ANALYTICAL AND EXPERIMENTAL CHARACTERIZATION OF SOQPSK AND MULTI-H CPM IN A MULTIPATH CHANNEL

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ABSTRACT

Shaped Offset QPSK (SOQPSK) has been shown to be nearly identical in performance to Feher-patented FQPSK, which is the Advanced Range Telemetry (ATRM) program's Tier I waveform. Multi-h CPM has been selected as the ARTM Tier II waveform, because it offers 50% better spectral efficiency than the Tier I waveform. Both the Tier I and Tier II waveforms must operate in a multipath channel in order to meet the range community's telemetry requirements. This paper presents an analytical and experimental characterization of SOQPSK and Multi-h CPM in the presence of multipath. Quantitative results are presented which demonstrate the relative robustness of the ARTM Tier I and Tier II waveforms, in channels representative of a typical range environment.

KEY WORDS

Shaped Offset QPSK, FQPSK, SOQPSK, Multi-h CPM, Multipath

INTRODUCTION

The objective of the Advanced Range Telemetry (ARTM) project is to find means of transmitting more telemetry data in less bandwidth, including, among other approaches, the development of spectrally efficient modulation techniques. Feher-patented FQPSK has been adopted as the Tier I ARTM waveform because it offers approximately twice the data capacity of traditional PCM/FM in the same bandwidth. Offering triple the data capacity of PCM/FM, multi-h CPM has been selected as the ARTM Tier II waveform.

While conservation of increasingly scarce spectrum is a seemingly desirable goal, there are reasons that such a strategy might not provide the anticipated improvements in overall data capacity. Multipath propagation effects, in particular, have the potential to reduce data integrity. Heuristically, one might expect that, since spread spectrum waveforms offer a measure of multipath mitigation, decreasing the bandwidth of the modulated signal might increase susceptibility to multipath effects. Conversely, the Tier II multi-h CPM waveform has significant "memory", and is recovered by means of a trellis demodulator, which one might expect to provide a modest measure of multipath mitigation, in a manner akin to trellis (Viterbi) decoding of a convolutional code. While an exhaustive exploration of the multidimensional multipath parameter space is beyond the scope of this paper, we provide a preliminary answer to these questions for a limited set of channels.

WAVEFORM DEFINITIONS

As stated above, Feher-patented FQPSK is the ARTM Tier I waveform, and it would be desirable to include FQPSK results in the present paper. Unfortunately, FQPSK is a proprietary modulation whose details are not known to the author. However, Shaped Offset QPSK (SOQPSK) has been previously shown [1, 2, 3, 4] to be nearly identical to, and interoperable with, FQPSK. Consequently, we will use SOQPSK as representative of the Tier I waveform, for the results presented here.

SOQPSK describes a family of constant-envelope modulations, all of which are a derivative of, and interoperable with, the SOQPSK waveform defined in MIL-STD-188-181 and 188-182. In general terms, all members of the SOQPSK family can be thought of as offset QPSK, modified so that the 90-degree phase transitions are smooth, and always on the unit circle. The particular variant of SOQPSK considered here is SOQPSK-A as defined in [1], [2], [3], and [4].

While the ARTM Tier I modulation occupies approximately half the bandwidth of the ubiquitous PCM/FM waveform, the multi-h CPM Tier II waveform collapses the spectrum even further, to approximately one-third of PCM/FM. This modulation has been previously defined and analyzed in [5]. Like SOQPSK, multi-h CPM is a very large family of modulations. Our analysis here is restricted to the M=4, 3RC, h = 4/16, 5/16 version described in [5]. The power spectral densities of some relevant modulations for telemetry use are presented in Figure 1.

