HOW WELL DOES A BLIND, ADAPTIVE CMA EQUALIZER WORK IN A SIMULATED TELEMETRY MULTIPATH ENVIRONMENT

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ABSTRACT

This paper will present the results of experiments to characterize the performance of a blind, adaptive constant modulus algorithm (CMA) equalizer in simulated telemetry multipath environments. The variables included modulation method, bit rate, received signal-to-noise ratio, delay of the indirect path relative to the direct path, amplitude of the indirect path relative to the direct path, and fade rate. The main measured parameter was bit error probability (BEP). The tests showed that the equalizer usually improved the data quality in the presence of multipath.

KEY WORDS

Adaptive equalization, multipath fading, CMA equalizer, telemetry, PCM/FM, SOQPSK-TG, ARTM CPM

OVERVIEW

Multipath can be a significant problem in some aeronautical telemetry flight tests. Flight tests were performed at Edwards AFB to characterize the telemetry channel in their high desert environment [1]. One possible solution to the multipath problem is an adaptive equalizer [2]. Reference 2 presents results with a blind, adaptive equalizer based on the constant modulus equalization algorithm. The Nova Engineering MMD44 demodulator was also used for the test results reported herein. The multipath fading was generated using a Rohde & Schwartz (R&S) SMIQ signal generator operated with 2 paths and a 10 Hz fading rate. The measurement interval was 10 seconds. Therefore, approximately 100 fades occurred in each measurement interval. The SMIQ can generate delays in steps of 50 ns. The delays determined in reference [1] were usually less than 400 ns so delays of 50, 100, 200, and 400 ns were used in this experiment. The bit rates used for these tests were 2, 6 and 10.5 Mb/s. The modulation methods used were pulse code modulation/frequency modulation (PCM/FM), shaped offset quadrature phase shift keying (SOQPSK-TG), and Advanced Range Telemetry (ARTM) continuous phase modulation (CPM).

TEST SETUP AND TEST RESULTS

The R&S AMIQ generator was used in conjunction with the R&S SMIQ to generate the modulated radio frequency (RF) signals as shown in figure 1. The RF signal was applied to a telemetry receiver and the intermediate frequency (IF) output of the receiver was connected to a Nova Engineering model MMD44 demodulator. The data and clock from the MMD44 were connected to the AMIQ to allow measurement of the BEP. The SMIQ output level was adjusted to produce signal energy per bit to noise power per Hz ratios (E_b/N_0) for the direct signal path of approximately 15, 25, and 35 dB for each bit rate. This paper uses refection coefficient (Γ) to be consistent with references 1 and 2 but the hardware used for the test is programmed in terms of excess path loss. The second ray path loss was set to 10 dB (Γ_2=0.316) and the BEP was measured over a 10 second interval. The second ray path loss was decreased and the BEP measured. This process was repeated until the BEP exceeded 10^{-3}. A decision was made to declare "acceptable" performance to be a BEP of 10^{-5} or lower. Additional measurements at higher second ray path losses were performed when the BEP was larger than 10^{-5} with a 10 dB loss. For comparison purposes, the test was also performed using a conventional single symbol demodulator/bit detector for 10.5 Mb/s PCM/FM. A few tests were also performed at a fade rate of 1 fade/s to verify that the 10 Hz fade rate was not a significant factor in the results. The results were essentially the same at 1 Hz and 10 Hz fade rates.

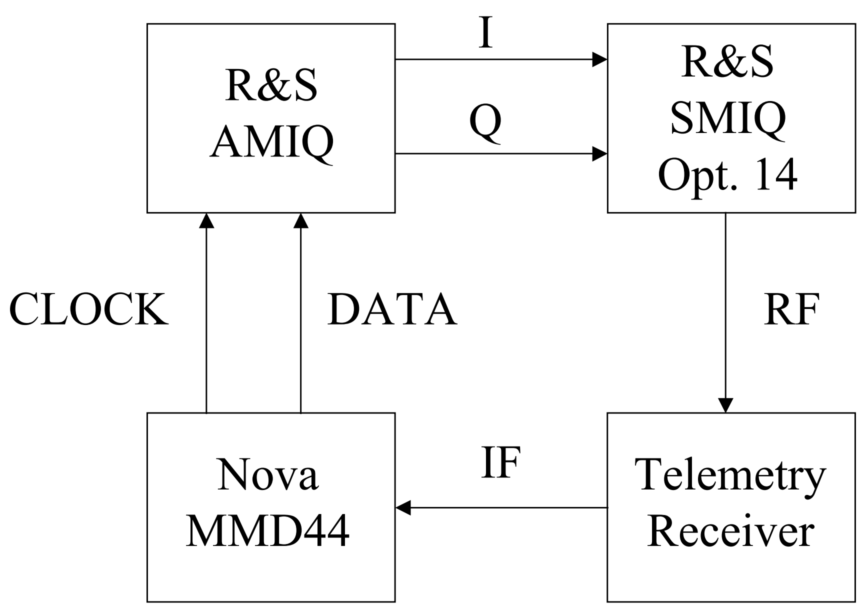

Figure 1. Test setup.

