IMPROVING THE DETECTION EFFICIENCY OF CONVENTIONAL PCM/FM TELEMETRY BY USING A MULTI-SYMBOL DEMODULATOR

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ABSTRACT

Binary PCM/FM has been widely adopted as a standard by the telemetry community. It offers a reasonable balance between detection efficiency and spectral efficiency, with very simple implementation in both the transmitter and receiver. Current technology, however, allows practical implementations of more sophisticated demodulators, which can substantially improve the detection efficiency of the waveform, with no changes to the modulator. This is accomplished by exploiting the memory inherent in the phase continuity of the waveform. This paper describes the implementation and performance of a noncoherent multi-symbol demodulator for PCM/FM. Sensitivity to offsets in carrier frequency, timing, and modulation index is also examined. Simulation results are presented which demonstrate improvements in detection efficiency of approximately 2.5 dB over traditional noncoherent single symbol detectors.

KEY WORDS

Multiple Symbol Demodulation, Binary PCM/FM, and Noncoherent Detection.

INTRODUCTION

There currently exists a large installed base of PCM/FM telemetry transmitter and receiver equipment. This work investigates using a multiple symbol demodulator to significantly enhance the detection efficiency of binary PCM/FM, and examines the robustness of the detector to offsets in carrier frequency, symbol timing, and modulation index.

It is well established that the detection performance of a continuous phase waveform may be significantly improved by increasing the observation interval of the detector. Several implementations of multiple symbol demodulators have been published including trellis detectors that estimate the state of the phase process using the Viterbi algorithm, and fixed length sliding correlators that make decisions on one or more bits. The Viterbi algorithm is an efficient computational method that can match the performance of a detector with an infinite observation interval when the signal can be described by a finite state process. However, imprecise knowledge of the transmitter parameters, channel effects, and the fact that extending the observation interval beyond a few symbols periods may yield little improvement, make the simpler fixed length correlator architectures attractive. Therefore, this paper chooses to use the non-coherent multi-symbol correlator architecture originally described by Osborne and Luntz [1] to detect the PCM/FM signal commonly used in telemetry systems.

SYSTEM DESCRIPTION

A block diagram of the communication system is shown in Figure 1. The current recommendation for PCM/FM telemetry systems with NRZ-L data code are for a pre-modulation filter with a 3 dB cutoff frequency at 0.7 bit rates and a peak deviation equal to 0.35 times the bit rate. The PCM/FM waveform is generated by passing the NRZ-L source data through a fourth order Bessel pre-modulation filter and applying it to the input of a FM modulator. The resulting output is a constant envelope continuous phase PCM/FM waveform with a modulation index of h = 0.7. The transmitted signal is corrupted by Additive White Gaussian Noise (AWGN) and processed by the multi-symbol demodulator.

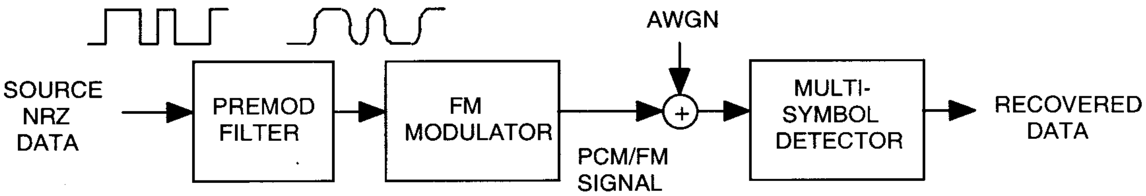

Figure 1. System Description

Following the notation from [2], the constant-envelope PCM/FM signal can be represented as

$$s(t) = \sqrt{2E/T}\cos[2\pi f_o t + \phi(t,\bar{\alpha}) + \phi_o]$$

$$\phi(t,\bar{\alpha}) = 2\pi h \int_{-\infty}^{t} \sum_{i=-\infty}^{+\infty} \alpha_i g(\tau - iT)\,d\tau \quad -\infty < t < +\infty$$

where the information bearing phase N(t,") is determined by the M-ary data sequence $\alpha = [\alpha_{-\infty}\ldots\alpha_{+\infty}]$ where "$_i$ = ±1, the frequency function g(t), and the modulation index h. The Bessel filter smoothes and extends NRZ rectangular frequency pulse as shown in Figure 2. Note that g(t) now extends over two symbols instead of one, thereby creating a partial response signal. The resulting phase tree of the PCM/FM signal is depicted in Figure 3.

