AERONAUTICAL TELEMETRY FADING SOURCES AT TEST RANGES

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ABSTRACT

This paper describes the two main causes of fading encountered at test ranges. The first cause of fading results from nulls in the transmit antenna gain pattern. Variations in the received signal level are a result of changes in the gain pattern as the spatial relationship between transmitter and receiver change. The second cause of fading is due to multipath interference. This occurs when multiple copies of the transmitted signal with different delays arrive at the receiver and are phased relative to each other so that destructive interference occurs.

KEY WORDS

Multipath, antenna patterns, frequency selective fading

INTRODUCTION

Continual variations in received signal levels typically occur in airborne telemetry applications as illustrated by the signal-to-noise ratio (SNR) versus time plot in Figure 1. The SNR's are the average value over each 10 ms interval for part of a missile test flight. The actual signal level variations would be larger without the averaging. The minor variations do not cause problems if sufficient link margin is available as it is in this case. The larger variations are often called "signal drop outs" or fades. The large variations around a time of 45 seconds resulted in noisy data.

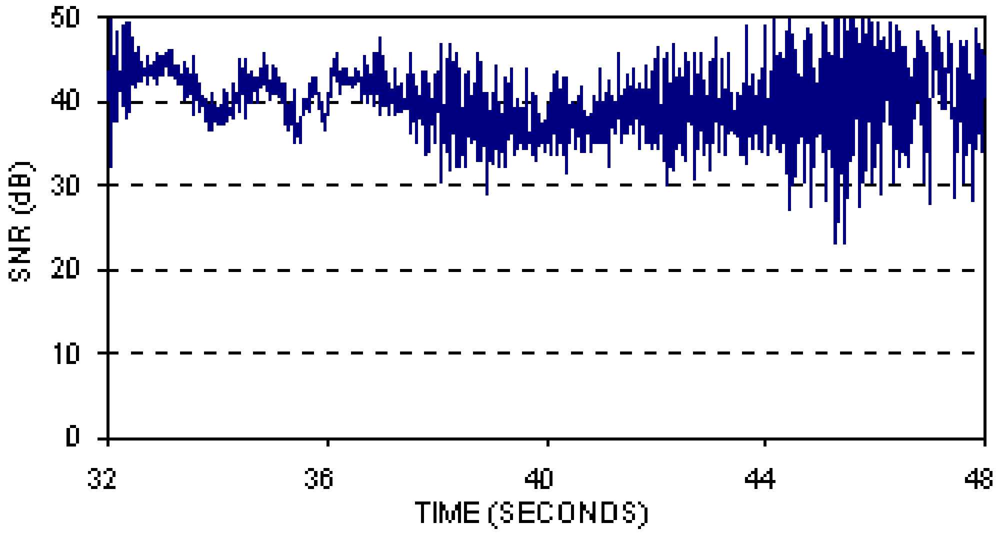

Figure 1. SNR versus time measured during a missile flight.

This example illustrates two features typical of received signal levels: rapid variations around the average signal level superimposed on slow variations in the average signal level. The slow variations result from changes in the transmit antenna gain due to changes in the spatial relationship between the missile and the ground-based tracking station.

The rapid variations are most likely due to destructive interference resulting from the reception of randomly phased, multiple reflections of the transmitted signal. This phenomenon is termed *multipath interference* causing *multipath fades*. This paper discusses these two sources of fading as they apply to aeronautical telemetry systems.

FADING DUE TO ANTENNA GAIN PATTERN VARIATIONS

The power received at the ground-based tracking station is a function of the airborne transmit antenna gain which varies with the aspect angle between the transmit antenna and receive antennas. The spatial variations of the transmit antenna gain are quantified by an *antenna gain pattern* which is a function of the azimuth and elevation angles. An example of a typical gain pattern common to missile systems is illustrated in Figure 2. The two-dimensional data presented are a yaw cut of the three-dimensional pattern. The gain varies by nearly 20 dB as the azimuth ranges through 360 degrees. The deep nulls occur at the tail, the nose, and 30 degrees port side of the nose. In these instances, the link carrier-to-noise ratio (CNR) is reduced by approximately 12 dB from the nominal value.

