Capsim Application Note

Blind Equalization of Mobile Fading Channels

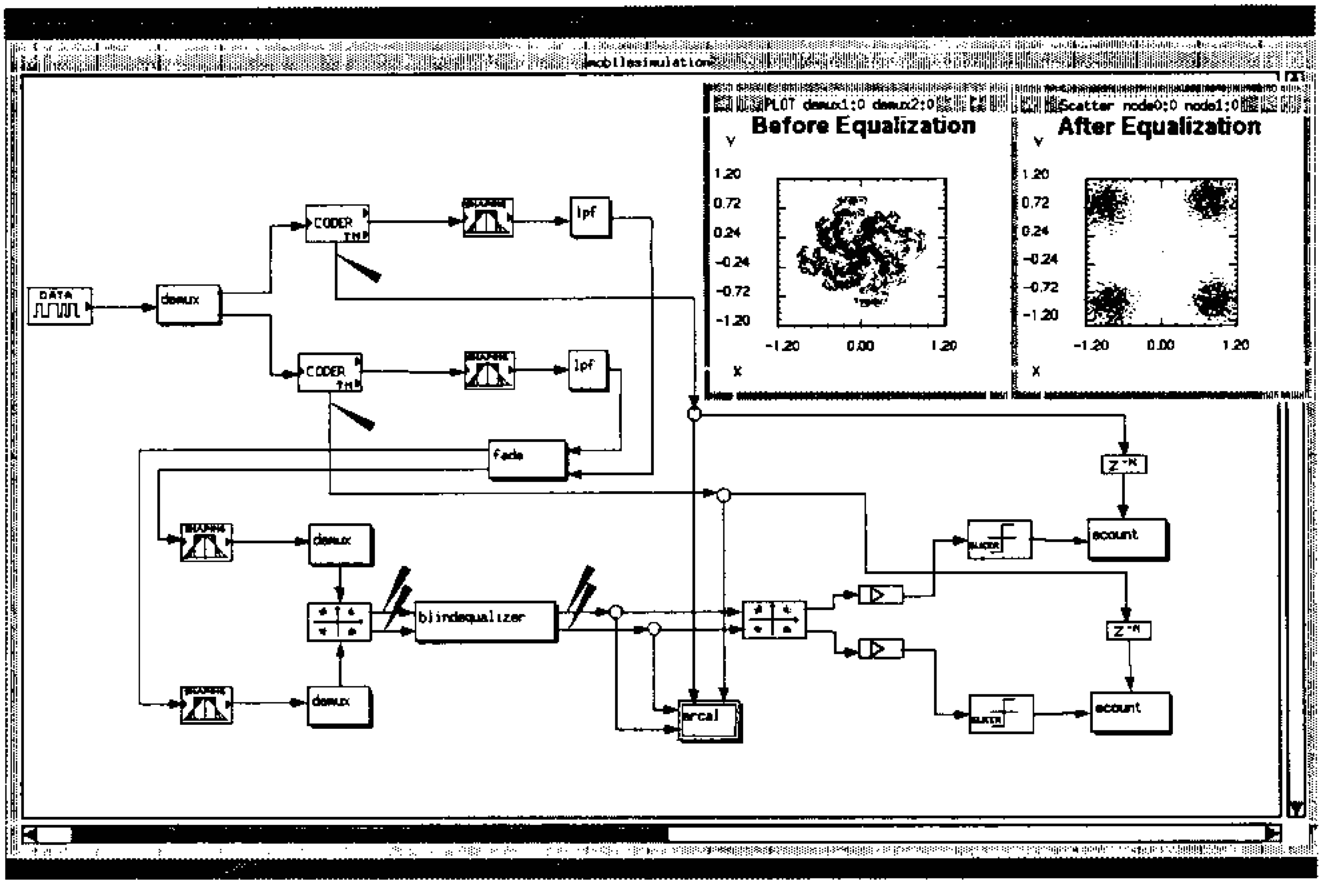

Figure 1. CAPSIM* topology for the simulation of the Optimal Decision Directed Blind Equalization Algorthm [1] in a mobile fading channel environment