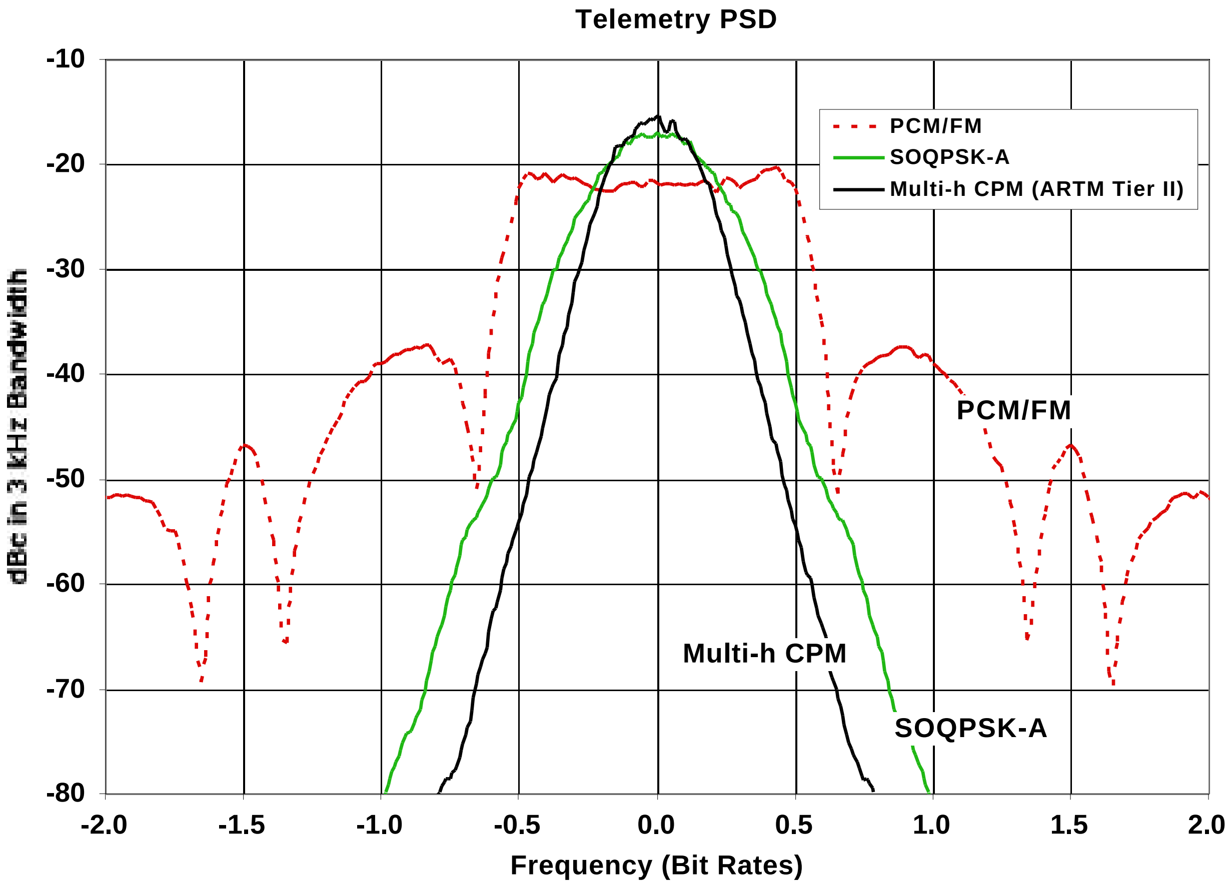

Figure 1. Power Spectral Density for PCM/FM, SOQPSK-A, and ARTM Tier II waveform.

EXPERIMENTAL TECHNIQUE

A block diagram of the test configuration is depicted in Figure 2. The multipath channel being modeled is a simple two-ray configuration, with a complex reflection coefficient, ρ. Therefore the impulse response of the channel is given by

$$h(t) = 1.0 * \delta(t) + \rho * \delta(t-\tau)$$

where δ(t) is the unit impulse function, and the frequency response is given by

$$H(\omega) = 1 + \rho * e^{-j\omega\tau}$$

Such a channel has a periodic frequency response, with a period of $2\pi / \tau$ radians per second, and a peak-to-null amplitude ripple of $20 \log ((1 + |\rho|) / (1 - |\rho|))$ in dB. The phase angle of ρ affects only the relative shift of the frequency response on the frequency axis.

