OPTIMIZED LOW BIT RATE PCM/FM TELEMETRY WITH WIDE IF BANDWIDTHS

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ABSTRACT

This paper will present the results of some experiments with non-coherent, single symbol detection of pulse code modulation (PCM)/frequency modulation (FM) where the receiver intermediate frequency (IF) bandwidth is much wider than the bit rate. The experiments involved varying the peak deviation and measuring the bit error probability (BEP) at various signal energy per bit to noise power spectral density ratios (E_b/N_o). The experiments showed that the optimum peak-to-peak deviation was about 0.7 to 0.8 times the –3 dB IF bandwidth and that the E_b/N_o required for a given BEP increased as the ratio of IF bandwidth to bit rate increased. Further, bi-phase-level/FM performed slightly better than non-return-to-zero-level (NRZ-L)/FM with an ac coupled RF signal generator and IF bandwidths much wider than the bit rate.

KEY WORDS

Bi-phase-level, non-return-to-zero-level, PCM/FM, peak deviation, IF bandwidth

INTRODUCTION

Sometimes one only needs to transmit a few tens of kilobits per second from a test vehicle. However, the narrowest receiver IF filter bandwidth at many telemetry ground stations is about 500 kHz. Therefore, the receiver IF bandwidth may be 10 (or more) times the bit rate which is wider than optimum for PCM/FM telemetry. The questions that this paper will attempt to answer include: what is the optimum peak deviation and code (NRZ or bi-phase (Biϕ, aka Manchester)) when the IF bandwidth is 10 (or more) times the bit rate?

Several authors [1-4] have reported on investigations of the E_b/N_o required for a given BEP under optimum non-coherent conditions with bi-phase/FM and NRZ-L/FM. Tan *et al.*, came up with optimum conditions for bi-phase/FM of IF bandwidth 1.8 times bit rate and peak-to-peak deviation/bit rate (h) of about 1.35 which resulted in an E_b/N_o of about 14.5 dB for a BEP of 10^{-5} The optimum conditions for NRZ-L/FM are an IF bandwidth equal to the bit rate, a peak-to-peak deviation of about 0.7 times the bit rate which result in an E_b/N_o of about 11.8 dB for a BEP of 10^{-5}. An additional concern with small peak deviations is the effects of incidental frequency modulation on data quality. This topic will not be addressed in this paper. The published papers I have seen only looked at IF bandwidth/bit rate ratios of 10 or less. This paper will present measured results for IF bandwidth/bit rate ratios in the range of 10 to 100.

TEST RESULTS

The test setup is shown in figure 1. A bit error test set generated a pseudo-noise signal which was filtered (with –3 dB point of two times the bit rate for bi-phase-L and one times the bit rate for NRZ-L, a 4-pole Butterworth filter was used for these tests because it was available) and applied to the external FM input of an RF signal generator (ac-coupled, -3 dB of about 5 Hz to 10 MHz). The RF generator was connected to a FastBit 2000A noise test set that added noise to achieve a calibrated E_b/N_o. The signal plus noise was then applied to a telemetry receiver with internal FM demodulator. The demodulated signal was connected to a bit synchronizer and the data and clock outputs were connected back to the bit error test set.

