its output diverges.

## VI. SIMULATION RESULTS

In this section, the simulation is carried out for mitigation of the inter channel interference (ICI) on the basis of Minimum mean square error (MMSE) equalizer and Least mean square (LMS) equalizer. Simulations are performed using MATLAB. Fig. 5 shows the BER analysis for Compensate inter-channel interference using Minimum mean square error (MMSE) equalizer and Zero Forcing (ZF) equalizer. Fig. 6 demonstrates the BER analysis for Compensate inter-channel interference using Minimum mean square error (MMSE) equalizer and least mean square (LMS) equalizer. Fig. 7depits the BER analysis for Compensate inter-channel interference using Minimum mean square error (MMSE) equalizer, least mean square (LMS) equalizer and Zero Forcing (ZF) equalizer.

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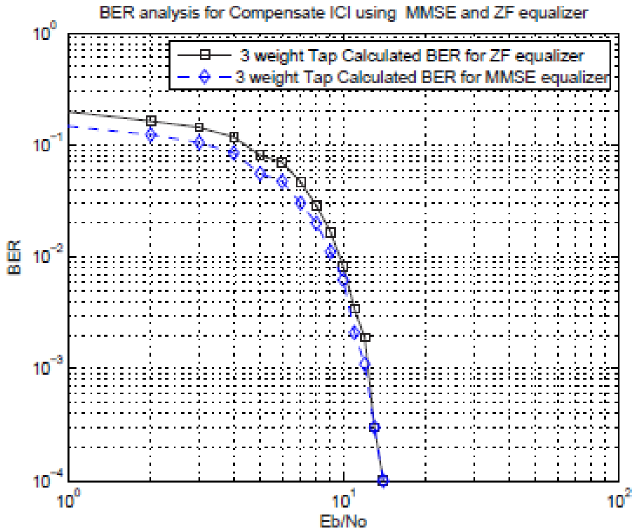


**Fig. 5 BER analysis for Compensate inter-channel interference using Minimum mean square error (MMSE) equalizer and Zero Forcing (ZF) equalizer**

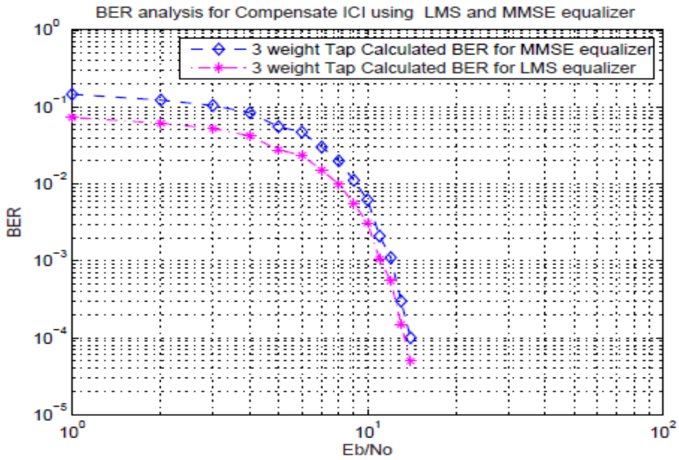


**Fig. 6 BER analysis for Compensate inter-channel interference using Minimum mean square error (MMSE) equalizer and least mean square (LMS) equalizer**

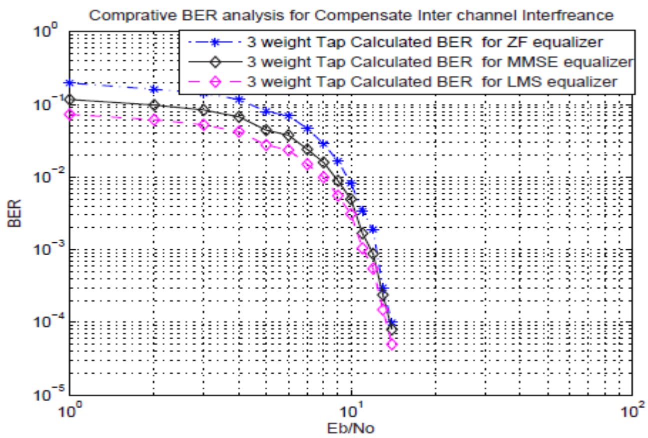


**Fig. 7 BER analysis for Compensate inter-channel interference using Minimum mean square error (MMSE) equalizer, least mean square (LMS) equalizer and Zero Forcing (ZF) equalizer.**

## VI. CONCLUSIONS

Different equalization techniques are employed to reduce the effect of inter-channel interference. Here, we use two equalization techniques to reduce the effect of inter-channel interference. Firstly, Minimum mean square error (MMSE) equalization technique is applied at the receiver to reduce the effect of ICI in channel by applying inverse filtering. Secondly, we use least mean square (LMS) equalization technique is apply at the receiver to reduce the effect of ICI in channel. Experimental results are performed to evaluate the effectiveness of the proposed equalization techniques. Results reveal that the LMS equalizer performed better than MMSE equalizer in terms of bit error rate.

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