Figure 2 shows measured BEP values versus Γ_2 for 10.5 Mb/s NRZ-L PCM/FM with a receiver demodulator and single symbol bit detector. The first value in the ordered pairs in the legend is the second path delay in ns and the second value is the approximate E_b/N_0 value of the direct path in dB. Note that bit errors start to occur at a Γ_2 value of about 0.5 or lower and bit errors start at higher values of Γ_2 with the higher value of E_b/N_0. Higher values of Γ_2 indicate more severe multipath fading. Also, the worst performance (lowest value of Γ_2 for a given BEP) occurs for a second path delay of 100 ns which is a delay of about one bit time.

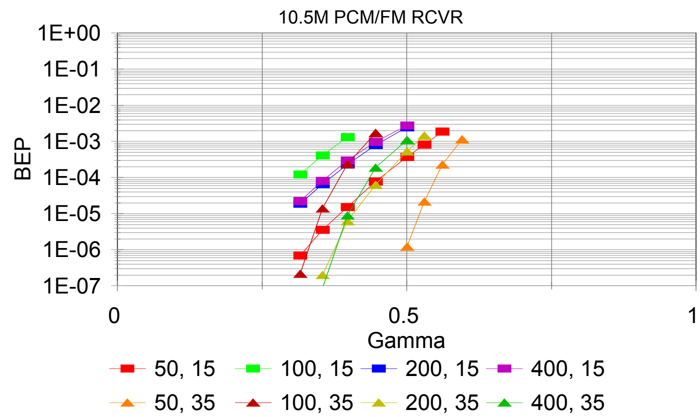

Figure 2. Measured BEPs for 10.5 Mb/s NRZ-L PCM/FM with receiver/bit sync.

Figure 3 shows the measured BEP values versus Γ_2 for 10.5 Mb/s NRZ-L PCM/FM with a Nova MMD44 demodulator with equalizer off. Note the clustering of the data by E_b/N_0 values with the 35 dB E_b/N_0 values having the higher values of Γ_2. The values of Γ_2 are higher for figure 3 than for figure 2 which shows that the Nova MMD44 performs better under these multipath conditions than does the receiver demodulator/bit detector used in figure 2.

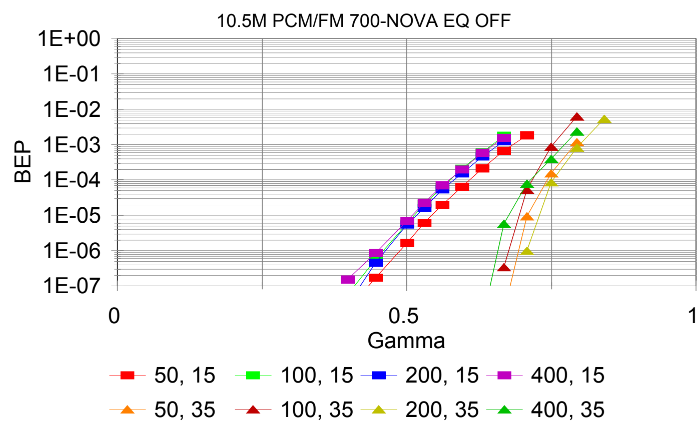

Figure 3. Measured BEPs for 10.5 Mb/s NRZ-L PCM/FM with Nova MMD44 (equalizer off).

Figure 4 shows the measured BEP values versus Γ_2 for 10.5 Mb/s NRZ-L PCM/FM with a Nova MMD44 demodulator with equalizer on and equalizer gain at the default value of 314. Note that the values of Γ_2 are higher for figure 4 than for figure 3 which shows that the Nova MMD44 equalizer is reducing the multipath effects. The equalizer performs best with the 35 dB E_b/N_0 values especially with the 50 and 100 ns delays. The poorest equalizer performance was with the 400 ns delays.

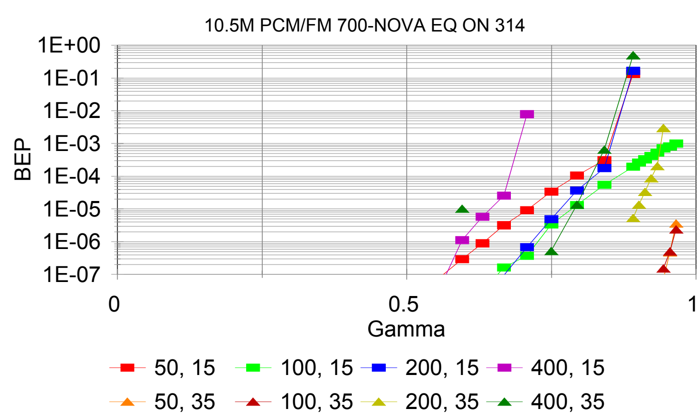

Figure 4. Measured BEPs for 10.5 Mb/s NRZ-L PCM/FM with Nova MMD44 (equalizer on).