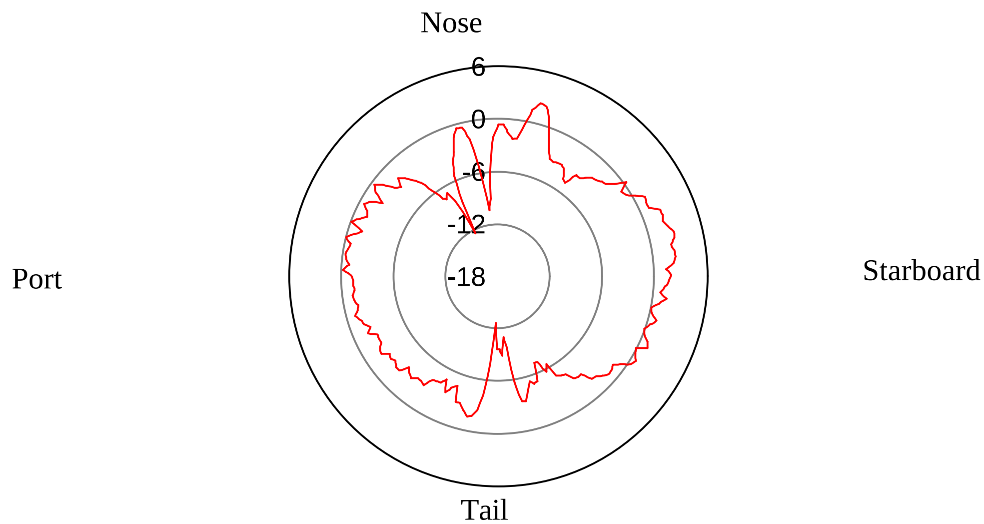

Figure 2. Antenna pattern (yaw cut).

When the flight path and attitude of the airborne antenna are known, Pedroza [1] explains how variations in antenna gain pattern should be incorporated in link budget calculations using aspect angles calculated from the known transmitter and receiver positions. When the attitude is not known, a statistical approach must be used. The cumulative probability density function assuming equally likely aspect angles (4π steradians) is often approximately Rayleigh distributed as illustrated in Figure 3. This information is useful in predicting per-cent availability levels which are needed in link budgets. For the example illustrated in Figure 3, the loss due to antenna gain pattern is greater than 19 or 23 dB, depending on which curve is used, 1 percent of the time. Thus, for 99 percent availability, 19 or 23 dB of link margin would be consumed by variations in antenna gain pattern when all aspect angles are equally likely. Figure 3 also includes a Rayleigh probability density curve . The general shape of the Rayleigh curve is the same as the measured data.

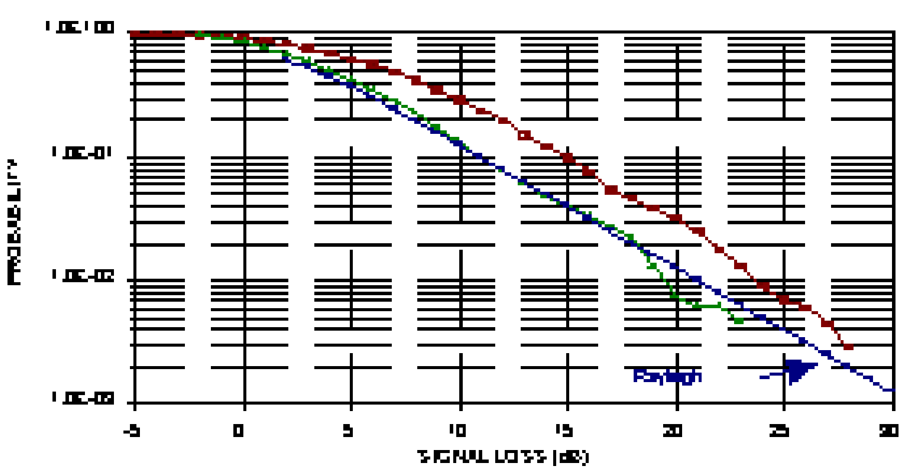

Figure 3. Cumulative density antenna patterns.

FADING DUE TO MULTIPATH INTERFERENCE

The signal transmitted by the airborne antenna arrives at the tracking station via many paths. Most of the time, there is a direct, line-of-site path between the transmitter and receiver and this is the strongest signal arriving at the tracking station. In addition to this direct signal, delayed and attenuated versions of the transmitted signal arrive at the receiver. These signals are the result of reflections of the transmitted signal from the ocean, ground, mountains, structures near the airborne antenna (such as wings, fuel tanks, etc.), or structures near the receive antenna. The delays imposed by the reflected paths result in phase variations in the reflected signals which cause the reflected signal to interfere either constructively or destructively with the line-of-site signal. When destructive interference occurs, the resultant signal level is much lower than the direct line-of-site signal and a fade results.