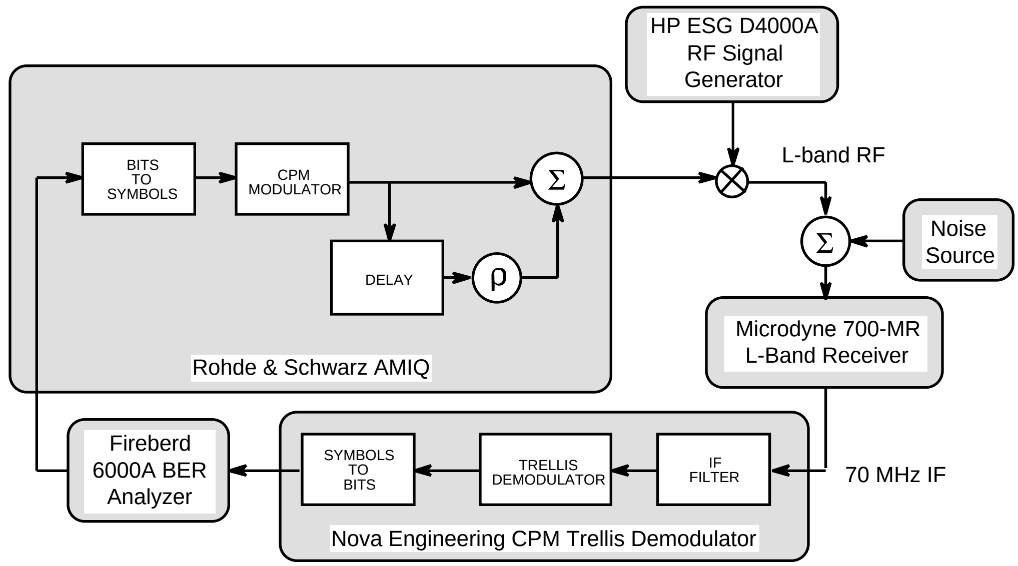

Figure 2. Experimental Test Configuration.

The magnitude response of the channel $h(t) = 1.0 * \delta(t) + (0.1 + j0.35) * \delta(t-1.5\ T_b)$, where T_b is the bit period, is shown in Figure 3.

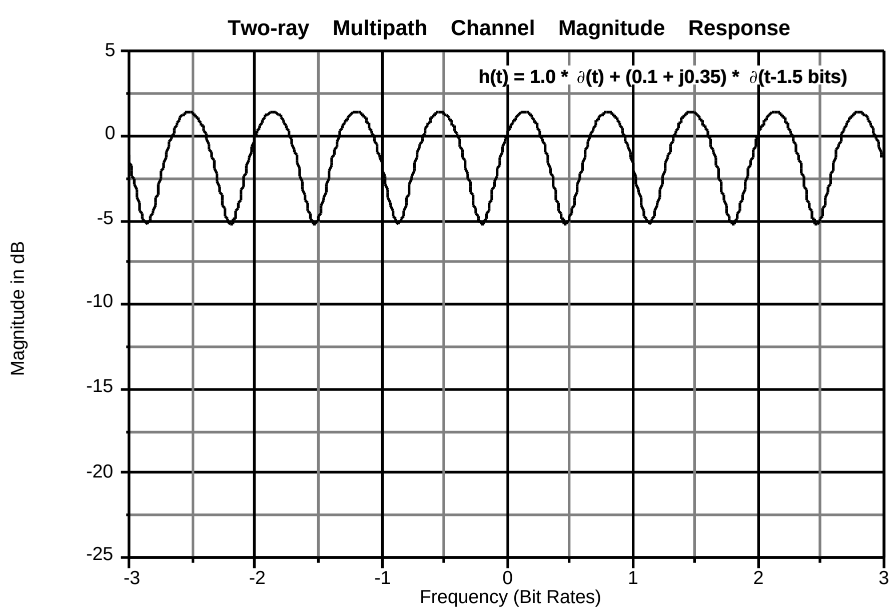

Figure 3. Typical Multipath Channel Response.

