ADAPTIVE FAST BLIND FEHER EQUALIZERS (FE) FOR FQPSK

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ABSTRACT

The performance of novel experimental blind equalizers suitable for a large class of applications including telemetry systems and other wireless applications is described. Experimental hardware research of these adaptive patent pending Feher Equalizers* (FE) confirms computer simulated data [1]. A two-ray RF selective faded telemetry channel has been simulated. A dynamically changing channel environment with a selective fade rate in the 1Hz to 50Hz range has been constructed by laboratory hardware. The Test and Evaluation (T&E) setup had RF frequency selective dynamic notch depth variations in the Power Spectral Density (PSD) within the band of the signal of up to 15dB. As an illustrative example of the adaptive equalizer capability we used a 1Mb/s rate Feher patented FQPSK [1] Commercially Of The Shelf (COTS) product. Both hardware experimental results as well as simulation indicate substantial performance improvement with the utilization of the FE. It is demonstrated that the FE improves for a large class of frequency selective faded systems the Bit Error Rate(BER) from 10^{-2} to 10^{-6}. Similar performance improvements are presented for the Block Error Rate (BLER).

KEY WORDS

Adaptive equalization, telemetry, Test and Evaluation (T&E), Feher patented Quadrature Phase Shift Keying (FQPSK), Feher Equalizer (FE).

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* Significant part of the material in this publication is based on Feher et al. patents [1] and on other material which remains property of the authors

INTRODUCTION

This paper describes experimental research and obtained results related to novel low-complexity IF adaptive equalization techniques [1]. IF equalization techniques offer some advantages over baseband techniques in terms of simpler implementation complexity, faster synchronization time as well as performance in low C/N environments. An original technique for adaptation is introduced here. It does not require any training sequence or redundancy in the transmitted information, a frequent requirement in adaptive equalization. This technique of non-redundant error detection is successfully used in combination with some additional logic circuitry for control and further processing and a simple equalizer to combat ISI. Two specific equalization techniques are proposed and described. The first technique is able to compensate more effectively for dynamically changing channel fade depths while the second is able to compensate for more significant changes of the fade position within the received signal bandwidth. The frequency selective fading channel that is implemented in lab conditions is similar to a popular channel model published in the related literature, namely the 2-path Rummler model [2] and [6]. As performance criteria for the proposed equalization techniques both BLER and BER have been used. The experimental results clearly indicate significant performance improvement (about at least 5 dB) with the proposed equalization techniques.

In the second part brief description of the IF equalization concepts is presented as well as the constructed hardware channel model and its implementation. The third part introduces briefly the PE concept and the used specific implementation of the PE detector. Parts IV and V describe the obtained measurement results. In part VI the computer simulation model and simulated results are presented. In part VII conclusions are drawn about the overall performance of the proposed FE techniques.

RF FADE SIMULATOR CONSTRUCTION BASED ON THE RUMMLER PROPAGATION MODEL

The multipath fading channel model used in this experimental work can be described basically in terms of a primary ray and a dominant interference ray i.e. a simple two-ray model, originally described by Rummler [6]. This leads to a simplified two-ray model with a transfer function:

$$H(jw) = 1 + b^{*}e^{-jw\tau} \qquad (1)$$

The frequency response of such a channel is shown in Fig. 1. In (1) we have only 2 parameters, the relative delay τ of the second path and its relative amplitude “b”. The delay used by Rummler to characterize the channel is 6.3ns. For aeronautical telemetry channels we understand that the delay could be in the 5 ns to 2 microseconds range. For this reason the used delays in our experimental work are in the 500ns to 1.5 microseconds range.

As shown in Fig. 2 this channel model can be easily implemented in hardware by using easily available laboratory components such as delay lines, attenuators , mixers , power splitters/combiners. Here by changing the variable gain in one of the paths we can simplistically generate a dynamically changing time-variable RF channel.