1. Introduction

With the emergence of cellular telephones and mobile data communication systems, today's engineers face the challenging problem of combating time-varying multipath fading phenomenon introduced by mobile communication channels. One effective way for combating the distortion introduced by mobile communication channels is to use adaptive equalization in the receiver. However, rapid changing characteristics of mobile communication channels require the frequent use of training sequences which greatly reduces the transmission efficiency. Therefore, the concept of "blind" equalization is more appealing than ever for the equalization of mobile communication channels. However, there are two important limitations of blind equalizers which hinder their application

* Capsim is available from XCAD Corporation, Suite 429, 659 Cary Towne Blvd, Cary, NC 27511.

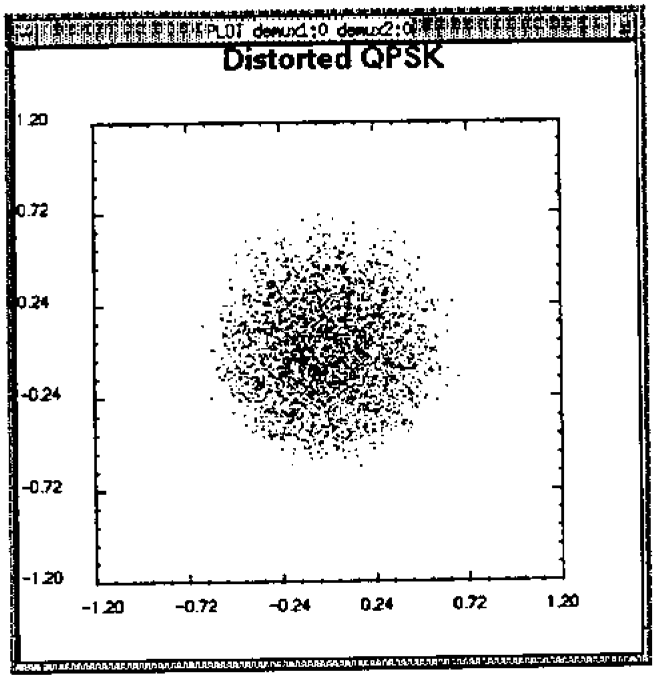

Figure 2. The distorted QPSK constellation at the receiver

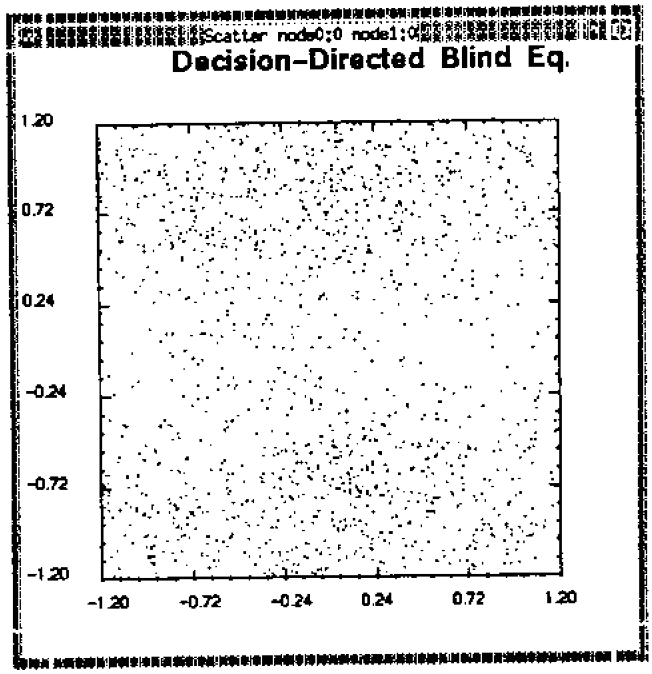

Figure 3. Output of the Classical Decision Directed Algorithm

to mobile communication channels: (1) Conventional blind equalization techniques cannot handle high channel distortion; (2) Their convergence rate is slow. In this application note, we demonstrate the performance of conventional blind equalization techniques applied to equalization of mobile communication channels. We also present a new optimal decision-directed blind equalization algorithm which outperforms all of the previous blind equalization techniques [1]. The superior performance of the new algorithm is demonstrated by the results obtained from the CAPSIM simulation environment.