Figures 5 and 6 show the performance with SOQPSK-TG modulation and with the equalizer off and on. Note that the values of Γ_2 are usually higher for figure 6 than for figure 5 which shows that the Nova MMD44 equalizer is reducing the multipath effects in most cases. The exceptions are slight degradation with an E_b/N_0 value of 15 dB and the shorter delays. Interestingly, the equalizer did the best with short delays at 35 dB and the worst with short delays at 15 dB. The longer delays had the worst performance with the equalizer off.

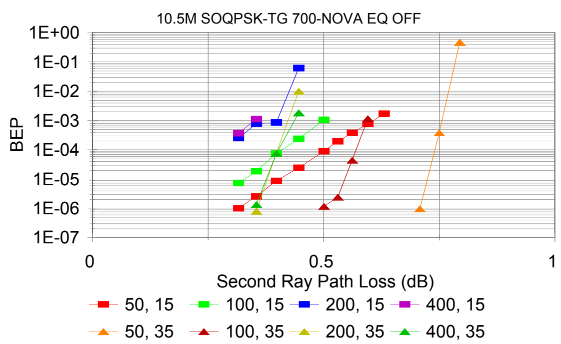

Figure 5. Measured BEPs for 10.5 Mb/s SOQPSK-TG with Nova MMD44 (equalizer off).

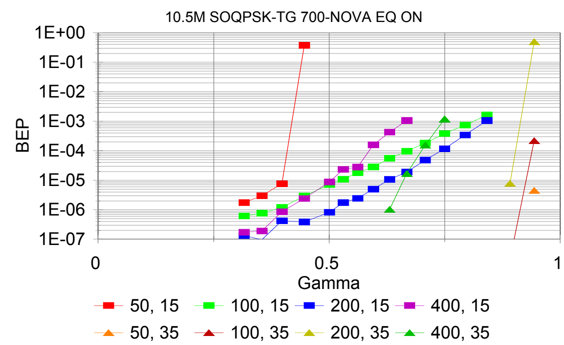

Figure 6. Measured BEPs for 10.5 Mb/s SOQPSK-TG with Nova MMD44 (equalizer on).

Figures 7 and 8 show the performance with ARTM CPM modulation and with the equalizer off and on. Note that the values of Γ_2 are usually higher for figure 8 than for figure 7 which shows that the Nova MMD44 equalizer is reducing the multipath effects in most cases. The exception is a slight degradation with an E_b/N_0 value of 15 dB and the 50 ns delay. Especially note the poor multipath performance of ARTM CPM with no equalizer for the 200 and 400 ns delays. The BEPs are all greater than 10^{-3} for a Γ_2 of 0.316. The equalizer performed much better with the 35 dB E_b/N_0 values especially for the shorter delays.

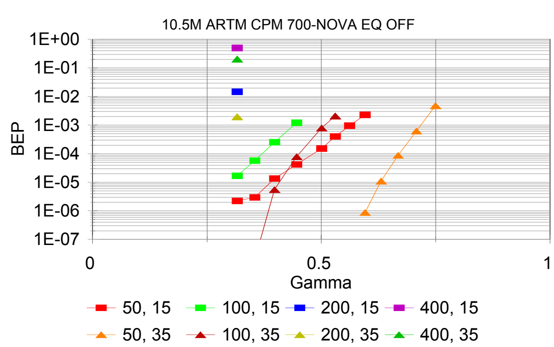

Figure 7. Measured BEPs for 10.5 Mb/s ARTM CPM with Nova MMD44 (equalizer off).

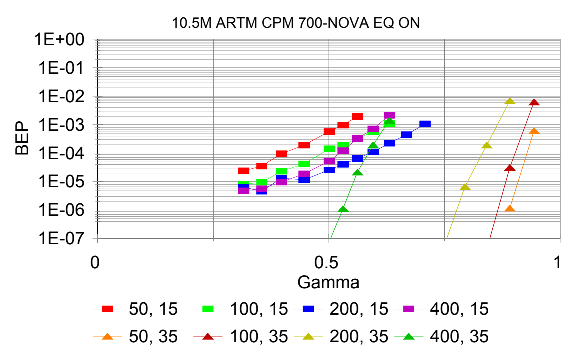

Figure 8. Measured BEPs for 10.5 Mb/s ARTM CPM with Nova MMD44 (equalizer on).