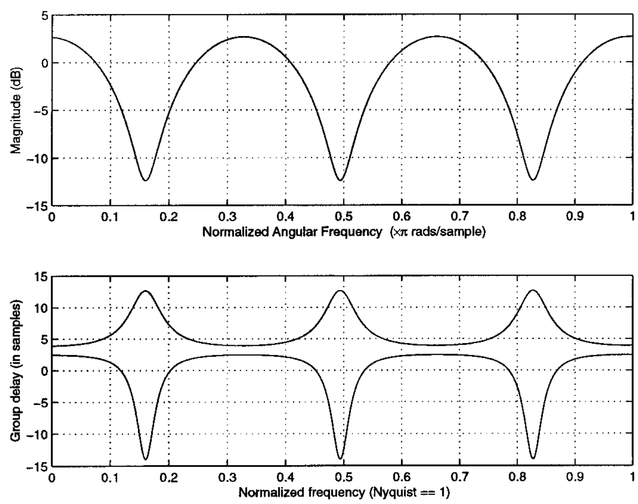


Fig. 1 RF channel frequency response and group delay

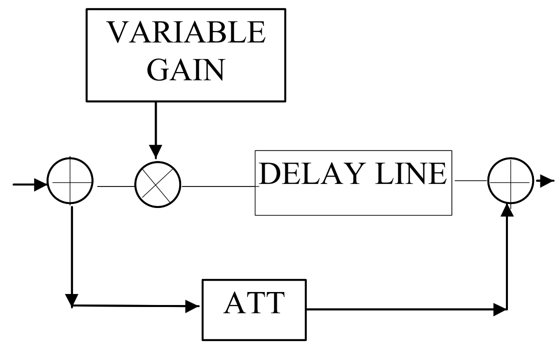
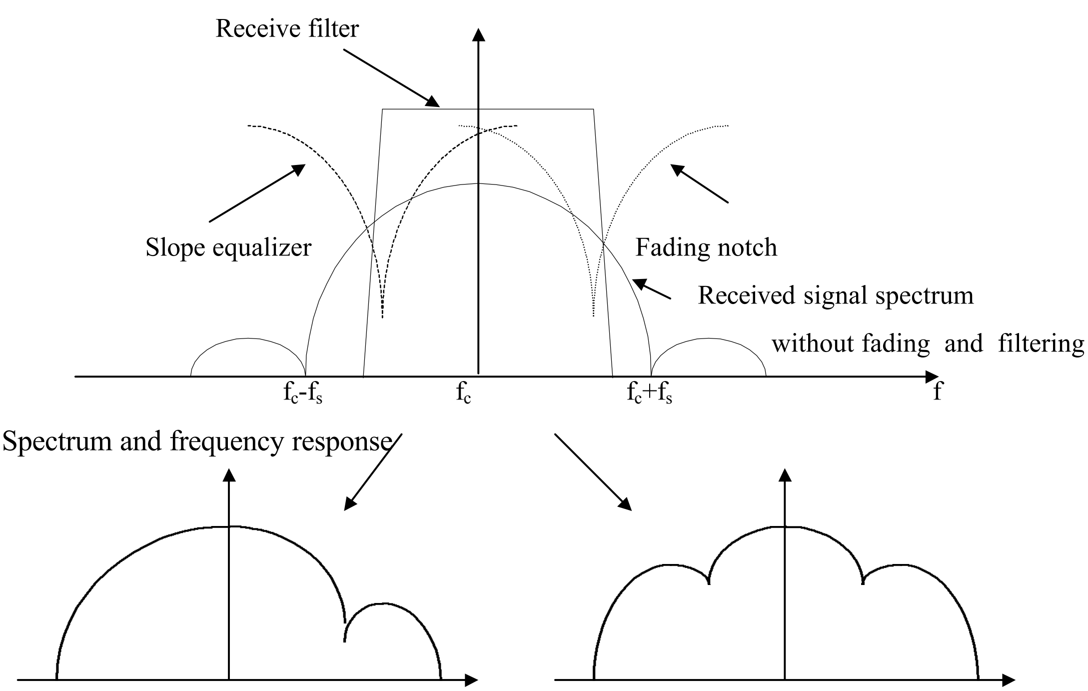