SIMULATION RESULTS

The experimental approach described above was implemented first via computer simulation. As a point of reference, the channel depicted in Figure 3 was applied to both PCM-FM and the M=4, 3RC, h = 3/14, 4/14 variant of multi-h CPM. The results are shown in Figure 4 below. Note that, for this channel, the degradation due to multipath was significant, but comparable for the two modulations.

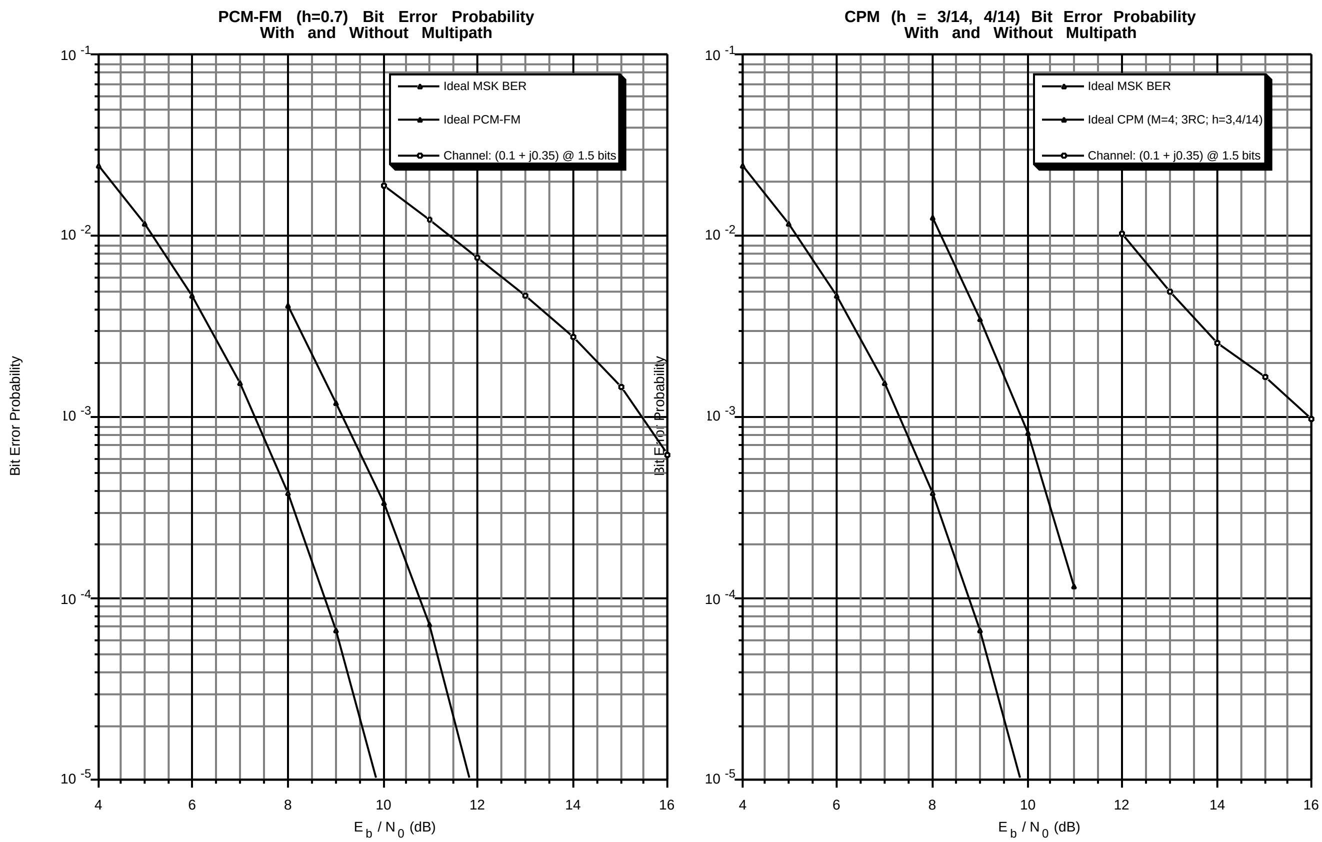

Figure 4. BER results for PCM-FM and multi-h CPM, with the multipath channel of Figure 3.

LABORATORY MEASURED RESULTS