During these tests several instances of "anomalous" equalizer performance were noted, that is, sometimes the equalizer would converge on an erroneous solution which resulted in a BEP of 0.5. Nova Engineering is working on a solution to this problem. There were also a few instances of convergence on a sub-optimum solution.

The results presented in Table 1 are the highest value of Γ_2 for which the BEP is approximately 10^{-5} for each modulation method, bit rate, E_b/N_0 value, and equalizer state (off or on (Nova EQ indicates the equalizer is on)). Some conclusions from looking at this data are: the lower bit rates are affected less by multipath than the higher bit rates, ARTM CPM is the most susceptible to multipath of these modulation methods and PCM/FM with the Nova demodulator is the least susceptible, the most dramatic improvement with the equalizer was for ARTM CPM with 400 ns delays.

Table 1. Measured Values of Γ_2 which resulted in a BEP of 10^{-5} for Various Test Conditions.

Modulation	Bit Rate (Mb/s)	E_b/N_0 (dB)	Demodulator/ Bit Detector	50 ns Γ_2	100 ns Γ_2	200 ns Γ_2	400 ns Γ_2
PCM/FM	2	15	Nova	0.58	0.59	0.59	0.56
PCM/FM	2	15	Nova EQ	0.58	0.6	0.68	0.79
PCM/FM	2	35	Nova	0.93	0.89	0.82	0.75
PCM/FM	2	35	Nova EQ	0.92	0.93	0.93	0.9
PCM/FM	10.5	15	Nova	0.54	0.51	0.51	0.51
PCM/FM	10.5	15	Nova EQ	0.71	0.79	0.77	0.64
PCM/FM	10.5	15	RCVR	0.39	0.25	0.3	0.3
PCM/FM	10.5	35	Nova	0.71	0.69	0.72	0.68
PCM/FM	10.5	35	Nova EQ	0.98	0.98	0.9	0.79
PCM/FM	10.5	35	RCVR	0.52	0.35	0.41	0.4
SOQPSK-TG	2	15	Nova	0.43	0.43	0.43	0.32
SOQPSK-TG	2	15	Nova EQ	0.32	0.39	0.45	0.5
SOQPSK-TG	2	35	Nova	0.9	0.87	0.78	0.63
SOQPSK-TG	2	35	Nova EQ	0.93	0.91	0.89	0.85
SOQPSK-TG	10.5	15	Nova	0.4	0.33	0.22	0.22
SOQPSK-TG	10.5	15	Nova EQ	0.41	0.53	0.63	0.5
SOQPSK-TG	10.5	35	Nova	0.72	0.55	0.38	0.38
SOQPSK-TG	10.5	35	Nova EQ	0.95	0.93	0.89	0.67
ARTM CPM	6	15	Nova	0.42	0.43	0.31	0.18
ARTM CPM	6	15	Nova EQ	0.5	0.53	0.62	0.65
ARTM CPM	6	35	Nova	0.85	0.58	0.35	0.22
ARTM CPM	6	35	Nova EQ	0.9	0.9	0.85	0.78
ARTM CPM	10.5	15	Nova	0.39	0.3	0.15	0.12
ARTM CPM	10.5	15	Nova EQ	0.28	0.35	0.45	0.4
ARTM CPM	10.5	35	Nova	0.63	0.41	0.23	0.19
ARTM CPM	10.5	35	Nova EQ	0.91	0.88	0.79	0.56

SUMMARY

The results reported in this paper show that the Nova Engineering MMD44 does a good job of correcting for multipath impairments at high values of E_b/N_0 (35 dB). The performance at an E_b/N_0 of 15 dB was usually fairly good but there were a few instances of degradation with short delays. The best performance was usually with the shorter delays except for the 15 dB E_b/N_0 with equalizer case where the best performance was with the longer delays. Other findings include: the lower bit rates are affected less by multipath than the higher bit rates, ARTM CPM is the most susceptible to multipath of these modulation methods and PCM/FM with the Nova demodulator is the least susceptible, the most dramatic improvement with the equalizer was for ARTM CPM with 400 ns delays, during these tests several instances of "anomalous" equalizer performance were noted, that is, sometimes the equalizer would converge on an erroneous solution which resulted in a BEP of 0.5. This erroneous solution problem is a significant limitation on the usefulness of this equalizer for flight test applications. Nova Engineering is working on a solution to this problem.

REFERENCES

[1] Michael Rice, Adam Davis, Christian Bettwieser; "A WIDEBAND CHANNEL MODEL FOR AERONAUTICAL TELEMETRY— PART 2: MODELING RESULTS"; Proceedings of the 2002 International Telemetering Conference.

[2] Mark Geoghegan, "EXPERIMENTAL RESULTS FOR PCM/FM, TIER 1 SOQPSK, AND TIER II MULTI-H CPM WITH CMA EQUALIZATION"; Proceedings of the 2003 International Telemetering Conference.