DEMODULATOR DESCRIPTION

A conceptual diagram of the non-coherent multi-symbol demodulator is shown in Figure 4. The detector correlates the received waveform with each of the possible transmitted signals over a fixed number of symbols, chooses the correlator with the largest magnitude, and makes a decision on the middle bit. Although this scheme is suboptimum, it is straightforward to implement and exhibits negligible loss compared to the optimal detector at high SNR's which is the case of interest for typical systems.

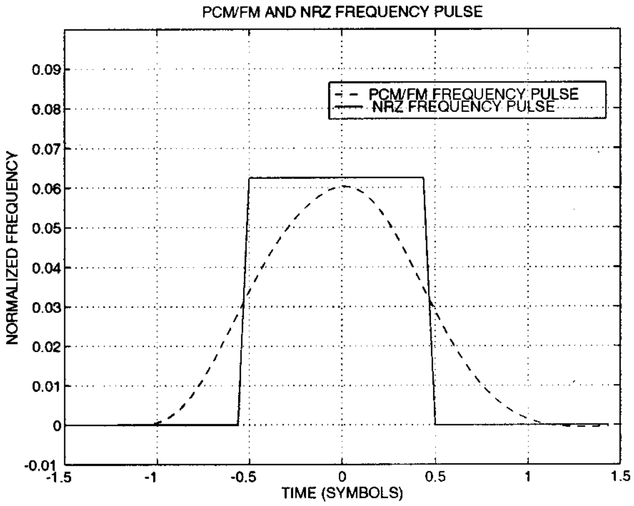

Figure 2. Frequency Pulse Shape Before and After Pre-Modulation Filter

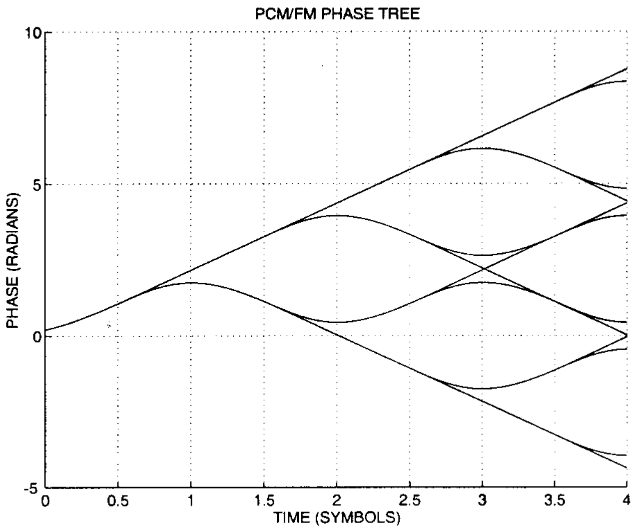

Figure 3. PCM/FM Phase Tree

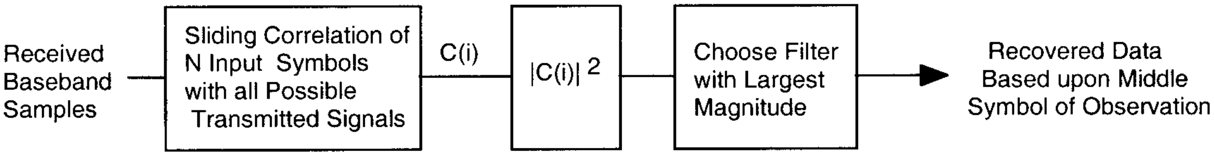

Figure 4. Conceptual Diagram of Multi-Symbol Detector

The filter outputs can be computed efficiently by recognizing that the correlations are simply the sum of a finite set of branch metrics, given that the receiver signal set can be described as a phase trellis. Representing the modulation index h as 2k/p , where k and p are relatively prime integers, yields a trellis structure with pM^L branch metrics. Therefore, by computing a subset of these branch metrics ($p'M^L$) and storing them in a delay line, each correlator can form its output by adding the appropriate partial correlation. Figure 5 illustrates the receiver implementation.