2. System Description

The baseband model of the two-dimensional mobile communication system which will be used in the CAPSIM simulations is shown in Fig.1. The transmitter site consists of a data generator, coders, pulse-shaping filters and low-pass filters. The transmission medium is modeled by a multipath Rayleigh Fading channel (see separate CAPSIM Application Note on the fading channel model). Finally, the receiver-end consists of matched filters, demultiplexers and a blind equalizer. A QPSK modulation scheme is employed in transmitting the digital data. In the transmitter, the QPSK signal spectrum is shaped by the pulse-shaping filter which has a square root raised-cosine frequency response with a specified excess bandwidth (roll-off factor beta). In the simulations an excess bandwidth of 25% is used. In the receiver, a square-root Nyquist filter is utilized as a matched filter. The system model does not include additive Gaussian noise after the channel because in mobile communications the dominant type of distortion for which the adaptive equalizers are employed is the time-varying multipath fading phenomenon. Also, the QPSK and BPSK modulation schemes are relatively immune to the additive noise levels present in mobile communication channels.

For comparison purposes, different equalization algorithms have been employed. The equalization algorithms that have been tried to combat multipath fading distortion are [1]: (1) The Fast Recursive-Least-Squares Decision-Feedback equalization (FRLS-DFE) algorithm, (2) the Godard blind equalization algorithm, (3) the Classical decision-directed blind equalization algorithm, (4) the Maximum Level Error (MLE) blind equalization algorithm, and finally (5) the new optimal decision-

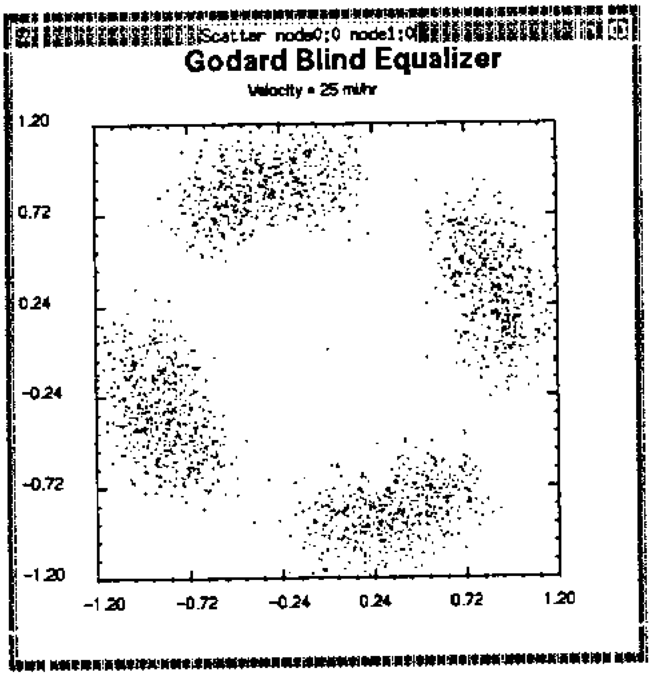

Figure 4. Output of the Godard Blind Equalizer for mobile velocity of 25 miles/hr

