BER ANALYSIS OF AN F-16 TEST RUN AT EDWARDS AFB

Daniel Friend
Department of Electrical and Computer Engineering
Brigham Young University
Provo, UT 84602
dfriend@ift.ee.byu.edu

Faculty Advisor:
Michael Rice

ABSTRACT

This paper analyzes the bit error rates (BER) using data recorded during an F-16 test at Edwards Air Force Base in September, 1996. The effects of multipath fading on BER are presented. It is shown that significant increases in BER can occur when the received signal power remains at an acceptable level. Recordings of the received power spectrum during the test show that these BER increases are caused by frequency selective fades due to multipath interference. This paper illustrates that in these cases, significant data degradation can occur without drops in the received signal power.

INTRODUCTION

Multipath interference is a common cause of signal degradation in aeronautical telemetry. Multipath occurs when multiple copies of a transmitted signal reflect off various surfaces and recombine at the receive antenna. Having traveled different paths, these multiple copies have different phases and amplitudes. The phase differences between the paths vary as the relative positions of transmit and receive stations change with time. This results in random periods of both constructive and destructive interference. The phase of the received copies is a function of the dielectric properties of the reflecting media, the delay imposed by the differential path length, and the wavelength of the electromagnetic wave front. Since the phase of received copies is a function of frequency, multipath may cause constructive interference at one frequency and destructive interference at another. When both frequencies are within the bandwidth of the transmitted signal, part of the spectrum of the transmitted signal may be attenuated while another may be unaffected. This phenomenon is called *frequency selective fading*.

Multipath interference in aeronautical telemetry applications is often modeled by a single dominant specular reflection [1, 2, 3]. For this model, the impulse response of the channel is

$$h(t) = \delta(t) + \Gamma e^{j(2\pi f_0 \tau + \theta)} \delta(t - \tau) \tag{1}$$

with transfer function

$$|H(f)|^2 = 1 + 2\Gamma \cos\left(2\pi(f - f_0)\tau + \theta\right) + \Gamma^2 \tag{2}$$

where Γ is the relative amplitude of the specular reflection, f_0 is the carrier frequency, *J* is the delay of the specular reflection relative to the line-of-sight path, and *2* is the phase induced by the reflecting medium. Figure 1 illustrates the characteristics of the transfer function. Note the null at 2.3385 GHz. In general, this null is a function of *J* and *2* which change in a random fashion as the reflection geometry changes during a test. Thus during real tests, the channel transfer function displays a null which sweeps through the spectrum at random intervals. Because the null appears for a short period of time at a particular frequency the SNR, which is an average of the power across the entire signal bandwidth, may drop only a few dB.

The effects of frequency selective multipath are difficult to quantify. This paper uses data collected during F-16 BER tests conducted at Edwards AFB in September, 1996 to illustrate the effects of frequency selective fading on both the received power and BER.

DATA ANALYSIS

The source of the data used for the analysis was an F-16 BER test conducted at Edwards AFB in September, 1996. For a complete description of the experiment, see [4]. This test flight involved an F-16 outfitted with a 5 Mbps PCM/FM transmitter with a carrier frequency of 2.3355 GHz. A pseudo-random bit stream was transmitted which was used by a link analyzer at the receive site to compute and record the real time BER. In addition, the spectrum analyzer output was recorded to VHS video tape and the AM and AGC voltages were also recorded. A number of test flights were conducted — this paper focuses on the low fly tests since low elevation angle tests are more prone to multipath [5].

Figures 2 and 3 show a 60 second segment of one of the low fly tests which include five fading events. Fading events occur when the bit error rate exceeds 10^{-6}. The first three (at approximately 18 seconds, 24 seconds, and 41 seconds) are not accompanied by a significant drop in the received power which is represented by the plot of the received AM voltage (Figure 3). The second fade (at 24 seconds) is so severe, synchronization is lost as indicated by a bit error rate of 1. The last two fades (at approximately 49 seconds) are accompanied by a 30 dB drop in the received power. This example demonstrates nicely the characteristic that fading is not always accompanied by a sizeable drop in the received signal level.

To further examine the fades, the spectrum analyzer output during the first three fade events are presented in Figures 4 through 6. During the first fade event, the right-hand side of the spectrum is attenuated approximately 10 dB relative to the left-hand side at the beginning of the fade event. Next, the attenuation affects the left-hand side of the spectrum. No sharp null is evident due to spectrum analyzer averaging. The two frames shown are approximately 0.1 seconds apart. Since the channel transfer function null sweeps through the spectrum in about this time, the null frequency changes at a rate of 100 MHz/sec.