The experimental setup shown in Figure 2 was utilized to gather data for both multi-h CPM (ARTM Tier II waveform) and SOQPSK-A (which is highly similar to FQPSK, the Tier I waveform). For the experimental results presented here, the CPM variant was the M=4, 3RC, h = 4/16, 5/16 version described in [5]. The channel response for the measured results was given by

$$h(t) = 1.0 * \delta(t) + \rho * \delta(t-1.5\ T_b)$$

where T_b is the bit period.

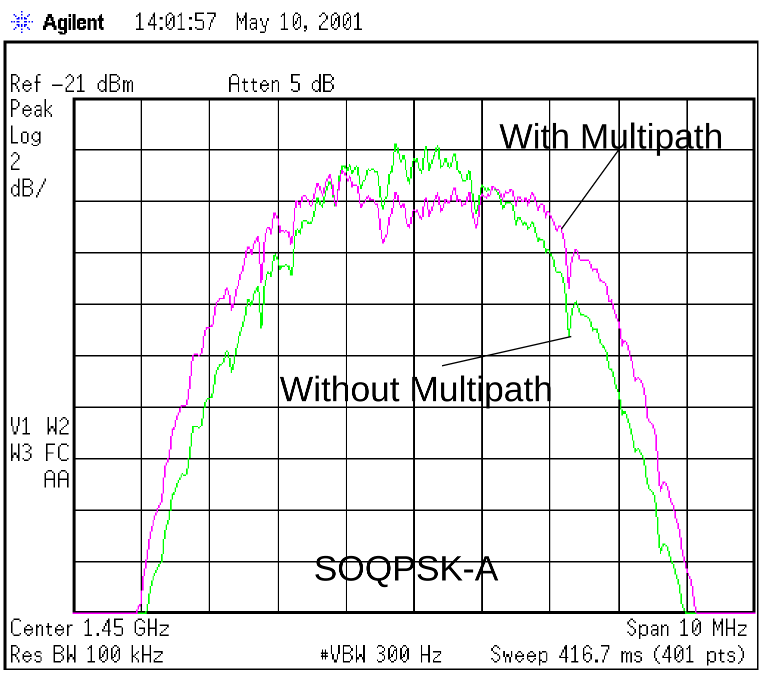

Figure 5. PSD for SOQPSK-A, with ρ = -0.3 and τ = 1.5 bits.

