International Journal of Engineering Sciences Paradigms and Researches Vol. 06, Issue 01, July 2013
ISSN (Online): 2319-6564
www.ijesonline.com

Activity Detection Using Adaptive Decision Feedback Equalizers (DFE) in Optical Communication

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Abstract

The current paper, proposes an adaptive equalizer by integrating the fractional spaced equalizer (FSE) with decision feedback equalizer (DFE) for optical channel to remove the problem of pulse dispersion effect in optical link, in addition, for further improvement in the performance of the equalizer we propose adopting the activity detection guidance(ADG) with tap decoupling (TD) in the fractional spaced decision feedback equalizer (FSDFE) to get fruitful outcomes in the performance of the system without shortcomings. We propose a fractionally spaced decision feedback equalization (FSDFE) structure which replaces the symbol spaced feedback filter with a fractionally spaced feedback filter. We could improve the stability, the steady-state error performance and the convergence rate. As the impulse response of a typical optical link would have regions that are essentially zero, the employment of the activity detection scheme with Tap Decoupling would further enhance the steady-state error performance and convergence rate. The simulation results revealed that: the FSDFE with ADG and TD offers a superior performance than its counterpart without ADG and TD. Where, it offers improvement in the effectiveness of amplitude distortion. Moreover, as the impulse response of a typical optical link would have regions that are essentially zero, the employment of the ADG scheme would further enhances the steady-state error performance and convergence rate.

Keywords: *I.S.I, DFE, FSE, FSDFE, ADFE, ADG and TD.*

1. Introduction

As communication speed is increasing rapidly over the years. Long haul transmission in optical communications usually consists of several key factors to ensure that the data transfer is error-free. These key factors which include the modulation method, type of amplifier used, and the error correction scheme and dispersion compensation. In optical communications, high-speed data transfer is often limited by signal distortion, which is mainly caused by the broadening of pulses that result in Inter symbol Interference (ISI).

There are two different forms of dispersion, such as: Intermodal dispersion which occurs only in multimode fiber due to different velocities for different modes and hence, it reduces the performance of optical network at higher data rates. Other is intra modal dispersion which occurs in all types of fibers. Intra modal dispersion occurs because different colors of light travel through different materials and different waveguide structures at different speeds. Intra modal dispersion or called chromatic dispersion (CD) can be divided into two types: the first one, is called material dispersion which limits the fiber bandwidth or the information-carrying capacity of the fiber and also limits the transmission distance, since the shorter the pulses, the more susceptible they are to lSI. The second type of dispersion is the waveguide dispersion, occurs because the single-mode fiber only confirms about 80 percent of the optical power to the core. Thus dispersion arises since the 20 percent of the light propagating in the cladding travels faster than the light confined to the core. So, dispersion occurs because light propagates differently in the core than in the cladding. Hence, intra modal dispersion can be expressed mathematically by:

$$\mathbf{Dintramodal = D_m + D_{WG}}$$

Where: $\mathbf{D_M}$ is the material dispersion,

$\mathbf{D_{WG}}$ is the waveguide dispersion.

The aim of this paper is first to evaluate the causes of dispersion in a typical optical link and its limiting effects to the possible communication capacity, by comparing AWGN channel and rayliigh channel and varying the value of τ in impulse response of optical channel and reproduce the original signal at the received end. The numerous techniques in adaptive equalization and equalizer structures are then researched upon, to come up with a suitable and effective equalization approach for a typical optical channel. Finally, the researches in these two main areas are combined to design an adaptive equalizer to mitigate the pulse dispersion effects of an optical link. A range of adaptive algorithms and equalizer structures were studied and evaluated. The Least Mean Square (LMS) algorithm was chosen for its robustness and computational simplicity.