The received PCM/FM spectrum during second fade event is illustrated in Figure 5. Again, the spectral attenuation moves from right to left across the frequency band as in the first fade event. In this case, however, the rate at which the null sweeps across the spectrum is slower (50 MHz/second) so that three different cases were clearly observable on the spectrum analyzer output. The interesting difference here is the 10 dB null in the center of the spectrum as illustrated in the second image in Figure 5. Note that the entire PCM/FM spectrum is 10 dB lower at this point. Since the sweep rate of the null was slower, the impact of this fade event on bit error rate was more severe than the first fade event as evidenced by the loss of synchronization.

The third fade event is illustrated in Figure 6. This event is very similar to the first event: the affects on bit error rate and received power level are approximately the same.

DISCUSSION AND CONCLUSIONS

We have demonstrated the effect of frequency selective fading on the performance of PCM/FM systems. In many cases, the increases in bit error rate were not accompanied by a significant drop in the received signal power. A thorough link analysis of this test was performed in [4]. Using these data, the predicted bit error rate using the results from [6] should have never exceeded 10^{-10} for the slant ranges encountered in the low-fly corridor. However, bit error rates well in excess of 10^{-0} were observed. It was shown that these occurrences corresponded to frequency selective fading observed in the spectrum of the received PCM/FM system.

There were other places in the data where flat fading (or frequency non-selective fading) was observed. During these fades, the entire frequency spectrum is attenuated by the same amount and is accompanied by a significant drop in the received signal power. These fades are most likely due to nulls in the transmit antenna gain pattern as discussed in [3, 7].

REFERENCES

[1] N. Tom Nelson. Probability of bit error on a standard IRIG telemetry channel using the aeronautical fading channel model. In *Proceedings of the International Telemetering Conference*, volume 30, pages 356-363, October 1994.

[2] Lyman Horne and Ricky Dye. Parameter characterization on a telemetry channel including the effects of the specular ray. In *Proceedings of the International Telemetering Conference*, volume 31, pages 210-215, October 1995.

[3] Michael Rice and Gene Law. Aeronautical telemetry fading sources. In *Proceedings of the International Telemetering Conference*, volume 33, October 1997.

[4] John Reddemann. Edwards range telemetry evaluation. In *International Test and Evaluation Conference*, Lancaster, CA, April 1997.

[5] Michael Rice and Daniel Friend. Antenna gain pattern effects on multipath interference in aeronautical telemetering. In Proceedings of the *International Telemetering Conference*, volume 33, October 1997.

[6] Eugene Law. Binary PCM/FM, tradeoffs between specral occupancy and bit error probability. In *Proceedings of the International Telemetering Conference*, volume 30, pages 347-355, San Diego, October 1994.

[7] Moises Pedroza. Antenna pattern evaluation for link analysis. In *Proceedings of the International Telemetering Conference*, volume 32, pages 111-118, San Diego, CA, October 1996.

