CPM Transceivers Using a Limiter–Discriminator in Fading Channels

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Abstract—**We examine the performance of CPM signals using a receiver structure based on a limiter–discriminator detector in a Rayleigh fading environment. Limiter–discriminator type detection is simple and robust and is therefore well–suited for mobile receivers. We propose a new receiver processing strategy that improves the performance of the system. We then examine the transmitter parameters to determine what type of CPM signals perform well. Coding is examined next. For the type of transceiver considered, we find that a combination of bandwidth efficient modulation and convolutional coding performs best.**

I. INTRODUCTION

Recently, much effort has been put into simple demodulation techniques for mobile communication systems. A notable example is the Limiter–Discriminator (L–D) combination [1] – [15]. This technique has the advantage of being very robust, which is necessary in fading environments, and very simple, which makes it attractive for portable and hand–held devices. Another advantage of L–D type detection is that it is non–coherent, so a phase lock loop is not necessary.

An L–D detector is composed of two parts: an amplitude limiter and a frequency discriminator. The discriminator is basically a frequency to amplitude converter. If the input signal frequency is above a certain center frequency, f_c, then the output of the discriminator is positive, while if the input frequency is below f_c, then the output is negative. Ideally, the output amplitude is proportional to the input frequency. However, the output of the discriminator is also a function of the input amplitude. To remove the effect of the input amplitude, a limiter is added before the discriminator. Therefore, if the input signal is of the form

$$s_i(t) = A\cos[2\pi f_c t + \phi(t)] \tag{1}$$

then the output of the L–D combination is

$$s_o(t) = k\frac{d\phi(t)}{dt}$$

The signal represented by (1) is called Continuous Phase Modulation (CPM) if $\phi(t)$ is a continuous function. CPM has become a popular modulation scheme in recent years due to its desirable properties of bandwidth efficiency and constant envelope [16] – [18].

The phase, $\phi(t)$, of a CPM signal is defined by

$$\phi(t) = \phi(0) + 2\pi h \sum_{n=0}^{\infty} a(n) \int g(t - nT),$$

where $\phi(0)$ is the initial phase, h is the modulation index, $a(n) \in \{1, -1\}$ is the information sequence and $g(t)$ is the frequency pulse. The frequency pulse is continuous and satisfies $g(t) = 0$ for $t \leq 0$ and $t \geq LT$. L can be thought of as the memory length of the modulation scheme because each symbol affects the signal shape for a maximum of L symbol intervals. The case when $L = 1$ is called full response signalling. Partial response signalling results when $L \geq 2$.

In this paper, we examine the transceiver from three viewpoints. After introducing the transceiver model in section II, we first examine the receiver side of the transceiver in section III. Here, we propose a new processing strategy that is robust to fading and transmitter parameters. Second, in section IV, we look at what types of CPM signals perform well. Third, in section V, we propose a coding strategy for systems that use a limiter–discriminator. Finally, conclusions are presented in section VI.

The performance of the communication systems examined in this paper was found by using computer simulations. Each system was implemented digitally using the Signal Processing Worksystem (SPW) [1] from Comdisco Systems. The error probabilities were then found using Monte Carlo simulations. The reason for using simulations is that analytical techniques are difficult to apply and subject to simplifying assumptions. For fast fading environments, the complexity is increased further. Also, if some simplifying assumptions are used, important effects may be lost.

II. CPM TRANSCEIVER MODEL

The transceiver model considered in this paper is shown in figure 1. The transmitter consists of an encoder and a CPM modulator. The CPM modulator uses a signal shape $g(t)$ and a modulation index h.

The channel is considered to be a fast Rayleigh fading channel. The Rayleigh channel is composed of two parts: a multiplicative noise component, which is filtered white Gaussian noise, and an additive noise component, which is white Gaussian noise.

This work was supported in part by the Natural Sciences and Engineering Research Council of Canada.

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[1] Signal Processing Worksystem is a registered trademark and SPW is a trademark of Comdisco Systems Inc.