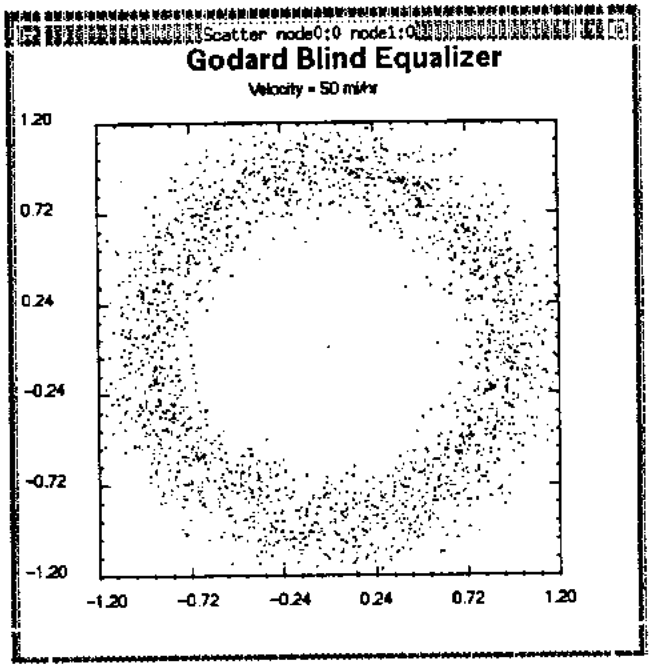

Figure 5. Output of the Godard Blind Equalizer for mobile velocity of 50 miles/hr

directed blind equalization algorithm.

3. Existing Blind Equalization Algorithms

In this section, we give the underlying methodology utilized by the popular blind equalization algorithms such as the Godard blind equalizer, the classical decision-directed blind equalizer, and the MLE blind equalizer [1]. There are some other blind equalization algorithms which are used in digital radio applications such as the Sato blind equalizer and the Stop-and-Go blind equalizer. However, both methods reduce to the classical decision directed algorithm for low order QAM applications such as QPSK and BPSK which are utilized in mobile communication systems.

All of the blind equalization algorithms mentioned above can be generalized under the following equalizer update formula:

$$\mathbf{w}(k+1) = \mathbf{w}(k) - \alpha\left[y(k) - \hat{a}(k)\right]\ \mathbf{r}^*(k)$$

where $\mathbf{w}(k)$ is the adjustable equalizer filter vector at time k. The equalizer output is denoted by y(k) and $\mathbf{r}(k)$ is the channel output vector stored in the equalizer delay taps. Finally, $\hat{a}(k)$ is the estimated value of the transmitted symbol. The performance of blind equalization algorithms depends on the reliability of the estimate $\hat{a}(k)$ of the transmitted symbol. All of the previous blind equalization algorithms have been heuristically developed by improving the reliability of the estimates of the transmitted symbol.

The Godard, classical decision-directed, and MLE blind equalization algorithms are the only available blind equalization algorithms for reconstructing BPSK and QPSK signals in a mobile communication environment. However, there are serious drawbacks to these algorithms which hinders their use for mobile communications applications. The Godard blind equalization algorithm utilizes a "phase-blind" cost function. Therefore, it cannot handle random time-varying phase distortion due to fading and scattering phenomena in mobile communication channels. The MLE algorithm has an extremely slow convergence rate. Finally, the classical decision-directed blind equalization algorithm can only guarantee convergence in open-eye situations, i.e. low distortion, which are almost