Fig. 2 A simple experimental hardware implementation of a two-ray RF channel transfer function



(a) Spectrum and frequency response

(b) Spectrum before IF equalization

(c) Spectrum after IF equalization

Fig. 3 Concept of a very simple IF equalizer

In general the adaptive IF equalizer corrects RF path distortions by generating complimentary distortions of amplitude and associated group delay which will cancel the channel distortion. As illustrated in Fig. 3 the frequency response of a simplest IF equalizer is symmetrical to that of the fading channel. Also its slope is opposite to the slope of the RF channel transfer function. The spectrum of the faded signal prior to the IF slope equalizer is asymmetrical and has a deeper notch , while the spectrum of the equalized signal after IF slope equalizer is symmetrical and has two shallower notches. Thus an IF equalization stage could be used at the receiver side for compensation of the distortion introduced by the channel.

Two different equalization techniques have been considered in this work:

1. The time variable gain in the RF channel block diagram leads to a dynamically changing channel fade depth. A simple IF equalization stage is being driven by a PE derived control parameter and compensates accordingly for the dynamic variations of the channel fade depth.
2. A dynamically changing fade position within the signal bandwidth is being compensated by multiple IF stages each associated with a different delay of the second path. Thus this equalization technique (Feher Rake-"FR" [1]) adaptively introduces a compensation notch at a different location within the signal bandwidth any given time.

PSEUDO-ERROR MONITOR TECHNIQUES

A pseudo-error detector can be used successfully for the measurement of the BER of an on-line digital communication link [1]. It is basically implemented in the form of a second detector, which is intentionally more perturbation sensitive i.e. for a specified S/N ratio or ISI or other impairment it introduces more errors than the primary signal path detector. Thus a pseudo-error derived control signal which is a measure of the amount of ISI present in the received signal is further processed and used in an adaptive control loop.

PSEUDO-ERROR BASED FEHER EQUALIZER (FE)

A time-variable RF fading channel is simulated by laboratory hardware set-up. Throughout the experiment the dynamic change in the channel and the effect of equalization can be observed both on the spectrum analyzer in terms of the received signal spectrum and on the oscilloscope in terms of the eye diagram opening or closing. Figure 4 shows a frequency domain picture of the normal spectrum and the distorted one. We clearly see the introduced channel notch within the spectrum. Figure 5 shows again the normal spectrum vs. the equalized one. The introduced by the equalizer compensation notch significantly opens the eye pattern. The corresponding eyes for figures 4 and 5 are shown in figures 6 and 7 respectively.

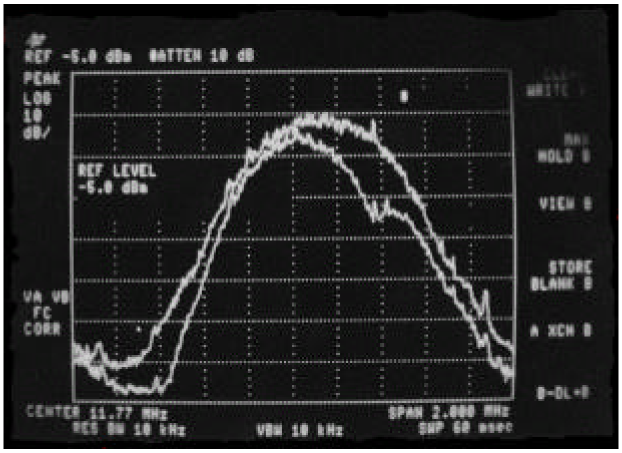


Fig.4 Undistorted spectrum vs. distorted (RF delay spread) received spectrum of a 1Mb/s rate FQPSK hardware system without adaptive FE equalizer