2. Impulse Response Analysis of Optical Channel

The impulse response of a typical optical channel represented by a cosine-squared pulse shape and is given by:

$$h(t) = \begin{cases} \frac{2cos^2}{\tau}\frac{\pi t}{\tau}, & -\frac{\tau}{2} \leq t \leq \frac{\tau}{2} \\ 0 & elsewhere \end{cases}$$

and the frequency response of the base band is given by

$$H(f) = \frac{\sin \pi f \tau}{\pi f \tau}\left[\frac{1}{1-f^2\tau^2}\right]$$

3. Proposed Adaptive Equalizer

Linear equalizer is no longer useful for high data bit rate with a dispersive optical channel which suffers from ISI or amplitude distortion. The only optimum use for this equalizer is when the channel does not suffer from amplitude distortion. On the other hand, non-linear equalizer has approved its capability to provide superior performance in amplitude distorted channel and it will be very beneficial and relevant to the application in optical communications. So in this paper, proposes to enhance the performance of optical communication channel by employing adaptive nonlinear equalizer in the receiver section. The principles of adaptive equalizer have been compensate the dispersion in optical channel, which allow longer haul communication before requiring a repeater, there benefits are to save infrastructure and equipment cost for optical communication link. It is defined as the equalizer which adjusts himself to different environments. Adaptive equalizer involves a process of filtering some input signal to match a desired response. Its parameters are updated automatically by making a set of measurements of the underlying signals and applying that set to the adaptive filtering algorithm such that the difference between the filter output and the desired response is minimized in either a statistical or deterministic sense. We have several numbers of adaptive algorithms, the most important of them are the least mean squares (LMS) error algorithm and recursive least squares (RLS) algorithm. Each one algorithm has its own unique properties and applications. The criterion used in the adaptive LMS algorithm is the minimization of the mean square error (MSE) between the desired equalizer output and the actual equalizer output in forthe N-taps adaptive transversal filter and the output is given by:
$y(n)=\sum_{i=0}^{N-1} w_i\,(n)\,x(n-i)$

Where: x(n) is the filter input, w(n) is the tap weight

Fractionally-Spaced Equalizer (FSE)

Fractionally Spaced Equalizer (FSE), which is based on sampling the incoming signal at least as fast as the Nyquist rate. Fractionally-spaced is independent of the channel delay distortion, which have taps that are spaced closer than conventional adaptive equalizers. It is almost Fractional spaced equalizer can negate the channel distortion without enhancing the noise (R. D. Gitlin, et al. 1981). Given the above properties, the FSE technique is a highly desirable application since it minimizes noise enhancement. With appropriately chosen tap spacing; the FSE can be configured as the excellent feed forward filter. When we combine the DFE with FSE technique, we can expect an equalizer with the following qualities:

1. Minimize noise enhancement
2. Excellent amplitude distortion performance

Decision Feedback Equalizer

In a Decision Feedback Equalizer, both the feed forward and feedback filters are essentially linear filters. DFE is a non-linear structure because of the non-linear operation in the feedback loop (decision threshold); its current output is based on the output of previous symbols. The reason for choosing DFE over linear equalizer is that the latter's performance in channel that exhibit nulls is not effective. In contrast, the decision feedback equalizer has zero noise enhancements in the feedback loop. The above DFE structure has $N_1 + N_2 + 1$ feed forward taps and N_3 feedback taps. The output of the equalizer is given by:

$$d_k^{\wedge}=\sum_{n=N_i}^{N_2} c_n^{*}\, y_{k-n} \sum_{i=1}^{N_2} F_i\, d_{k-i}$$

Where c_n^* is the tap gain andy_n is the input for the forward filter,$F_i^*$is the tap gain for the feed back filter and d_i (i<k) is the previous decision made on the detected signal.