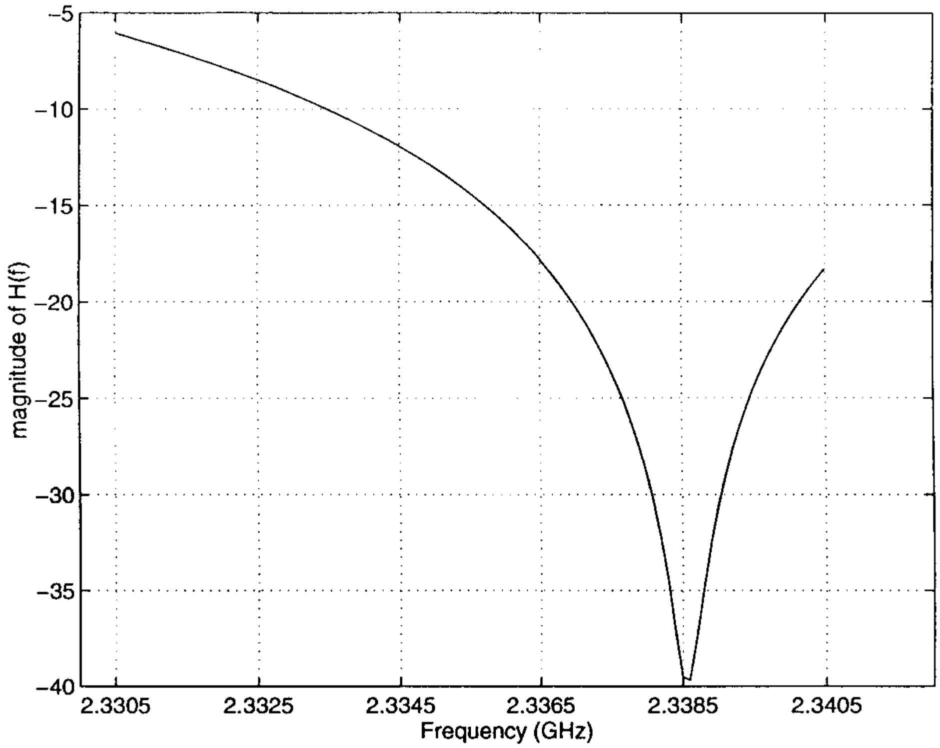

Figure 1: Example of T@ansfer Function IH(f)1' Illustrating the Null

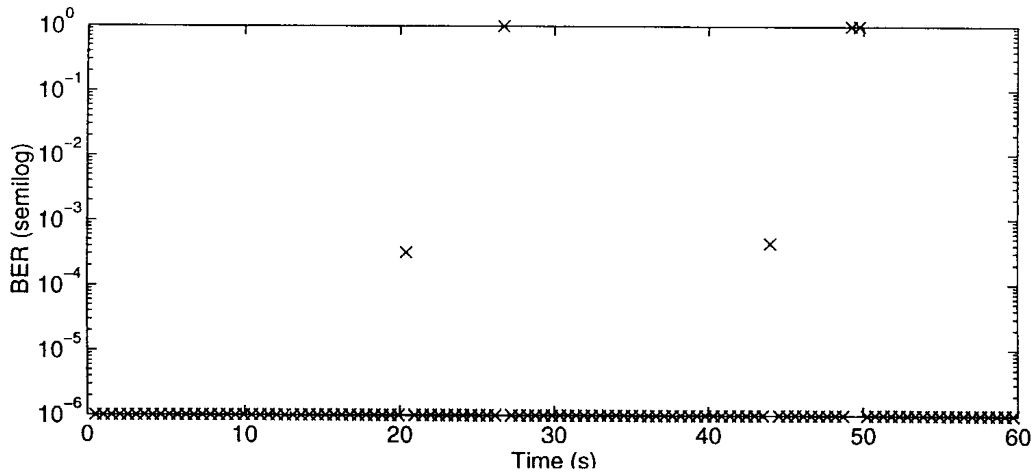

Figure 2: Recorded Bit Error Probabilities for a One Minute Window of the F-16 Low F1 Test.

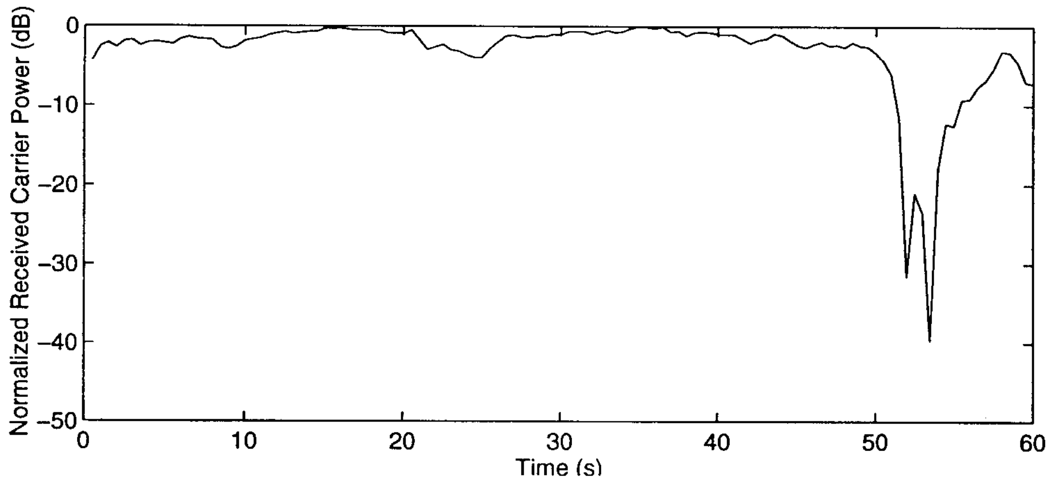

Figure 3: Recorded AM Output for a One Minute Window of the F-16 Low Fly Test.