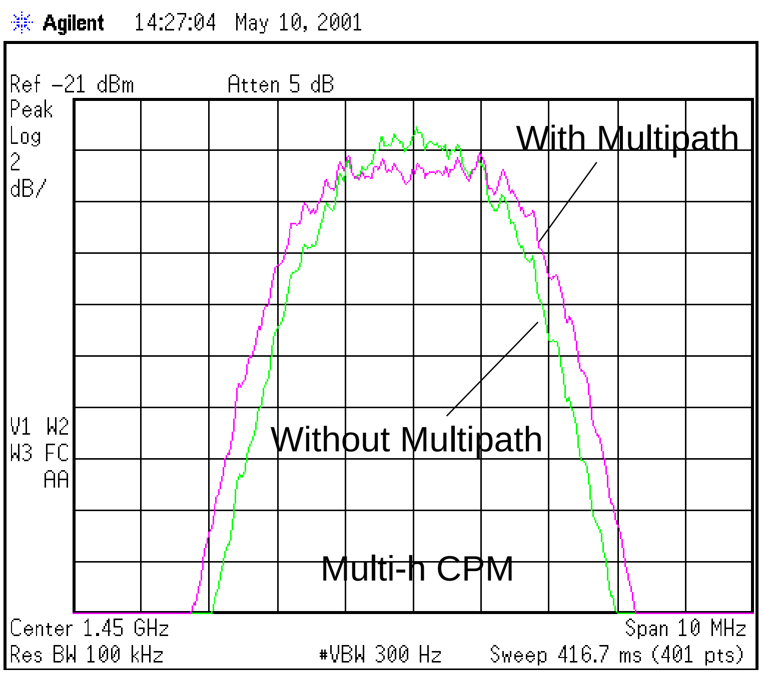

Figure 6. PSD for multi-h CPM, with ρ = -0.3 and τ = 1.5 bits.

For the results presented here, ρ was purely real and negative. This channel exhibits a periodic response similar to that in Figure 3, but because ρ is purely real and negative, a null occurs at exactly the center of signal spectrum. The measured effect of this channel on the PSD of both SOQPSK-A and multi-h CPM is shown in Figures 5 and 6. Note that the spectrum analyzer is set to 2 dB per vertical division in these plots.