Activity Detection Guidance

Activity detection guidance is a method of detecting active taps in a communication channel. By implementing a technique capable of detecting active taps in the channel, non-active taps can be excluded in the estimation of the channel response. This relieves the computational burden of the LMS algorithm, as well as to give a better convergence rate and asymptotic performance. The detection of the 'active' taps of a time-invariant channel is governed by the equation (John Homer, et al. 1998):

$$c_{k,n} = \frac{\left(\frac{1}{N}\sum_{i=1}^{N} iu.y_{i-k+1}\right)^2}{\frac{1}{N}\sum_{i=1}^{N}(y_{i-k+1})^2}$$

where i=time index, k=tap index, and N is the number of input samples. C_k is known as the activity measure. In order to determine a tap to be active, the value of the activity measure, C_k, must be above a certain threshold. This activity threshold is given by:

$$C_{K,N} \; > \sum_{i=1}^{N} \frac{(iu)^2.\log{(i)}}{i}$$

Activity Detection Guidance with Tap Decoupling

Modifications to the activity measure have to be made to reduce the tap coupling effect (John Homer, et al. 1998).

$$CC_k{}^{=}\textstyle\sum_{i=1}^{N} \frac{[(iu-hiu_i+H_k y_{i-k+1}).(Y_{i-k+1})]^2}{\sum_{i=1}^{N}(Y_{i-k+1})^2}$$

4. Simulation Results and Discussions

Performance Evaluation for FSDFE using Standard LMS Algorithm:

It is clear that the simulated impulse response is resembling a cosine-square shape and having a total of 7-taps. The feed forward section has a total of 6-taps, the first tap has a magnitude of I and the fourth tap has a magnitude of 0.8. The rest of the taps are in active or zero except for tap 7, which is the feedback tap with a magnitude of 1. On the other hand, for the estimated channel impulse response we have run the equalizer for 30000 sample inputs in order to achieve an impulse response in close proximity to the actual simulated channel. It is clear that the channel bears a fair resemblance of the simulated channel. But, the inactive taps, which were supposed to be zero, were not flat. This is due to the noisy estimates of the inactive taps in the channel.