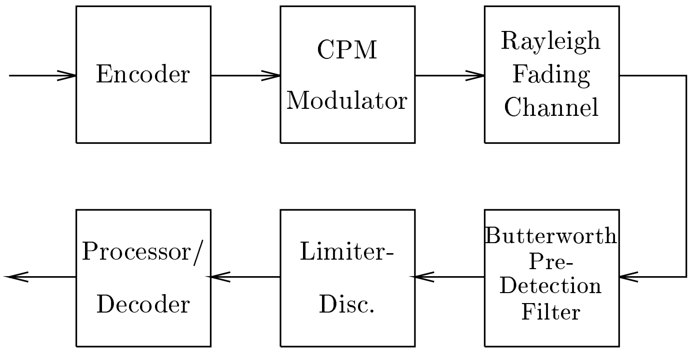

Fig. 1. CPM Transceiver Model

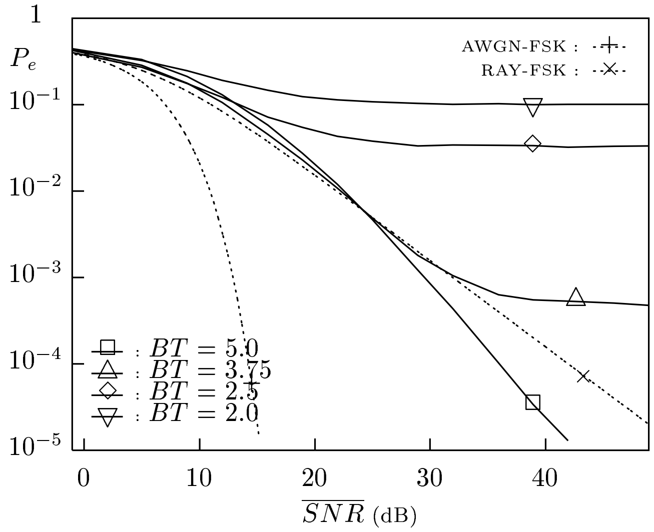

Fig. 2. Performance of FSK with an ISD processor for various normalized pre–detection filter bandwidths, BT, compared to optimal values in AWGN and Rayleigh fading channels.

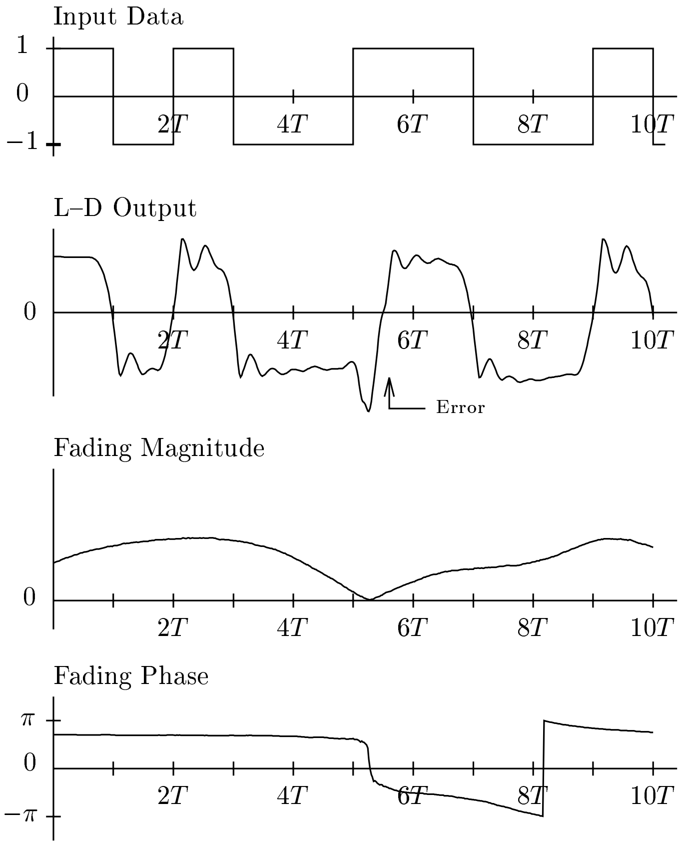

Fig. 3. The output of the limiter–discriminator during a typical error event.