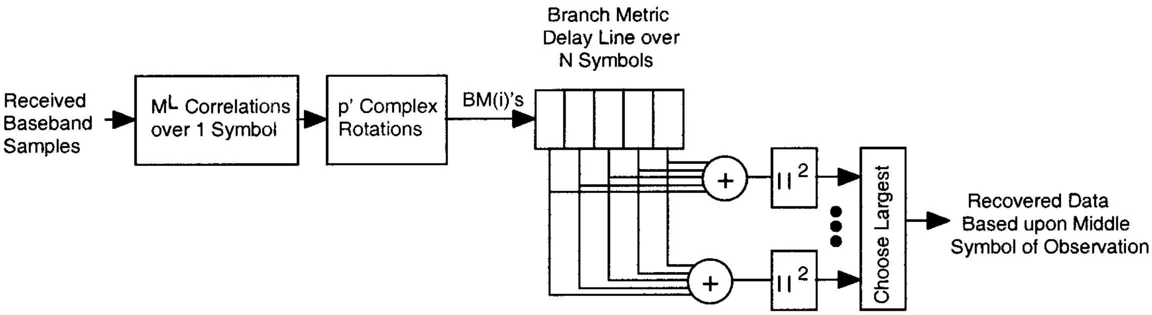

Figure 5. Implementation of Multi-Symbol Detector

DEMODULATOR PERFORMANCE

The demodulator performance depends upon the correlation length N and the duration and shape (L andg_r(t))of the frequency pulse that generates the receiver signal set.. Figures 6 and 7 illustrate the transmit and receive signal sets and the performance of a 3 and 5 symbol detector with $g_r(t) = g_t(t)$ using a combination of performance bounds as in [1] and data from Monte Carlo simulations. For comparison, the performance of a traditional limiter-discriminator single symbol detector [3] is also shown. Note that there is roughly a 2.5 dB improvement using a 5 symbol detector as compared to the single symbol baseline.

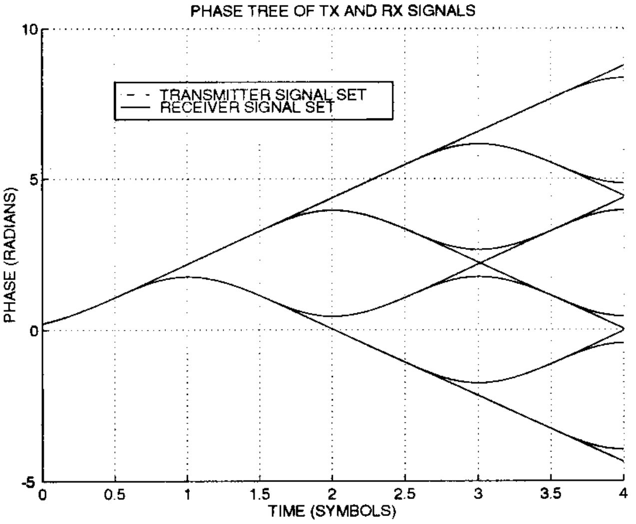

Figure 6. Transmit and Receive Signal Sets ($g_R(t) = g_T(t)$)

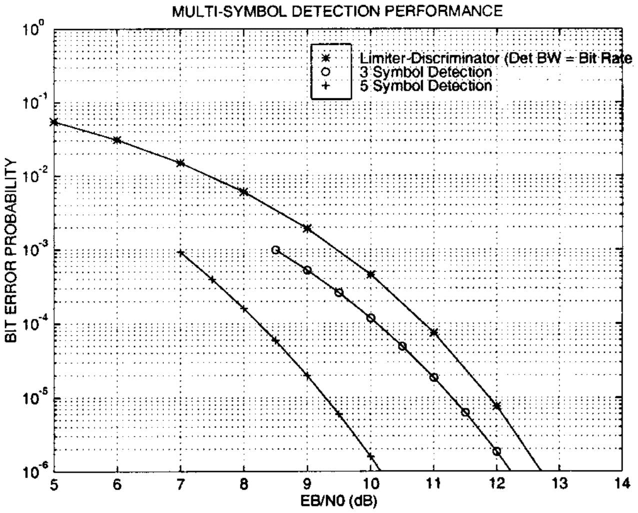

Figure 7. Multi-Symbol Detection Performance

DEMODULATOR SENSITIVITY

The previous section has shown that a multi-symbol demodulator can indeed enhance the detection efficiency of PCM/FM. This section investigates the sensitivity of the receiver to offsets in carrier frequency, symbol timing, and modulation index. Figures 8, 9, and 10 show the effect of offsets in frequency, timing, and modulation index between the transmit and receive signal sets. Relative to the receiver, the transmitter phase tree is tilted by a frequency offset, shifted by a timing offset, and either expanded or contracted due to an offset in modulation index. Although the phase trees are aligned in the figures to better illustrate the effect of synchronization error, the noncoherent envelope detector is insensitive to the initial phase alignment.