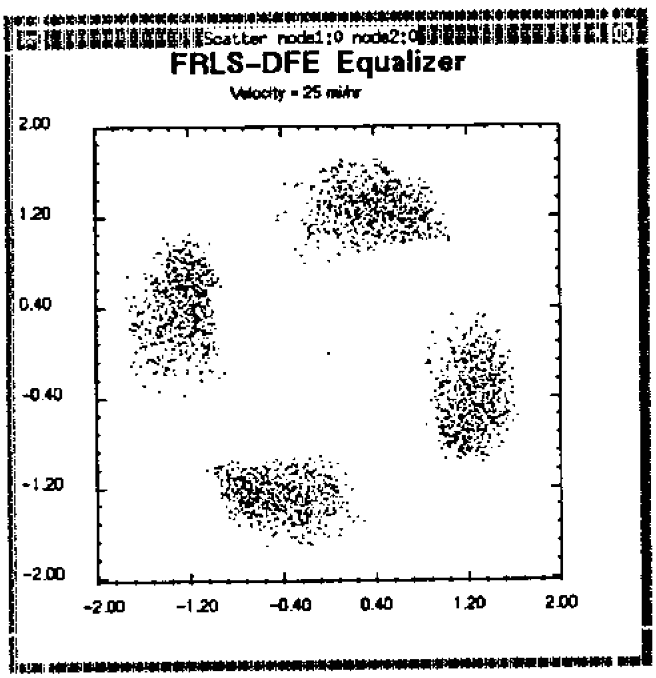

Figure 6. Fast RLS Decision Feedback Equalizer at 25 miles/hr

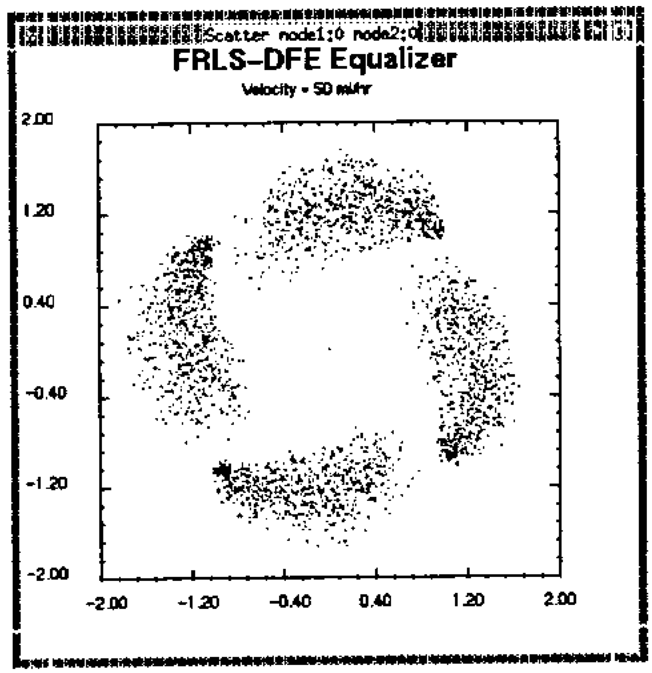

Figure 7 . Fast RLS Decision Feedback Equalizer at 50 miles/hr

never met for the time-varying mobile multipath fading channels.

4. Optimal Decision-Directed Blind Equalization Algorithm

The existing blind equalization algorithms are not feasible for the equalization of mobile communication channels due to their incapability of handling large amounts of distortion and their slow convergence. The poor performance of the existing techniques can be attributed to the sub-optimal estimators utilized in the adaptation rule. In [1], it is shown that the optimal decision-directed blind equalization algorithm uses a nonlinear estimator which is extremely close to the optimal one. The optimal estimator can be derived by *a-posteriori* Bayesian analysis. The superior performance of the optimal decision-directed blind equalization algorithm compared to the existing techniques is demonstrated in the next section.

5. CAPSIM Simulation Results

In this section , we present CAPSIM simulation results that demonstrate the general performance of different blind and supervised adaptive equalizers in combating the impairments introduced by mobile communication channels.

Fig. 2 illustrates the distorted QPSK constellation which is ideally composed of four symbols symmetric around the origin. The scattering diagram is recorded over a period of 30 msec. The mobile multipath Rayleigh fading channel introduces a severe distortion which obviously results in a closed eye situation. Fig. 3 illustrates the output of the classical decision-directed blind equalization algorithm which failed to reconstruct the transmitted constellation. This is as expected since the classical decision-directed algorithm does not guarantee convergence for the closed-eye channel situations. The performance of the Godard blind equalizer is demonstrated in Figs. 4 and 5 for mobile velocities of 25 and 50 miles/hr, respectively. As noticed, due to the "phase-blind" nature of its cost function, the Godard blind equalizer cannot track the random phase rotation although it maintains a constant modulus output. The poor performance of the Godard blind equalizer is more apparent for higher