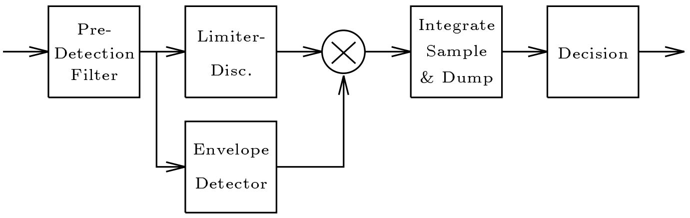

Fig. 4. Proposed post–detection processor (FM–ISD)

The receiver first removes out–of–band interference with a Butterworth pre–detection filter. Next, the L–D combination demodulates the signal. Finally, a processor/decoder circuit estimates the originally transmitted data.

III. Receiver Structures

As a benchmark for comparison, the performance of the system using an integrate–sample–and–dump (ISD) circuit is shown in figure 2. From the figure, we can see that the performance of the system at high $\overline{SNR}$ values gets worse as the bandwidth of the pre–detection filter decreases. This is due to the increase in ISI due to the narrower filter.

To improve the performance of the system, we look at the cause of the errors. In figure 3, the output of the L–D is shown compared to the magnitude and phase of the fading. From this figure, we can see that the error is due to a drop in the fading magnitude. Therefore, we can use this fact to improve the performance of the system.

This leads us to propose a new post–detection processor, which is shown in figure 4. We refer to this as the Fading Magnitude ISD (FM–ISD) processor. This processor is a type of estimator–correlator. It estimates the magnitude of the fading with an envelope detector and then correlates this estimate with the output of the L–D. This has the effect of reducing the influence of the fading by deemphasizing those parts of the signal that are the most distorted.

The performance of the FM–ISD processor is shown in figure 5. As shown in the figure, the FM–ISD processor improves the performance of the system. The improvement obtained depends on the modulation format used, but there is an improvement for all formats.

If the fading rate changes, the improvement in performance changes somewhat, but there is still an improvement. In general, the improvement decreases as the fading rate decreases. This is to be expected, because the FM–ISD processor compensates for errors caused by sudden changes in the fading. If the changes are more gradual, as in the case of slow fading, then the FM–ISD processor will not be able to improve the performance of the system. However, it will not degrade the performance either.

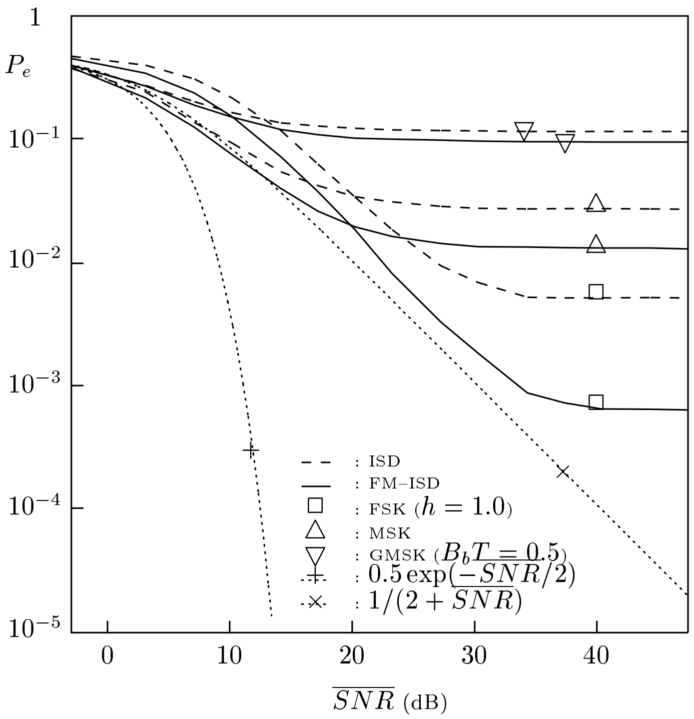

Fig. 5. Performance of the FM–ISD processor compared to the ISD processor.