Simulation results are presented to illustrate the effect of synchronization errors. The effect of carrier frequency offset is shown in Figure 11 and shows that the 5 symbol detector is much more sensitive to frequency error as compared to the 3 symbol detector. The error performance actually becomes worse with the longer observation interval at a frequency offset of 0.05 cycles/symbol. This is partially due to the fact that as the detection length increases, the correlation filters becomes narrower making frequency alignment more critical.

The effect of timing offset is shown in Figure 12. Since the detectors degrade similarly, the 5 symbol detector always outperforms the 3 symbol version even with moderate timing offsets. Finally, Figure 13 illustrates the performance degradation when the modulation index of the transmitter is offset over a range of +/- 10 percent and shows that the detectors experience similar degradation with small offsets in modulation index. However, the longer span detector appears to suffer much more loss with significantly under-deviated signals. The general conclusion is that while lengthening the observation interval increases detection efficiency it also increases the sensitivity to synchronization errors (particularly frequency offset).

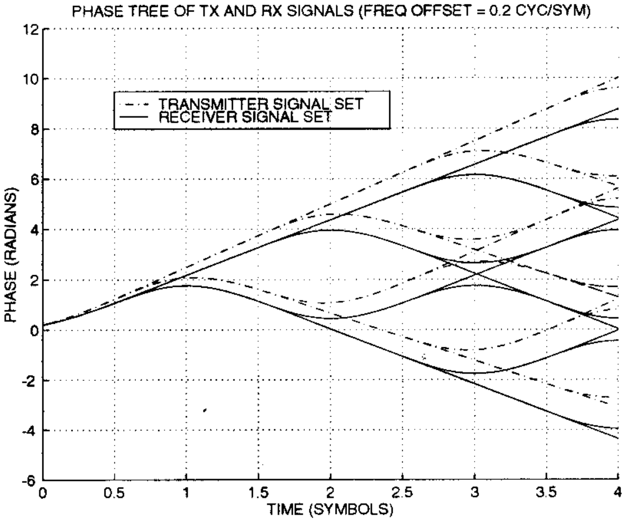

Figure 8. Transmit and Receive Signal Sets with Frequency Offset