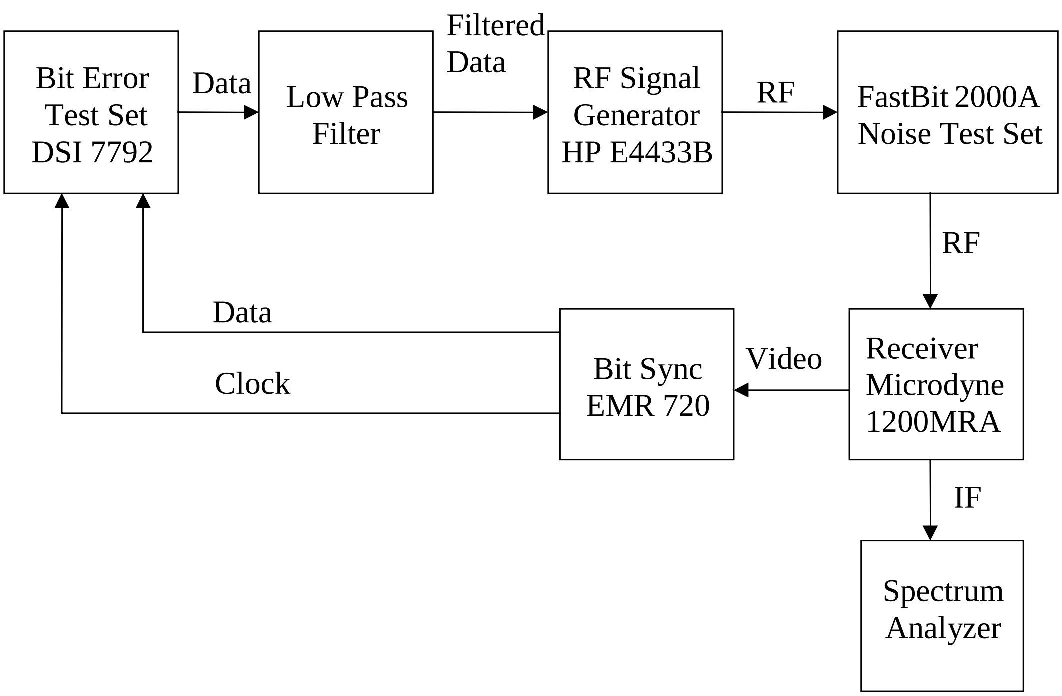

Figure 1. Test setup.

Figures 2 and 3 show the BEP versus E_b/N_o for 50 kb/s NRZ-L/FM and bi-phase-L/FM signals with a 500 kHz IF bandwidth (nominal –3 dB). Note that the bi-phase-L signal required a slightly lower E_b/N_o for a BEP of 10^{-5} (17 dB) than did NRZ-L. The optimum value of h for bi-phase-L was in the range of 7 to 8 while the optimum value of h for NRZ-L was 8 (values between 6 and 10 performed within a few tenths of a dB of each other for both codes, an h of 7 corresponds to a peak-to-peak deviation of 350 kHz and a peak-to-peak deviation/IF bandwidth ratio of 0.7). Additional tests at h=1.35 showed that a 3.5 dB larger E_b/N_o was needed for a BEP of 10^{-5} with h=1.35 than with h=7.

Figure 4 shows the BEP versus E_b/N_o for 50 kb/s bi-phase-L/FM with the center frequency offset in 25 kHz steps. Note that the minimum BEP is at an offset of about 25 kHz and is equivalent to about a 0.3-dB improvement with respect to no frequency offset. Figure 5 shows the measured IF filter response of the filter used for these tests. Note that the bandpass is slightly offset to the high side and the mean of the two –3 dB points is 20.025 MHz which matches the measured BEP data. Figure 6 shows the measured spectrum of the pseudo-random 50 kb/s bi-phase-L/FM signal with a peak-to-peak deviation of 350 kHz.

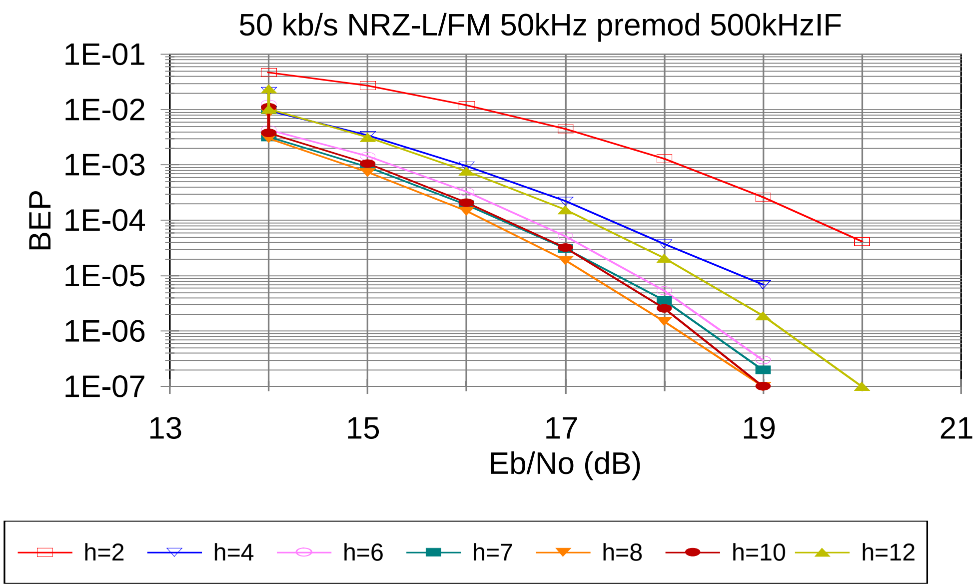

Figure 2. BEP for 50 kb/s NRZ-L/FM.