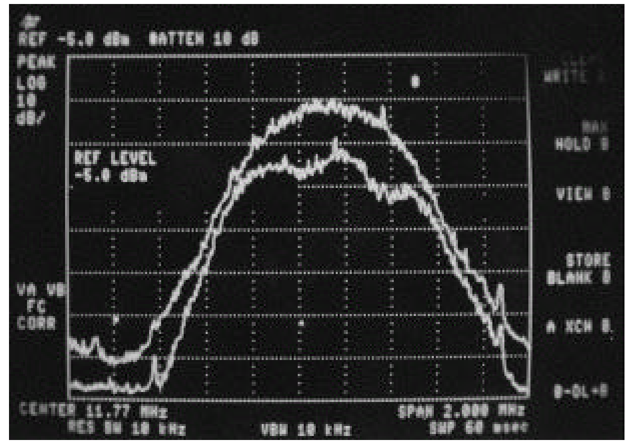


Fig. 5 Undistorted vs. equalized spectrum of a 1Mb/s FQPSK system, which has suffered spectrum distortions shown in Fig. 4

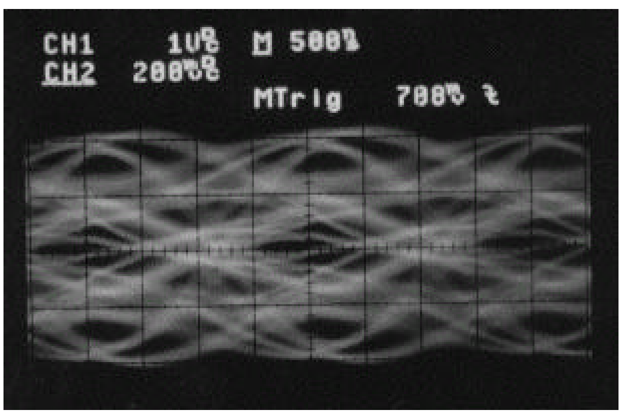


Fig.6 Unequalized eye diagram of an FQPSK receiver of a simplistically distorted RF spectrum (corresponding to Fig. 4) due to RF selective fading

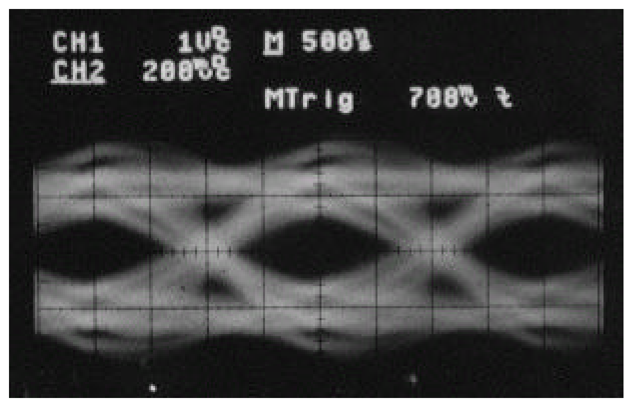


Fig. 7 The significantly distorted eye diagram of Fig.6 is improved by the adaptive FE (Feher Equalizer) ; the corresponding equalized spectrum is shown in Fig. 5

EXPERIMENTAL PRELIMINARY HARDWARE RESEARCH T&E RESULTS

The impact of the rate of change of the channel dynamics as well as the depth of the channel notch has been investigated and the performance of the described equalization techniques illustrated by the measurement results. Figure 8 displays obtained results with and without the equalizer for two different cases of the maximum range of the dynamically changing fade depth, namely for 10dB and 15 dB range of change. In both cases the rate of change of the fade is 2Hz. Figure 9 display similar results for fade rate of change of 50 Hz.

Both plots clearly indicate that the equalizer is able to eliminate the existing error floor and produce significant improvement.

From figures 8 and 9 we notice that despite some deterioration of equalizer performance in case of faster channel dynamics (Fig. 9) it is still able improve the performance considerably.