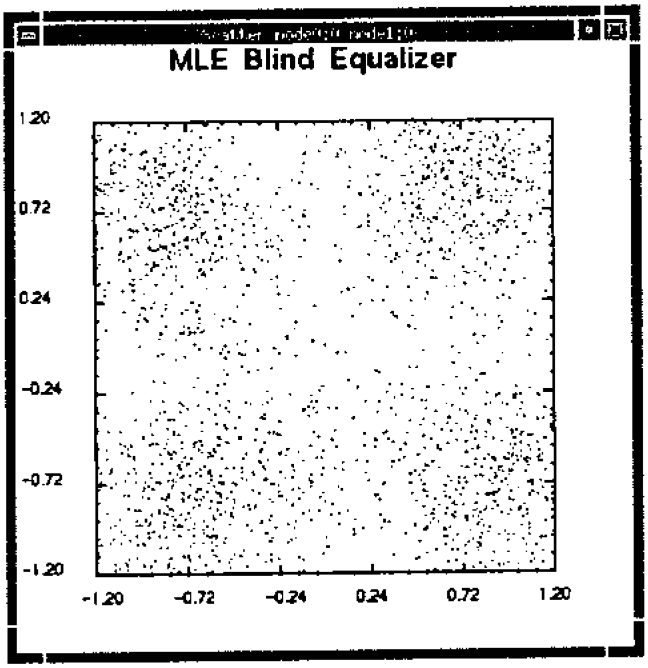

Figure 8. Output of the MLE Equalizer

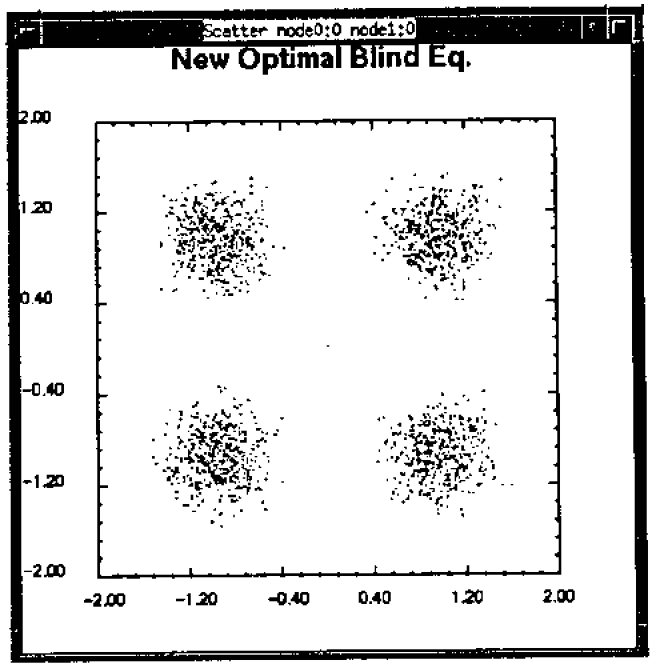

Figure 9 . New Optimal Decision Directed Blind Equalizer

mobile speeds as illustrated in Fig. 5. The fast recursive least squares decision-feedback (FRLS-DFE) has also been tried to combat the multipath fading channel. Although this algorithm is a supervised adaptive equalization algorithm, since it requires training sequence, it utilizes the classical decision directed rule in tracking the channel after training. As illustrated in Figs. 6 and 7, the FRLS-DFE algorithm is first able to converge due to training. However, it cannot track the changes in the channel once the training is over. This is apparent in the constellation where it begins to spread out. The performance of the Maximum Level Error (MLE) blind equalization algorithm is better compared to the other techniques. However, its convergence is extremely slow. Therefore, the reconstructed constellation illustrated in Fig. 8 is not very well defined since the MLE blind equalizer requires much more time to converge. The performance of the MLE equalizer is not as sensitive to different mobile speeds as the Godard and FRLS-DFE equalizers. Finally, Fig. 9 demonstrates the output of the new optimal decision-directed blind equalization algorithm. As illustrated, the performance of the new blind equalizer is superior to all of the previous techniques. The transmitted QPSK data constellation is completely reconstructed and very well defined (the velocity was 50 miles/hr). The performance of the new optimal decision-directed blind equalization algorithm is not sensitive to changing mobile velocities up to 90 mi/hr.