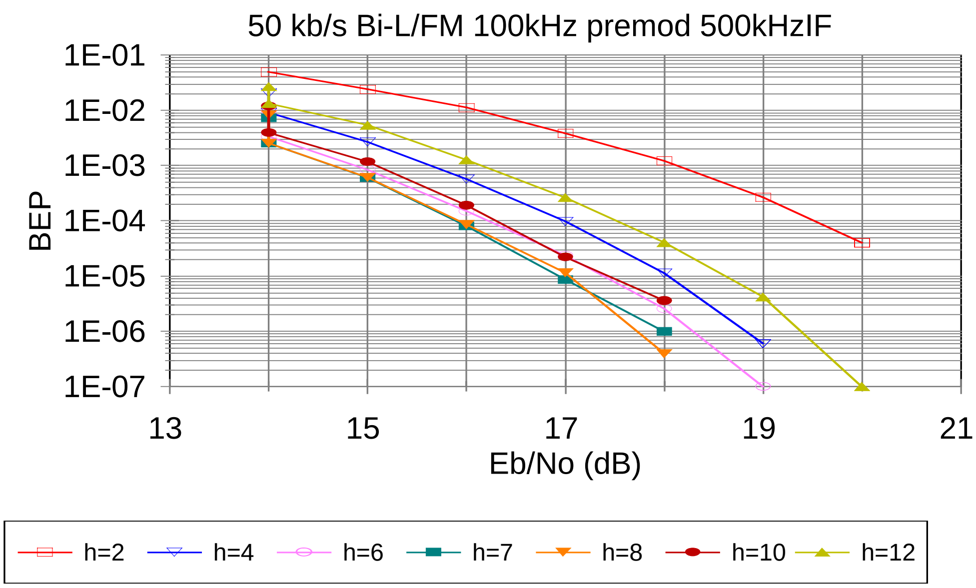

Figure 3. BEP for 50 kb/s bi-phase-L/FM.

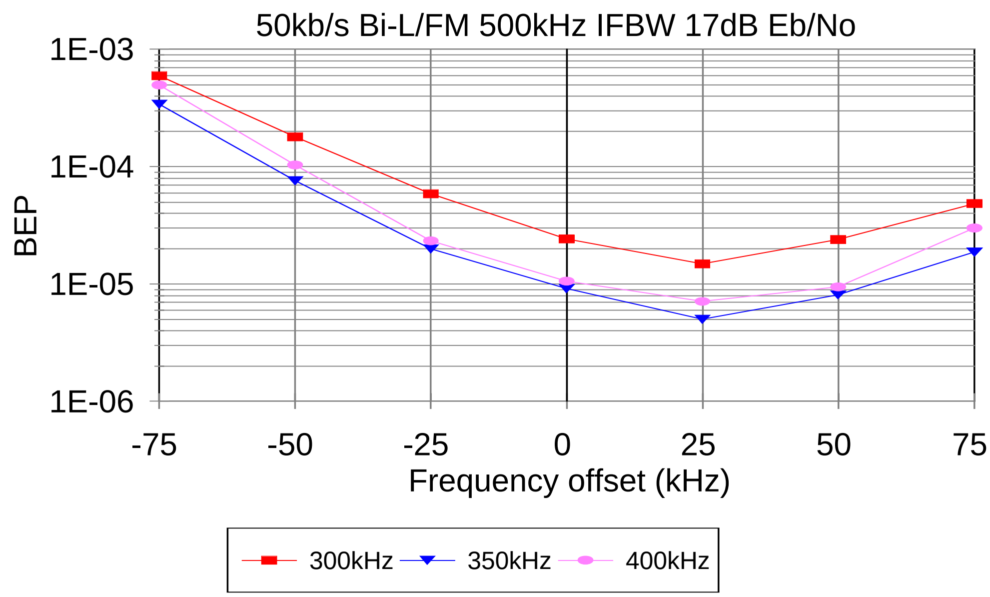

Figure 4. BEP for various frequency offsets.