PERFORMANCE OF AN EXPERIMENTAL ADAPTIVE FEHER RAKE (FR) ADAPTIVE RECEIVER [1]

The preliminary hardware research performance results of a Feher Rake ("FR") patent pending [1] adaptive systems are illustrated in Fig. 10 and 11 (BLER and BER respectively) and clearly indicate about 5dB improvement on the average with the "FR" equalizer.

COMPUTER SIMULATIONS OF THE HARDWARE EXPERIMENTS

Computer simulations in MATLAB of the above mentioned hardware research experiments were carried out. An NRZ data stream was modulated using computer simulated FQPSK modulator [1]. Analytically defined channel was simulated using equation (1) . Figures 12a,b present the computer simulated eye diagrams before and after equalization. An FQPSK demodulator was simulated and the obtained baseband eye sampled. One of the reasons for the slightly better computer simulated results shown below is the fact that the gain of the derived adaptive control signal depends not only on the amount of ISI but also on the current S/N ratios. While in the simulations this is easier to account for, in a hardware implementation this would suggest much more complicated design. A Monte Carlo simulation was carried out and the obtained results are compared to the hardware measurement under the same conditions. Generally the simulated curves follow the measured results as is seen from figure 13.

CONCLUSIONS

The initial performance of a new class of low-complexity adaptive blind equalization techniques has been described. Both the experimental hardware research and the computer simulations demonstrate substantial performance improvement with the proposed techniques. The carried out experimental work provides us with a qualitative as well as quantitative assessment of these techniques thus adding new alternative approaches and concepts to the body of knowledge on channel fading countermeasures and adaptive equalization.

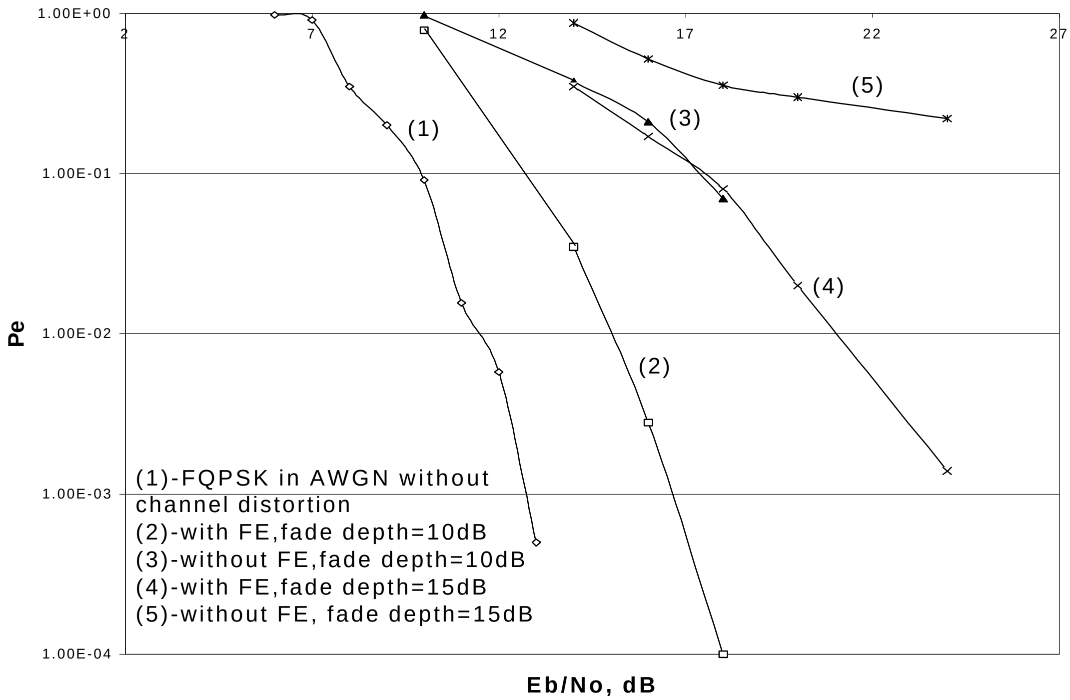


Fig. 8 Block Error Rate (BLER, 1 block=1000 bits) of FQPSK with two-ray dynamic RF channel, fade speed is 2Hz