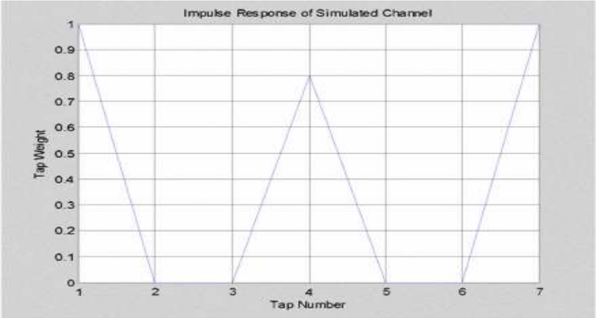

Fig. 1: Simulated channel impulse response for FSDFE

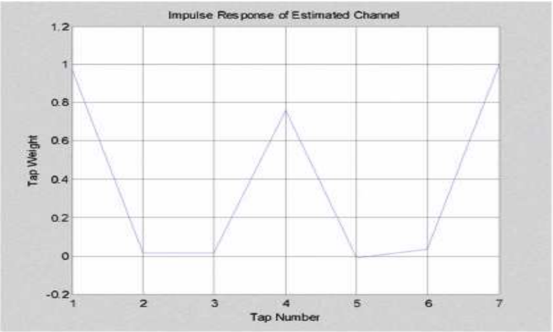

Fig. 2: Estimated channel impulse response for FSDFE

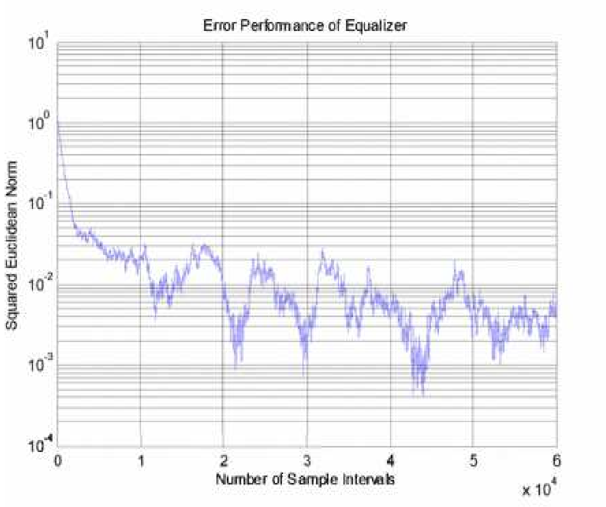

Fig. 3: Asymptotic performance for FSDF

Performance Evaluation for FSDFE with ADG and Tap Decoupling

We have noticed that the inactive taps in the estimated channel were not estimated at zero Adopting ADG with FSDFE could improve the convergence rate and asymptotic performance, detect the non active taps, disregard them in the calculation of the tap weight adoption and set them to zero. However, the true number of active taps cannot be detected accurately and the inactive taps will still suffer from the noisy estimates that are common in any communication channel. The inability to detect the true number of active taps accurately is due to the correlation within the input signal that is causing the coupling amongst the output of the unknown channel taps.

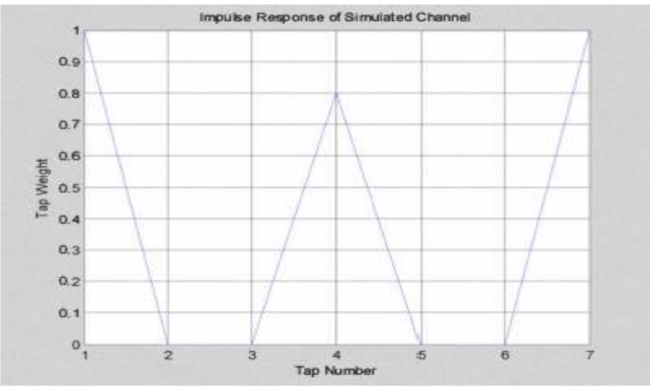

Fig. 4: Simulated channel impulse response.

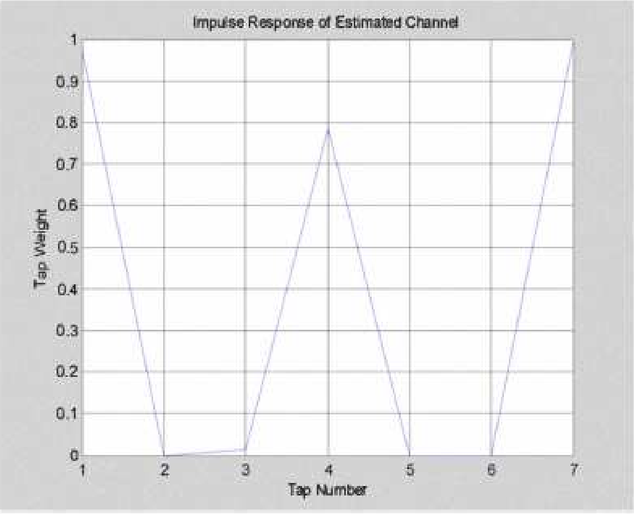

Fig. 5: Estimated channel impulse response.

Results of Impulse Response of Optical Channel When$\tau = 4$

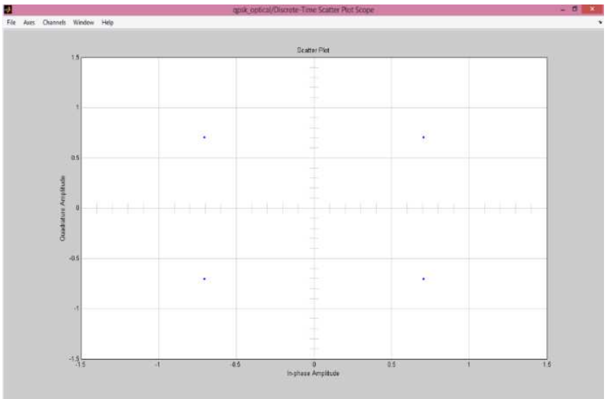

Figure 6.1:-Scatter plot before channel

The constellation diagram of QPSK before channel is shown in figure 6.1. QPSK uses four points on the constellation diagram, equispaced around a circle. With four phases, QPSK can encode two bits per symbol.