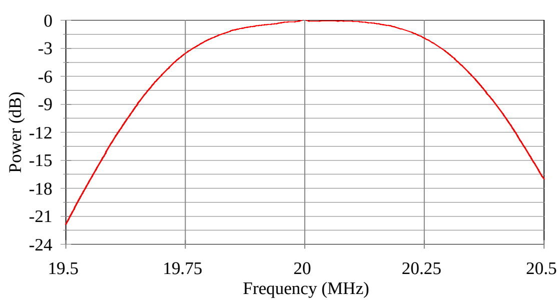

Figure 5. 500 kHz IF filter response.

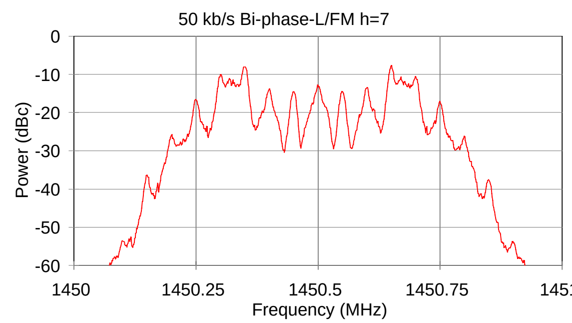

Figure 6. RF spectrum of 50 kb/s bi-phase-L/FM h=7.

Figures 7 and 8 show the BEP versus E_b/N_o for 10 kb/s NRZ-L/FM and bi-phase-L/FM signals with a 500 kHz IF bandwidth. Note that the bi-phase-L signal required a slightly lower E_b/N_o for a BEP of 10^{-5} (18.8 dB) than did NRZ-L. The optimum value of h was in the range of 35 to 40 (values between 30 and 50 performed within a few tenths of a dB of each other for both codes, an h of 35 corresponds to a peak-to-peak deviation of 350 kHz and a peak-to-peak deviation/IF bandwidth ratio of 0.7).

Figure 9 shows the BEP versus E_b/N_o for 5 kb/s bi-phase-L/FM with a 500 kHz IF bandwidth. Note that the bi-phase-L signal required an E_b/N_o of about 19.7 dB for a BEP of 10^{-5}. The optimum value of h was in the range of 70 to 80 (values between 60 and 100 performed within a few tenths of a dB of each other, an h of 70 corresponds to a peak-to-peak deviation of 350 kHz and a peak-to-peak deviation/IF bandwidth ratio of 0.7).

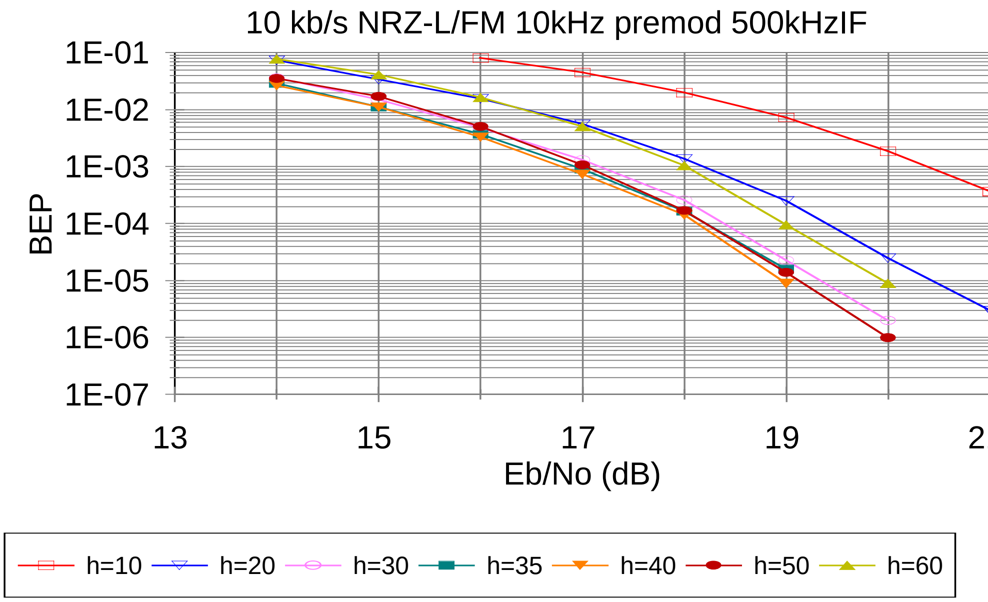

Figure 7. BEP for 10 kb/s NRZ-L/FM.