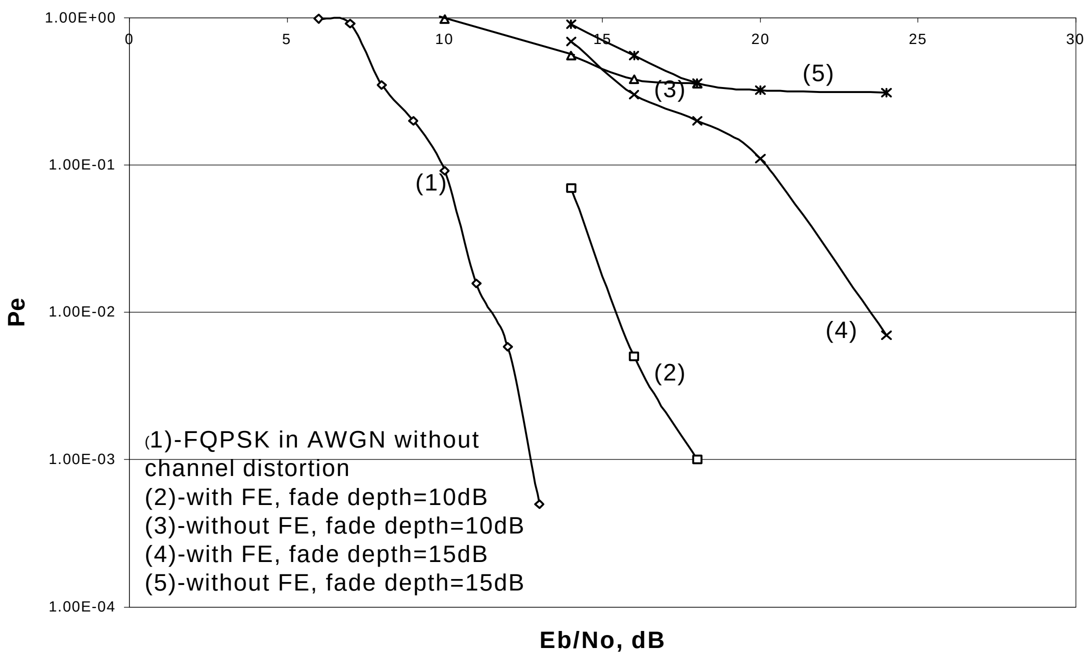


Fig. 9 Block Error Rate (BLER, 1 block=1000 bits) of FQPSK with two-ray dynamic RF channel, fade speed is 50Hz