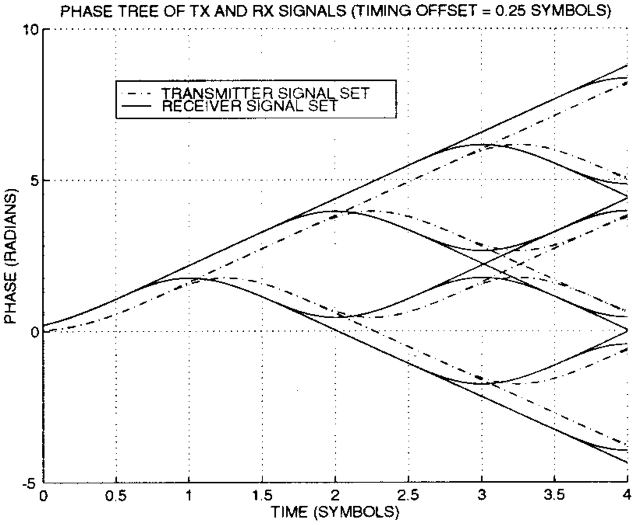

Figure 9. Transmit and Receive Signal Sets with Symbol Timing Offset

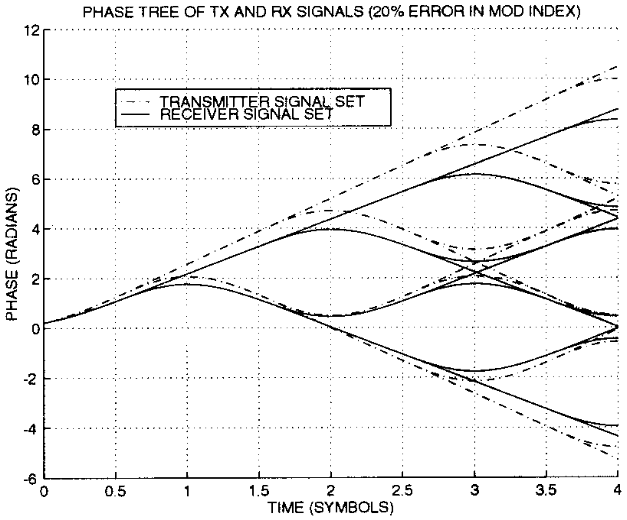

Figure 10. Transmit and Receive Signal Sets with a different Modulation Index

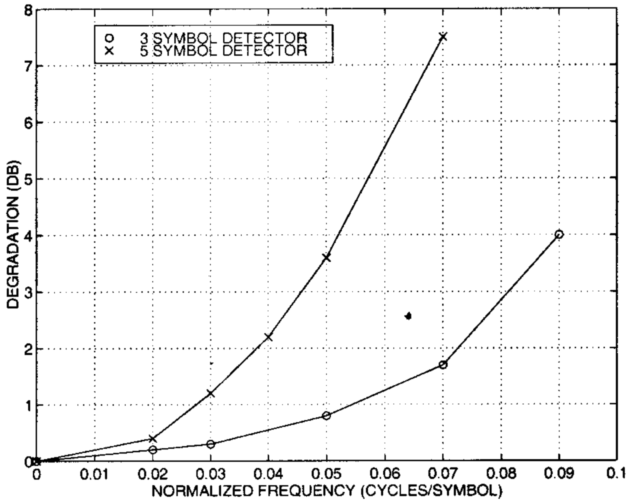

Figure 11. Degradation with Frequency Offset

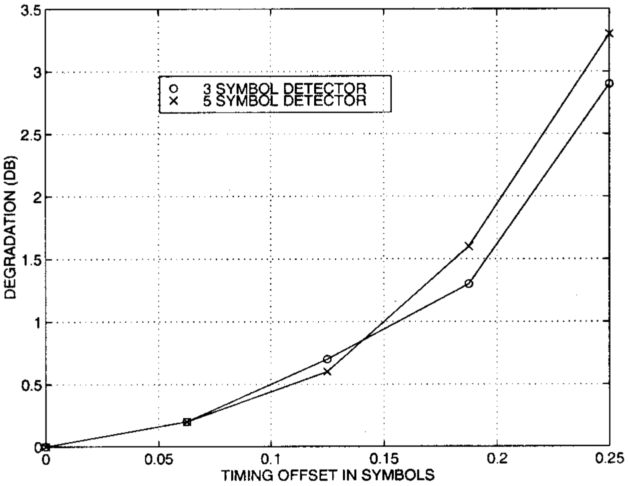

Figure 12. Degradation with Timing Offset

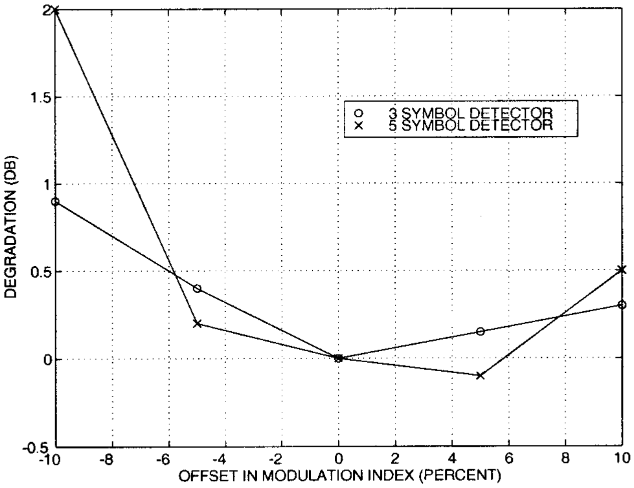

Figure 13. Degradation with Offset in Modulation Index

CONCLUSIONS

The implementation and performance of a noncoherent multi-symbol detector for PCM/FM has been presented and shows that by using a 5 symbol detector, an improvement of 2.5 dB can be realized over traditional single symbol detectors. Sensitivity to errors in frequency, timing, and modulation index were examined. In general, the longer the observation interval, the more sensitive the detector becomes to synchronization errors. The longer span detector was particularly more sensitive to frequency offset than either small offsets in timing or modulation index. Selection of observation length and receiver pulse shape should be based upon the desired level of performance, implementation constraints, and channel considerations. The presented architecture is also applicable to other full or partial response continuous phase signals as well.

REFERENCES

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