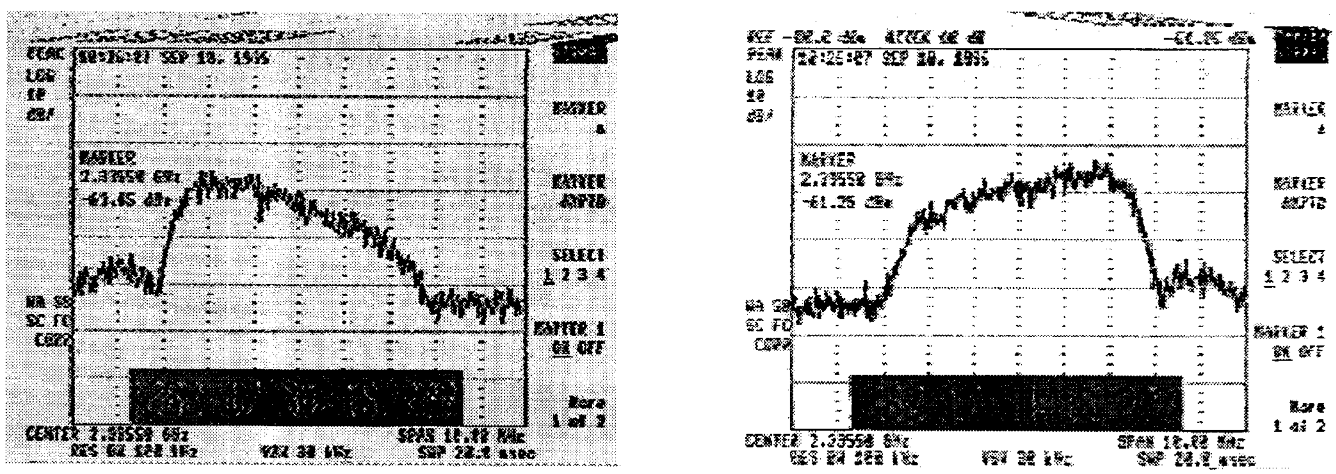

Figure 4: Received PCM/FM Spectrum During First Fade Event at 17:34:18

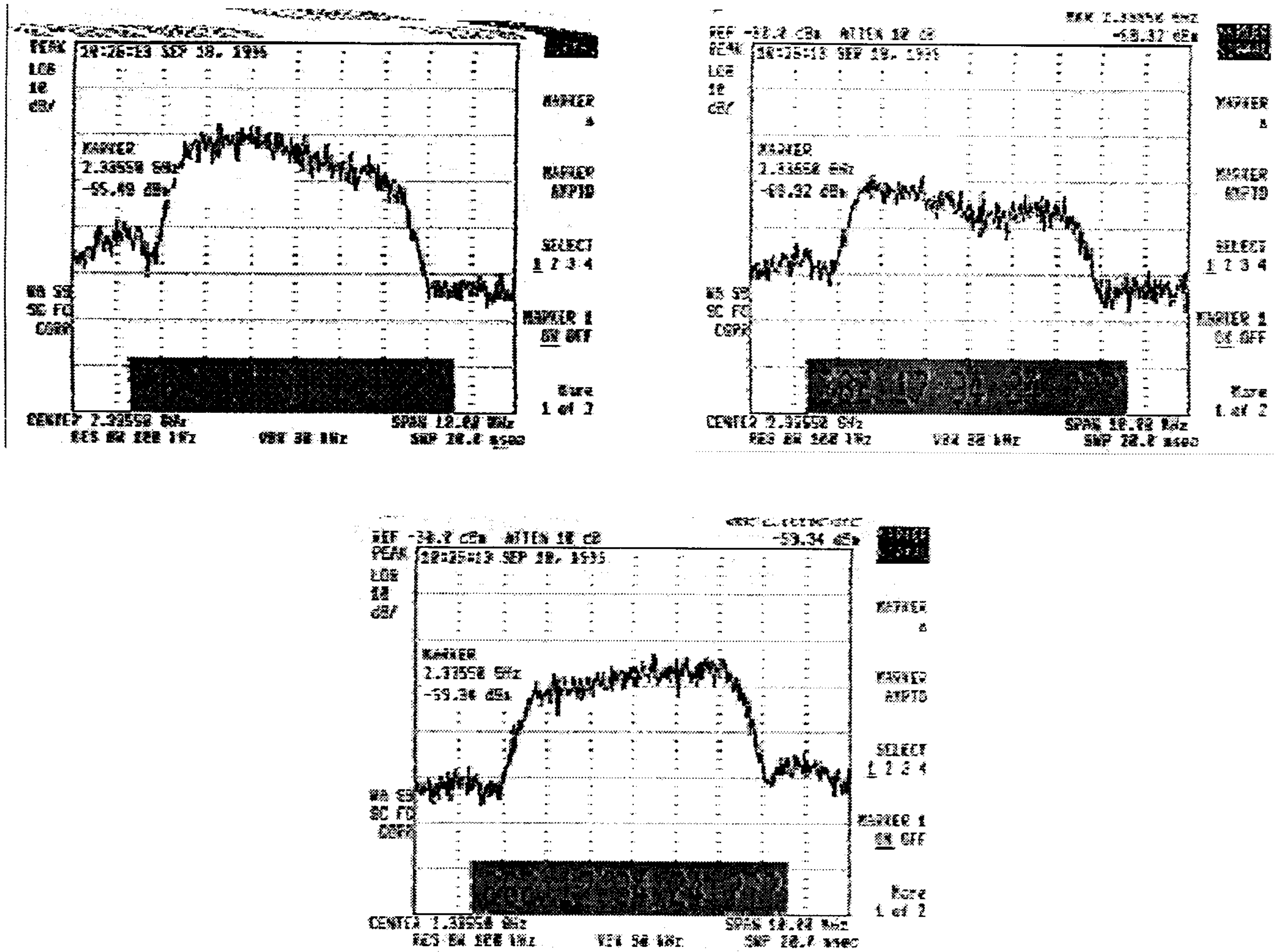