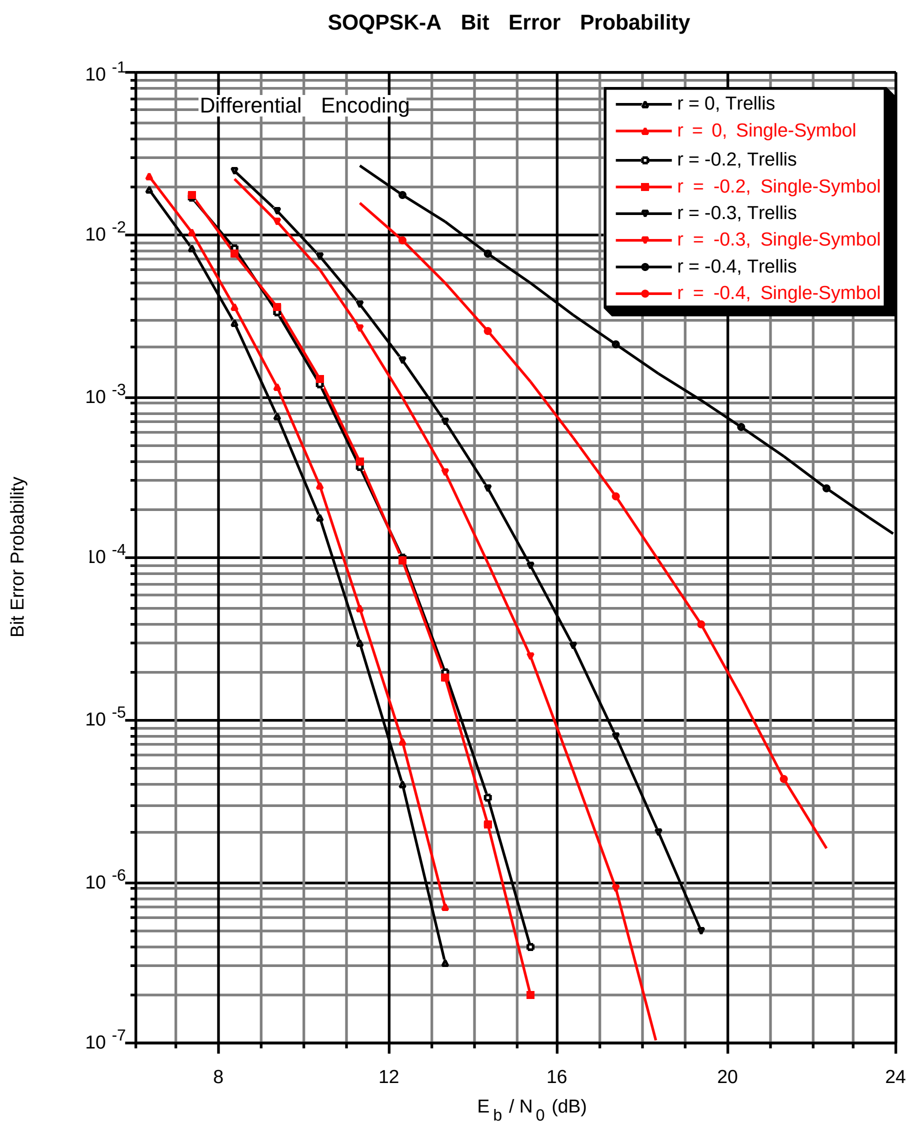

Figure 7. BER for SOQPSK-A, with ρ variable and τ = 1.5 bits.

The effect of this multipath channel on the BER performance of SOQPSK-A, using both a single-symbol detector and a trellis demodulator is shown in Figure 7. Note that as ρ is swept from –0.2 to

–0.4, performance degrades significantly. It is particularly interesting to note that, although the trellis demodulator offers about 0.4 dB of improvement (relative to the single-symbol detector) in a multipath-free channel, this advantage is lost as ρ is increased (in magnitude) beyond 0.2. For ρ beyond –0.2, the situation reverses, and the single-symbol detector offers better performance than the trellis demodulator.