For aeronautical telemetry applications, it is theorized that multipath interference is most frequently caused by a dominant specular reflection arriving within the main lobe of the tracking antenna gain pattern as illustrated in Figure 4 [4]. The effect of antenna gain pattern on the depth of multipath fading is investigated in [6]. In order for the reflection to arrive within the main lobe of the receive antenna, the elevation angle must be low (less than one-half of a beamwidth) which occurs when the airborne transmitter is far away, at a low altitude, or both. In order for the reflection to cause significant interference, the reflecting surface at the specular point must have a high coefficient of reflection, Γ, which is the case for seas (especially calm seas) and flat terrain. Unfortunately, these conditions are common at test ranges.

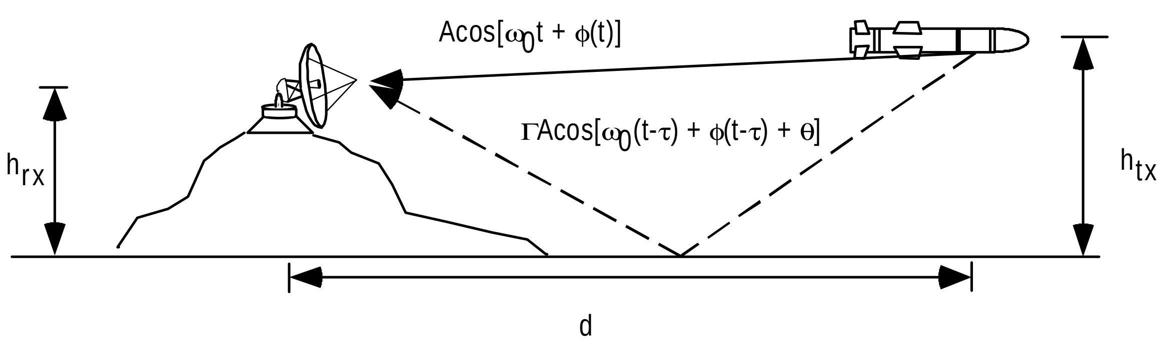

Figure 4. Geometry of multipath interference.

The path length difference (Δd) between the line-of-sight and the reflected paths is a function of the geometry and is directly related to the heights of the transmitting and receiving antennas and inversely proportional to the distance between the antennas. The differential path delay between the line-of-sight signal and the reflected signals is given by

$$t = \frac{\Delta d}{c}.$$

For typical aeronautical telemetry applications, transmitter to receiver separations are large so that Δd is small. This leads to differential path delays t as small as a few nanoseconds. Several studies have measured some of the characteristics of the aeronautical telemetry channel [2,3]. Efforts are underway to more accurately measure the characteristics of the aeronautical telemetry channel.

The impulse response of this channel is

$$h(t) = d(t) + \Gamma e^{j(2pf_0 t + q)} d(t - t)$$

which has transfer function

$$|H(f)|^2 = 1 + 2\Gamma\cos(2p(f - f_0)t + q) + \Gamma^2$$

The transfer function has a null at

$$f = f_0 \pm \frac{1}{2t} - \frac{q}{2pt}$$

as illustrated in Figure 5 for Γ = 0.995, τ = 10ns, and θ = -179 degrees. Since small changes in the path geometry lead to large variations in the delay τ, the location of the null sweeps across the spectrum as the transmitter moves. The spectra of telemetry signals transmitted through this channel are multiplied by the transfer function. When the transfer function null is located within the signal band, distortion is severe and high bit error rates at the demodulator output result. This case is illustrated in Figure 6 which shows a measured PCM/FM spectrum with a multipath null [5].

This type of fading is termed *frequency selective fading* since different parts of the spectrum are attenuated differently by the multipath interference. By way of contrast, frequency non-selective or “flat” fading is characterized by a constant attenuation across the entire frequency band. Frequency selective fading causes significant distortion which leads to increased bit error rates at the demodulator output with only modest reductions in CNR [5].