Figure 5: Received PCM/FM Spectrum During Second Fade Event at 17:34:24

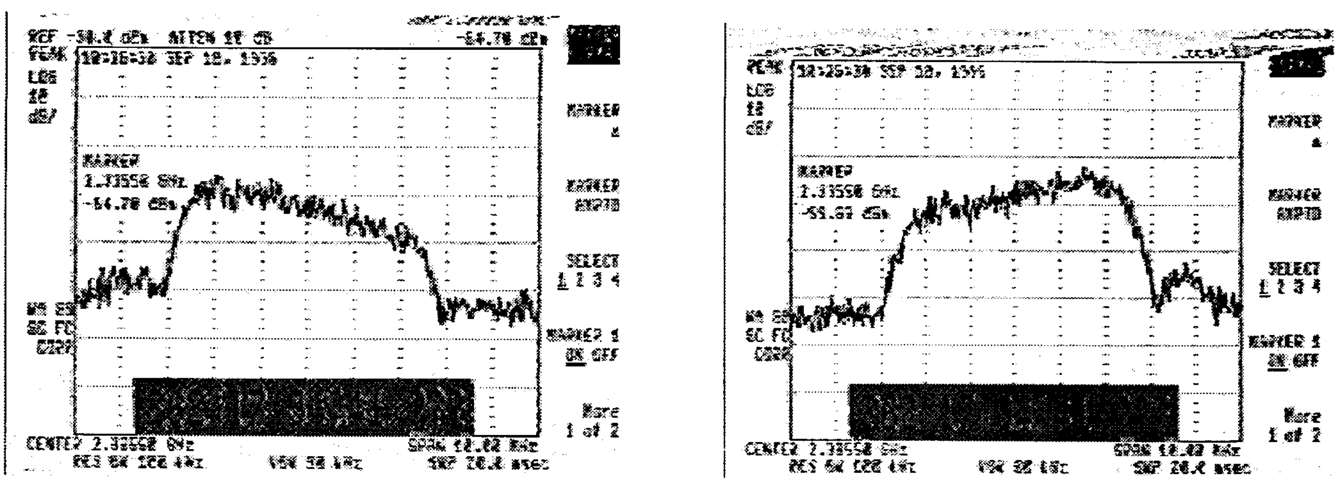

Figure 6: Received PCM/FM Spectrum During Third Fade Event at 17:34:41