6. Convergence Behavior

The convergence rate of the new optimal decision-directed blind equalization algorithm compared to the classical decision-directed and MLE blind equalization algorithm are illustrated in Figs. 10 an 11. As demonstrated, the classical decision-directed algorithm fails to converge for the multipath fading mobile communication channel. The MLE algorithm is able to converge for the same channel. However its convergence is twice as slow compared to the optimal decision-directed blind equalization algorithm.

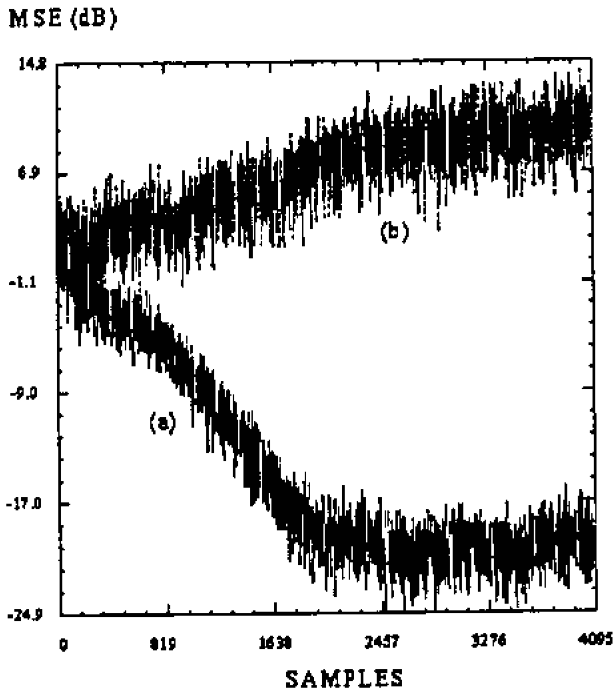

Figure 10. (a) Learning curve for the new optimal decision-directed blind equalization algorithm (b) Learning curve for the classical decision-directed blind equalization algorithm for the same channel.

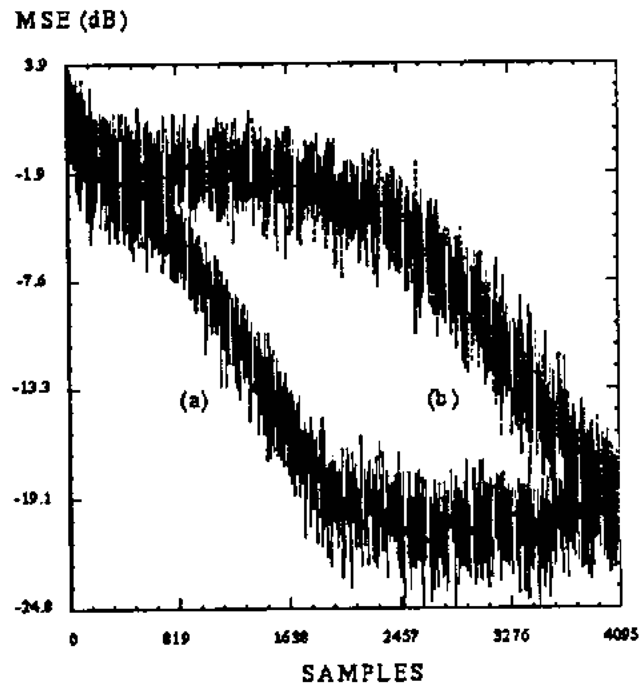

Figure 11. (a) Learning curve for the new optimal decision-directed blind equalization algorithm (b) Learning curve for theMLE blind equalization algorithm for the same channel.

7. Conclusion

In this application note, we presented the implementation of a mobile communications system with blind adaptive equalization in the CAPSIM simulation environment. Particularly, the superior performance of a new optimal decision-directed blind equalization algorithm compared to existing blind equalization techniques is demonstrated. CAPSIM was instramental in the development of this new algorithm.

8. Reference

[1] Jeyhan Karaoguz, "An Optimal Decision-Directed Blind Equalization Algorithm Applied to Equalization of Multipath Rayleigh Fading Mobile Communication Channels", *Ph.D. Dissertation,* Dept. of Electrical and Computer Engineering, North Carolina State University, April 1992.

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