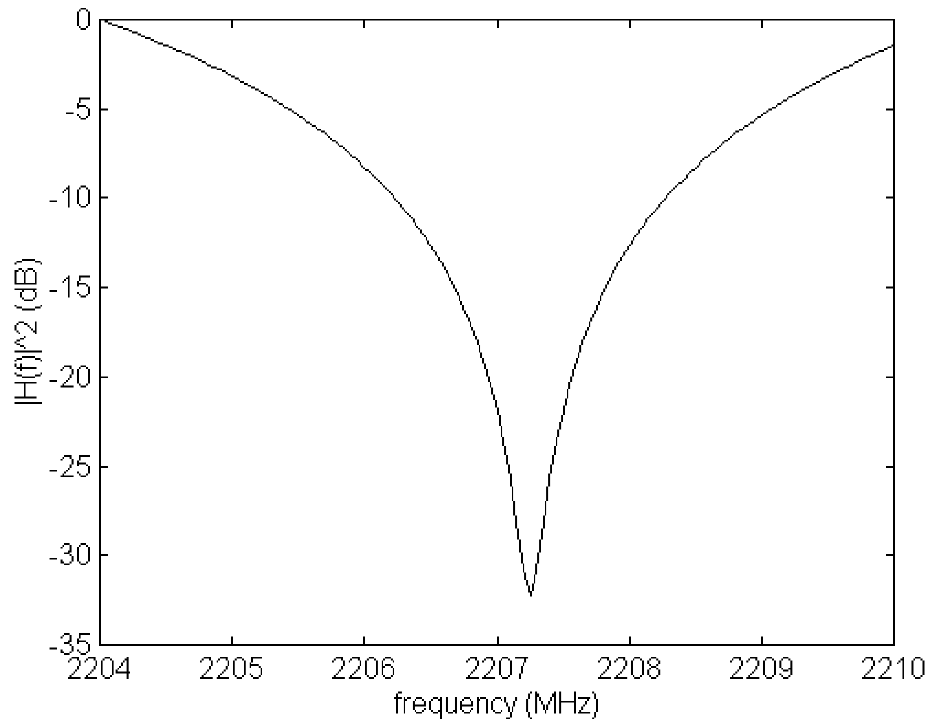

Figure 5. Computer simulation of multipath null.

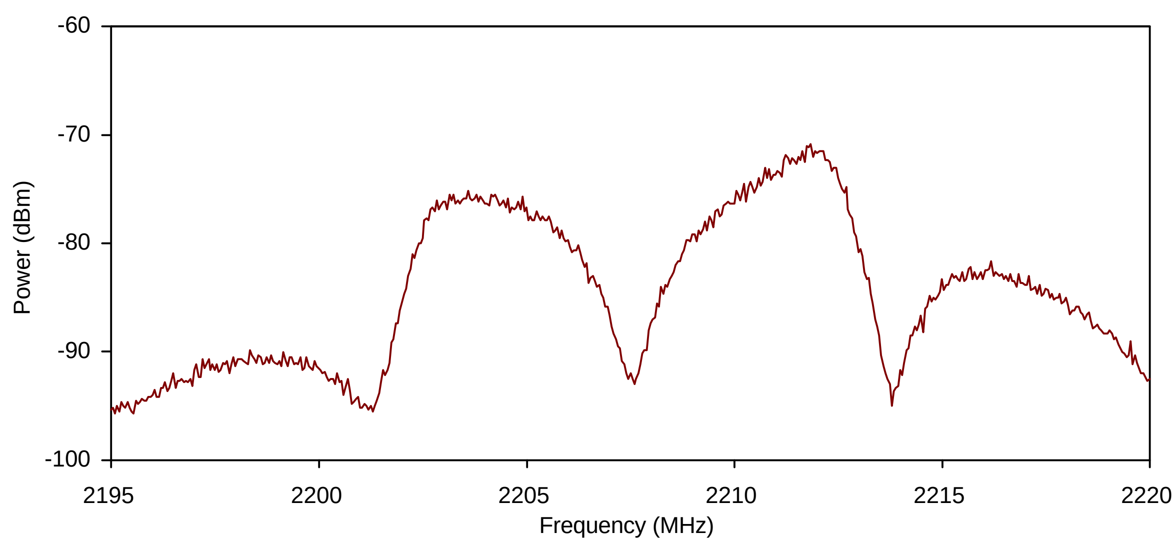

Figure 6. RF spectrum with multipath null.

CONCLUSIONS

Signal drop outs caused by fading are an essential component in proper link design. Fades due to nulls in the transmit antenna gain pattern typically occur across the entire signal bandwidth and usually lead to frequency non-selective fades. These type of fades are accompanied by reductions in CNR and are overcome by careful transmit antenna design or spatial diversity which uses different receiving sites which are located at different aspect angles relative to the airborne transmitter. Fades due to multipath interference are likely to affect different parts of the transmitted signal spectrum differently and are thus frequency selective fades. These fades cause significant signal distortion without large reductions in the received signal strength. Frequency selective fades are overcome using spatial diversity (where at least one tracking site does not have a low elevation angle), receive antenna with extremely narrow beam patterns which attenuate the reflections, or equalization techniques. Tests should be performed to better characterize the aeronautical telemetry channel and its effects on various modulation, error correction coding, and equalization methods.

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