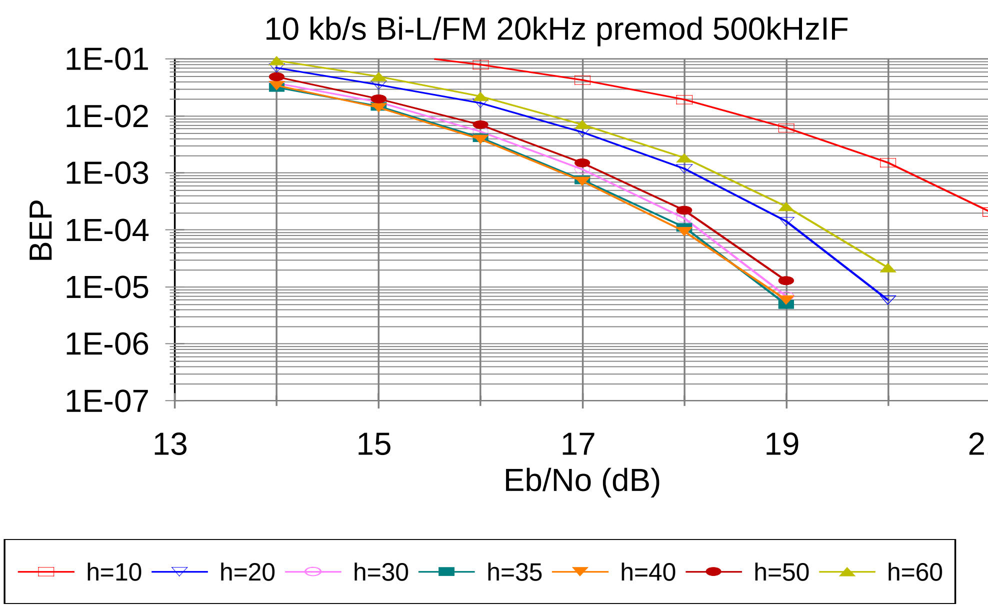

Figure 8. BEP for 10 kb/s bi-phase-L/FM.

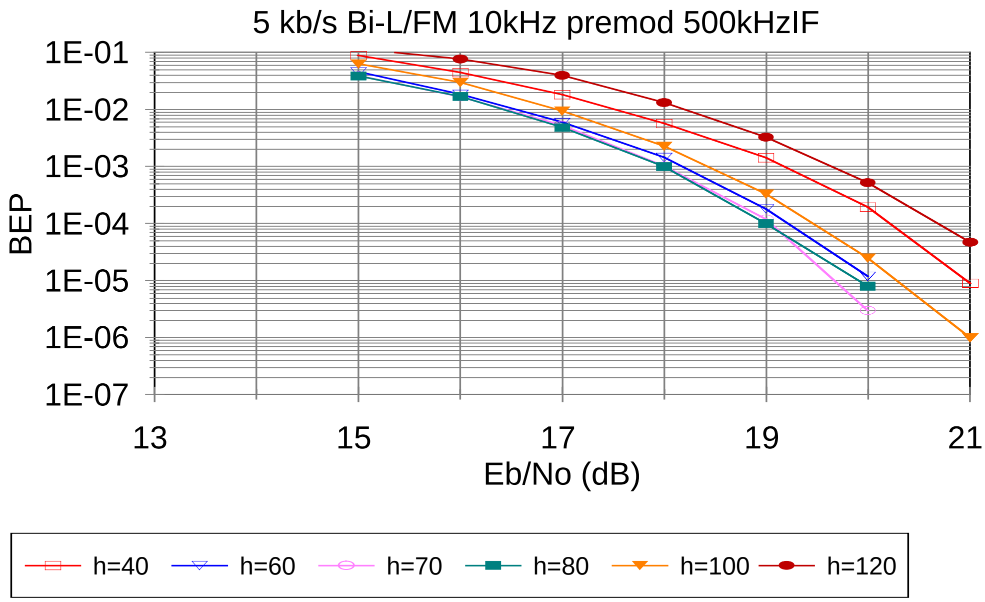

Figure 9. BEP for 5 kb/s bi-phase-L/FM.