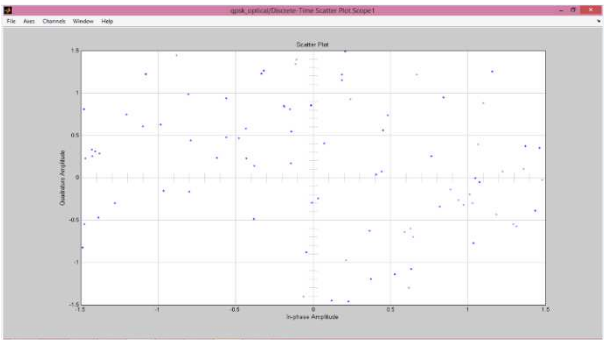

Figure 6.2:- Scatter plot after channel

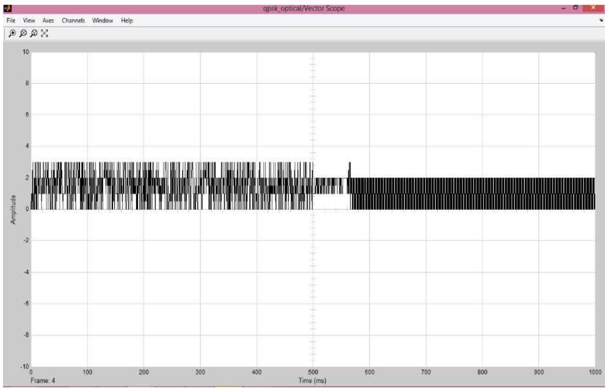

Figure 6.3- Scatter plot after demodulation

The Scatter plot after optical channel between in-phase amplitude and quadrature amplitude is shown in figure 6.2; noise is added with the transmitted signal.

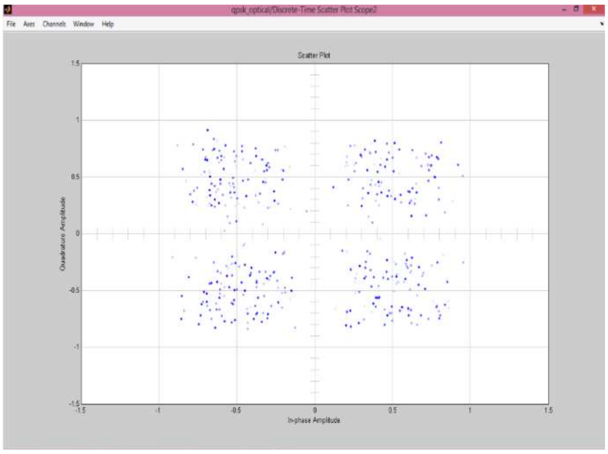

Figure 6.4- Scatter plot after equalizer

The scatter plot after equalizer, the error is reduced is shown in figure 6.4 and we get the confined results.