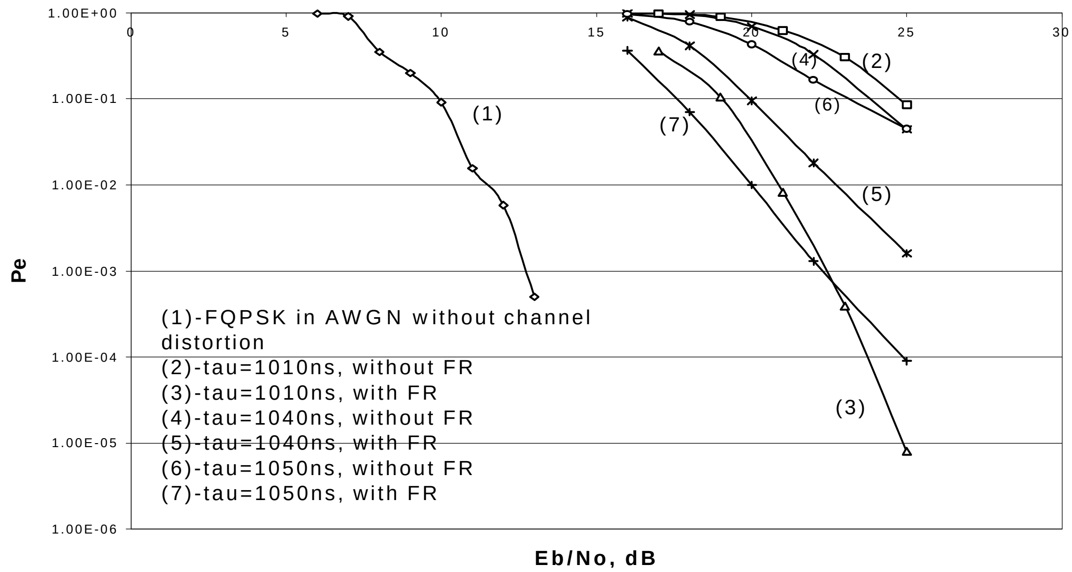


Fig. 10 BLER of FQPSK with and without Feher Rake (FR) equalizer for different delays (tau) of the RF channel fade

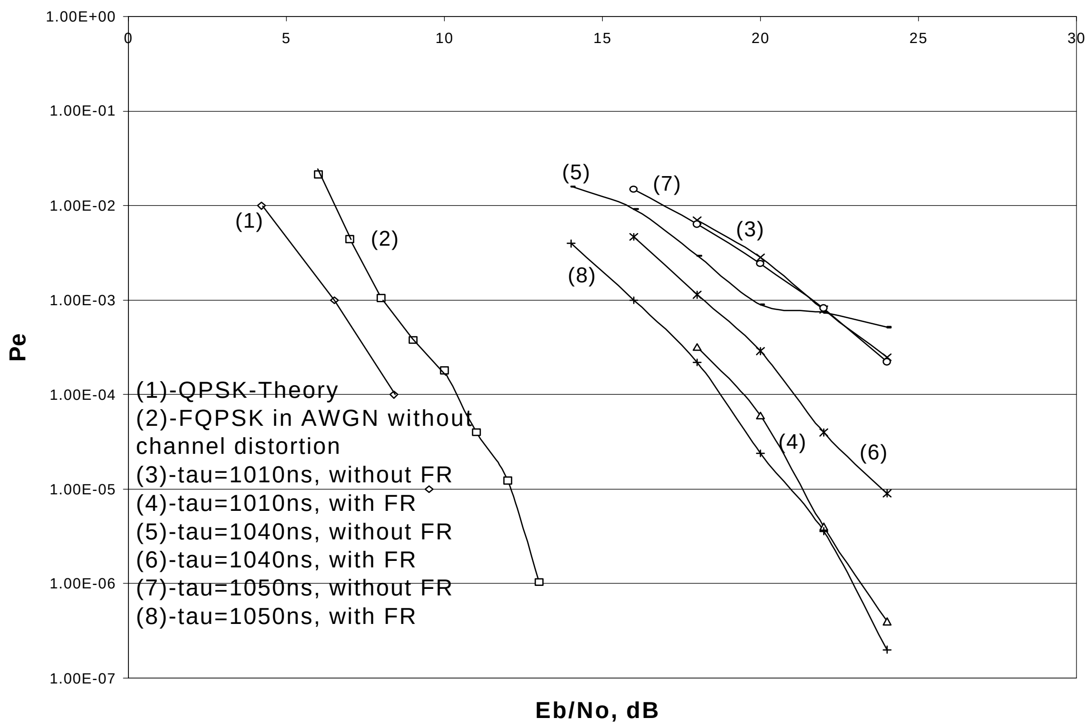


Fig. 11 BER of FQPSK with and without Feher Rake (FR) equalizer for different delays (tau) of the RF channel fade