The optimum peak-to-peak deviation was in the range of 0.7 to 0.8 times the IF bandwidth for all of the tests. Figure 10 shows the minimum E_b/N_o required for a BEP of 10^{-5} for various IF bandwidth/bit rate ratios. The required E_b/N_o for a BEP of 10^{-5} only increased by 3 dB for a 10 to 1 change in IF bandwidth/bit rate. Converting from E_b/N_o to IF signal-to-noise ratio (SNR) results in the following IF SNR values: about 7 dB at an IF bandwidth/bit rate ratio of 10 and about 0 dB at an IF bandwidth/bit rate ratio of 100.

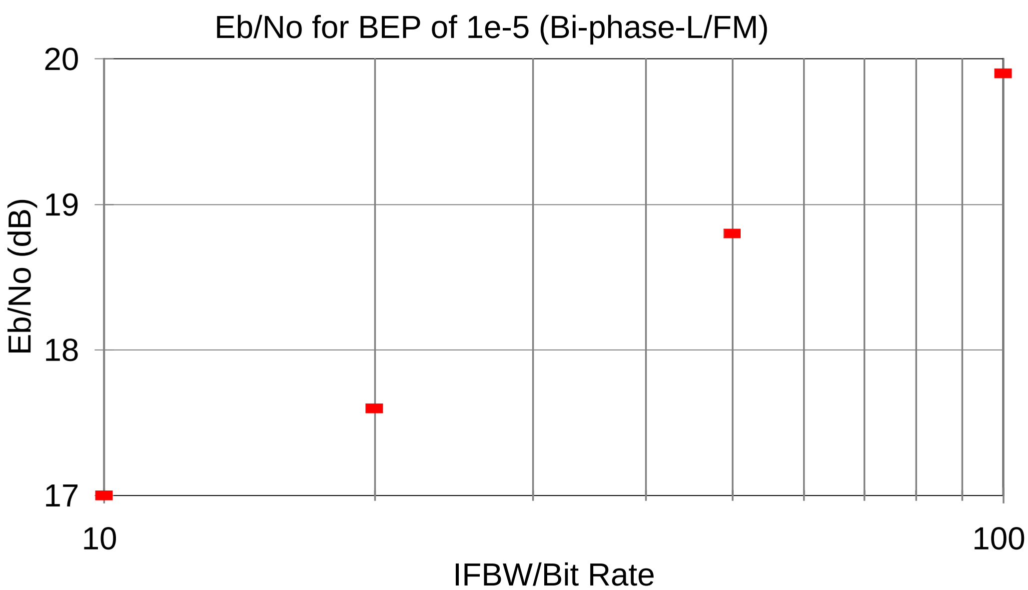

Figure 10. Eb/No for BEP of 1e-5 (bi-phase-L/FM).

SUMMARY

1. The optimum peak-to-peak deviation was in the range of 0.7 to 0.8 times the IF bandwidth for all of the tests (interestingly, the optimum values of peak-to-peak deviation for narrow band bi-phase/FM and NRZ-L/FM are also in the range of 0.7 to 0.75 times the IF bandwidth).
2. For IF bandwidths of 10 times the bit rate and wider, bi-phase-L/FM had slightly lower BEPs for a given E_b/N_o than NRZ-L/FM.
3. Using the optimum peak-to-peak deviation, the required E_b/N_o for a BEP of 10^{-5} varied from about 17 dB with an IF bandwidth of 10 times the bit rate up to 19.7 dB with an IF bandwidth of 100 times the bit rate.
4. With an IF bandwidth of 10 times the bit rate and bi-phase-L code; h=7 performed about 3.5 dB better than h=1.35.
5. Required E_b/N_o values with other telemetry equipment will be slightly different but the values measured during these tests should be close to the values required with current equipment at test ranges.

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