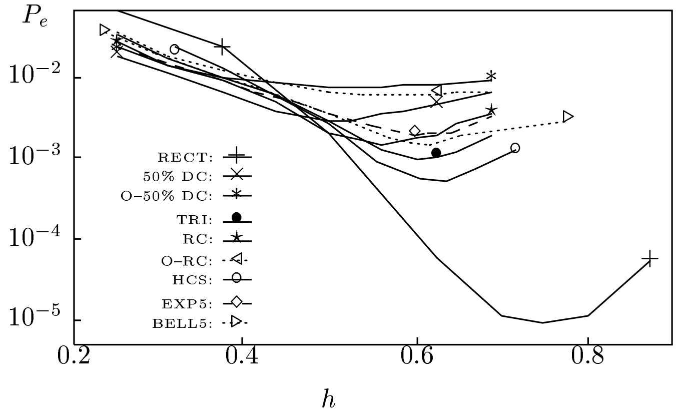

Fig. 6. Performance at $\overline{SNR} = 47dB$ for various pulse shapes and modulation indices.

IV. Transmitter Modifications

We now look at the transmitter side of the transceiver. We mainly examine what types of CPM signals perform well with L–D detection. The CPM signals can be completely characterized by the pulse shape $g(t)$ and the modulation index h.

In figure 6, we show the performance at $\overline{SNR} = 47dB$ for various pulse shapes. The rectangular pulse shape, which corresponds to FSK, has the best performance for values of h greater than 0.5. Below this value, a shortened rectangular pulse (50% DC) performs the best. We can also see from the figure that there is an optimal value of h for each pulse shape.

If the 99.9% bandwidth of the signal is plotted on the x–axis instead of h, the rectangular pulse again performs best for most bandwidth values. Therefore, we can say that generally the rectangular pulse is best suited for use with L–D detection.

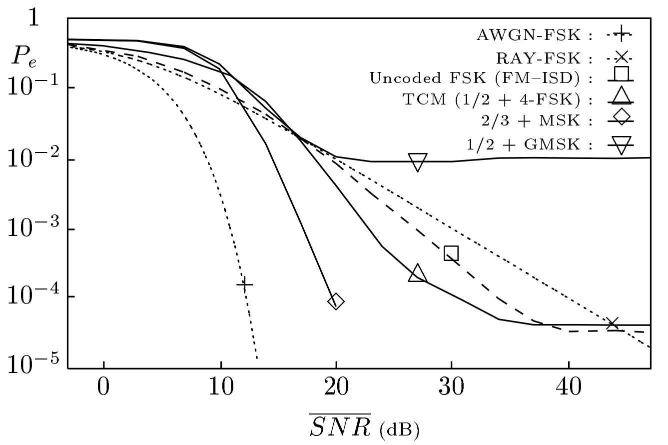

Fig. 7. Performance comparison of reduced bandwidth coding and TCM.

V. Coding

Now, we consider coding for use with L–D detection. We propose a coding strategy which we call reduced bandwidth coding.

Traditional coding methods result in an increase in the bandwidth occupied by the signal. Trellis coded modulation (TCM) uses a larger signal set so that the bandwidth of the resulting signal remains the same as the uncoded scheme. Reduced bandwidth coding uses a modulation scheme that is more bandwidth efficient and an appropriate rate convolutional code so that the resulting bandwidth is the same as the uncoded system.

In this paper, we consider uncoded FSK with a pre–detection filter bandwidth given by $BT = 3.75$ as a benchmark. The reduced bandwidth coding schemes that we consider are:

- GMSK + rate 1/2 convolutional code + $BT = 1.875$
- MSK + rate 2/3 convolutional code + $BT = 2.5$

For these combinations, the ratio of the bit rate to bandwidth BT is the same as that for the uncoded FSK benchmark. We also examine a TCM scheme by using 4–level FSK with a rate 1/2 convolutional code and $BT = 3.75$.

The performance of the various schemes is compared in figure 7. We can see that the reduced bandwidth coding technique gives the best performance as long as the bandwidth is chosen correctly. The GMSK scheme uses too narrow a bandwidth so that the performance of the overall system is reduced relative to the uncoded system. TCM does not perform as well with L–D detection because the distortion in the received pulse makes multi–level decisions difficult.

VI. Conclusions

In this paper, we examined a CPM transceiver which uses limiter–discriminator detection in Rayleigh fading environments. We proposed a simple, robust processing strategy, which improves the performance of the system compared to conventional integrate–sample–and dump type processors. As for the CPM signal itself, we found that rectangular pulse shapes generally perform the best. Finally, we proposed a coding scheme for limiter–discriminator detection that does not increase the required signal bandwidth. We found that this scheme is better than TCM for the transceiver considered in this paper.

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