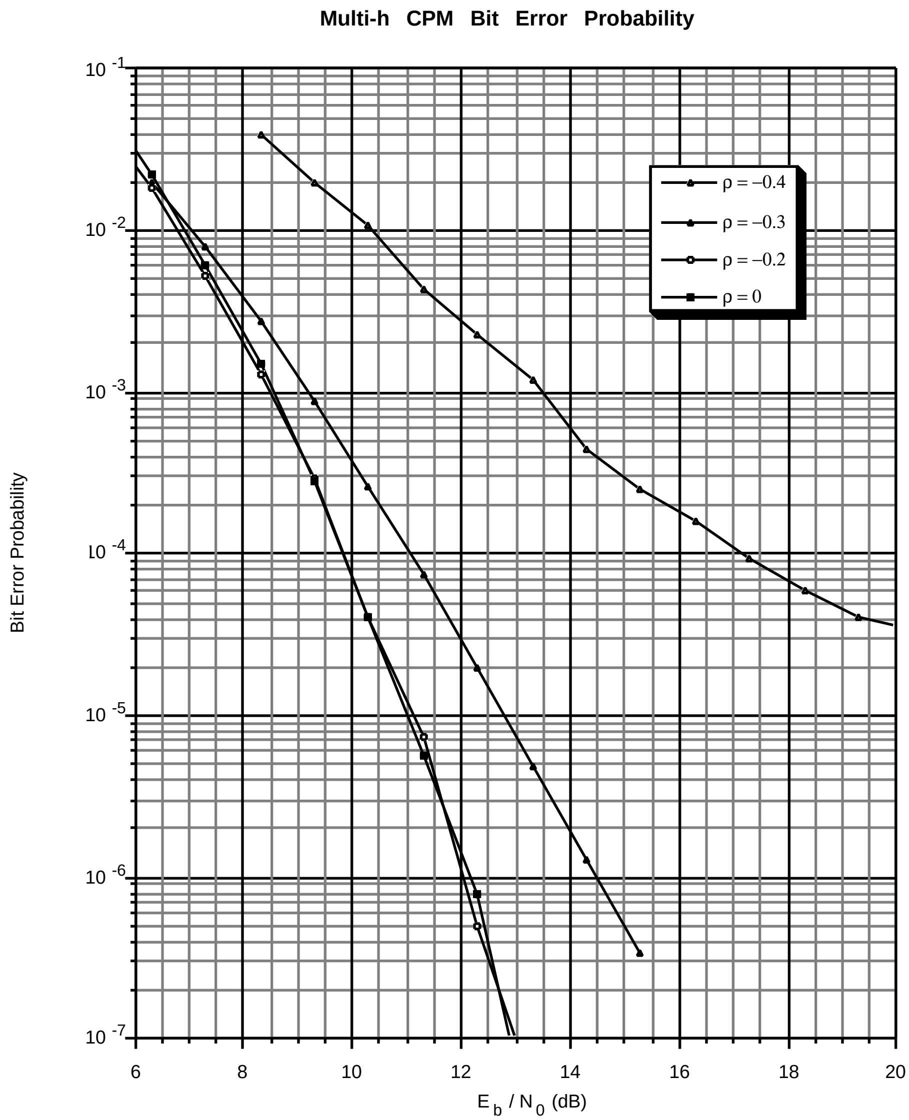

Figure 8. BER for Multi-h CPM, with ρ variable and τ = 1.5 bits.

Figure 8 shows the performance of the Tier II waveform in the same multipath channels. It is significant that, despite the fact that the spectrum is only two-thirds as wide as for the Tier I waveform, the degradation due to multipath is smaller for multi-h CPM than it is for SOQPSK-A, for moderate levels of multipath. For the most severe multipath, however, the multi-h CPM waveform is substantially degraded, exhibiting an error rate floor of about 1.0e-5.

Our hypothesis is that, with modest multipath distortion, the trellis demodulator is effectively providing coding gain against the multipath. Even though the SOQPSK-A signal is also being demodulated with a trellis demodulator, the multi-h CPM signal exhibits the merits of a greater "constraint length", essentially utilizing its longer memory of the channel to minimize the multipath effects. If the multipath is sufficiently severe, the trellis decoder for CPM loses it's "coding gain" because the multipath-delayed signal essentially changes the "encoder", and the trellis "decoder" is no longer correct. This suggests an adaptive equalizer strategy for future research, based on modifying the trellis in response to the multipath.

CONCLUSIONS

We have analyzed the performance of SOQPSK-A and multi-h CPM in the presence of static two-ray multipath. For the SOQPSK-A modulation, we have employed both single-symbol and trellis demodulators. With SOQPSK-A, we have found that the trellis detector is superior to the single-symbol detector for mild multipath, but the reverse is true for severe multipath. In spite of the significantly smaller bandwidth of the CPM waveform, we have found that it suffers less degradation due to multipath than SOQPSK-A for mild multipath. However, more difficult multipath dramatically degrades performance of multi-h CPM, to the point where overall detection efficiency is inferior to SOQPSK-A.

FUTURE RESEARCH

The results presented here suggest that multi-h CPM does not suffer excessive degradation in the presence of moderate multipath, relative to the less spectrally efficient SOQPSK. However, we have explored only a very limited region of the multidimensional multipath parameter space. Further investigation is required to evaluate the effects of additional paths, a wider range of differential delays and reflection coefficients, and most importantly, channel dynamics. Our results here do not address the synchronization performance of either modulation, which directly impacts the demodulator performance under dynamic channel conditions.

Looking beyond the simple analysis of these modulations in the presence of multipath, we conjecture that there are equalization and/or coding techniques which will improve performance. SOQPSK will most likely benefit from conventional linear equalization, with or without decision feedback. Multi-h CPM, on the other hand would quite probably require more sophisticated techniques. The author encourages contact from other researchers who have interest in pursuing these concepts.

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