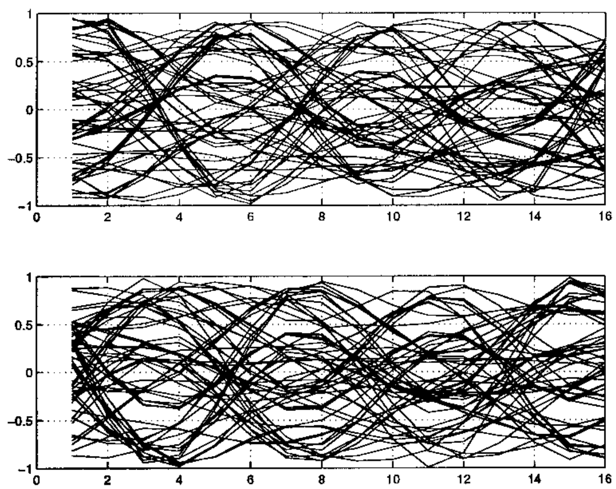


Fig. 12a Computer generated (in Matlab) demodulated eye diagram of the I-channel of a severely distorted (RF selective faded) FQPSK signal without FE (Feher Equalizer) illustrates unacceptably high ISI level corresponding to significant error floor

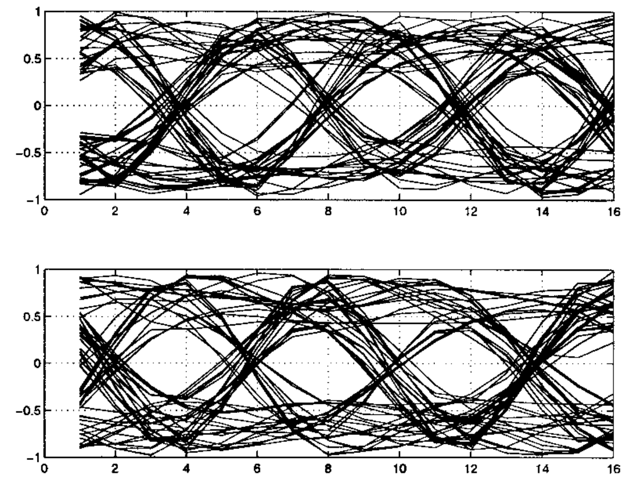


Fig. 12b The distorted eye diagram of Fig. 12a is “opened” significantly with the used adaptive FE(Feher Equalizer)

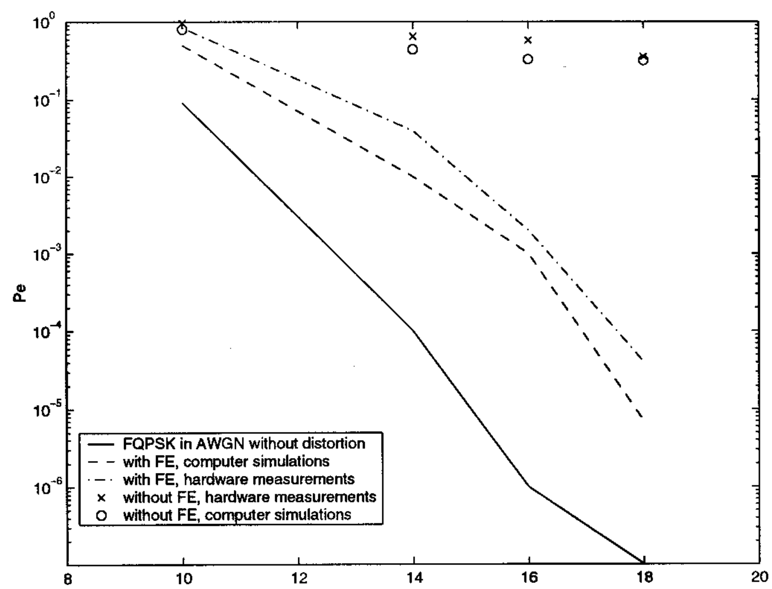


Fig. 13 BLER of FQPSK with two-ray RF fading channel, comparison of hardware measurement results and computer simulations

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