Result Of Impulse Response of Optical Channel When τ =3

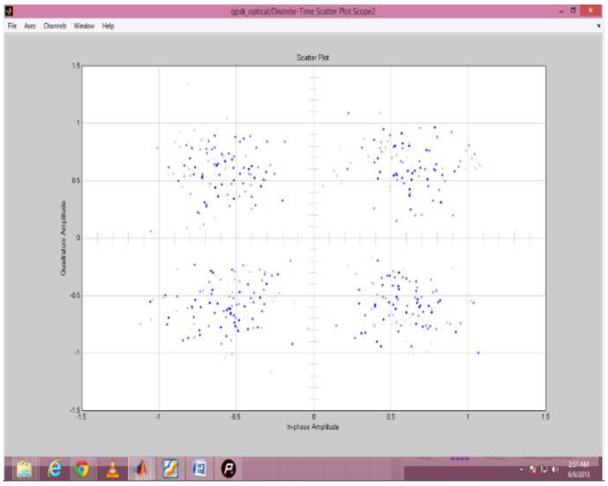

Figure7.1:- Scatter plot after Equalizer

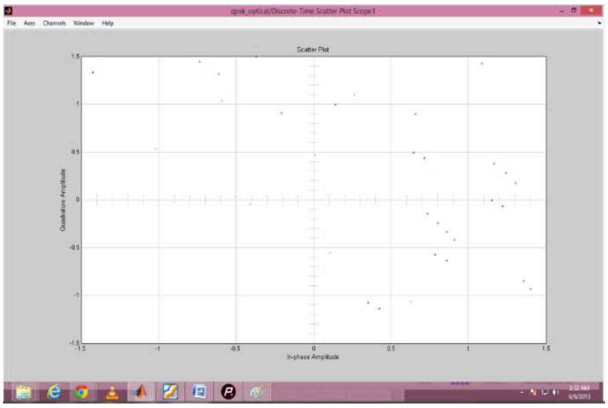

Figure7.2:- Scatter plot after Channel

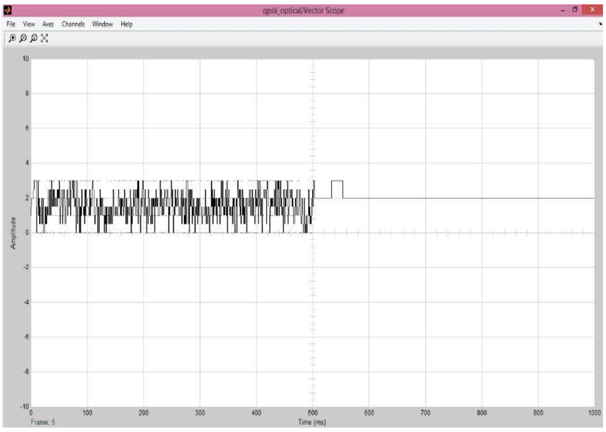

Figure7.3:- Scatter plot after modulation

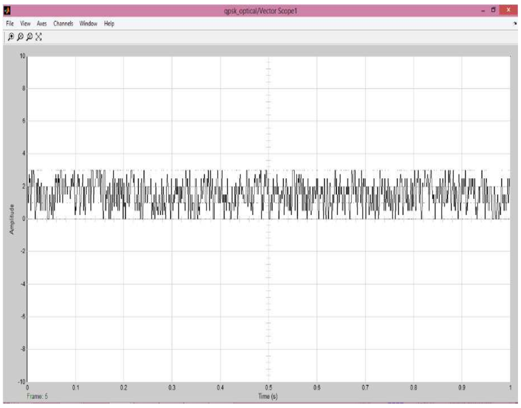

Figure 7.4:- Scatter plot Receiver

We have compared the results for τ = 4 and τ = 3.And at τ = 4 w get better Results. At the receiver error is reduced.

5. Conclusion

The objective of this paper is to develop a suitable adaptive equalization technique to mitigate the effects of ISI and dispersion in a typical optical communication channel. With the successful development of the adaptive modified Decision Feedback Equalizer with activity detection guidance and tap decoupling, it offers an excellent alternative to the existing equalization techniques available in the optical communication. The adaptive equalizer was implemented using the Least Mean Square (LMS) technique, using stochastic gradient adaptation. This led to a faster convergence rate, as only the active taps need to be adapted, and better asymptotic performance as shown clearly. In the nutshell, this work has demonstrated the successful implementation of an adaptive modified Decision Feedback Equalizer with ADG and TD in a typical optical communication channel. The theoretical research and findings were successfully implemented and proven. This design approach is a promising alternative for equalization in optical communications.

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