

A Study of  
Land Mobile Satellite Service Multipath Effects  
Using SATLAB Software\*

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A software package is proposed that uses the known properties of signals received in multipath environments along with the mathematical relationships between signal characteristics to explore the effects of antenna pattern, vehicle velocity, shadowing of the direct wave, distributions of scatterers around the moving vehicle and levels of scattered signals on the received complex envelope, fade rates and fade duration, Doppler spectrum, signal arrival angle spectrum and spatial correlation. The data base may be either actual measured received signals entered as ASCII flat files, or data synthesized using a built in model. An example illustrates the effect of using different antennas to receive signals in the same environment.

## INTRODUCTION

If an elevated CW transmitter illuminates a typical mobile radio environment, with a vehicle moving past roadside trees and other scatterers, the received signal will have fast (multipath) and slow (shadow) fading, a Doppler spectrum related to the vehicle velocity and the distribution of signal arrival angles, and a spatial correlation. Each of these signal characteristics is important to a different set of engineers: the envelope fade rates are needed by system engineers to determine reliability and fade margins; the fade rates and Doppler spectrum are needed by the engineers who design robust modulation and coding; the angular spectrum is needed by the antenna engineers; and the spatial correlation is needed to evaluate the effectiveness of space diversity and adaptive arrays. All of these signal characteristics can be determined from a record of the received complex envelope as a function of time, as the receiver moves through the multipath environment. Since each characteristic is obtained from the same time record, all of the signal characteristics are related. The Doppler spectrum is the Fourier transform of the complex time record, the signal arrival angle spectrum (obtained from the Doppler spectrum) is the Fourier transform of the spatial correlation and the fast and slow fading envelope is the envelope of the complex time record. If any

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characteristic of the receiver is changed, it will affect all of the signal characteristics. For example: if the antenna is changed from an omni directional to a gain antenna, the distribution of signal arrival angles will change. This will change the Doppler spectrum, which is the Fourier transform of the received complex envelope. We can see that adding a gain antenna to a system not only increases the signal level; it also changes the fade statistics, the Doppler spread and the spatial correlation.

The proposed software package uses the known characteristics of received signals in multipath environments along with the mathematical relationships between the signal characteristics to allow the engineer to explore the effects of antenna pattern, vehicle velocity, various amounts of shadowing of the direct wave, distributions of scatterers around the vehicle and levels of scattered signals on each of the received signal characteristics. The actual time record of the received signal may be either real data, as collected by Vogel and Goldhirsh or Campbell, or synthesized data with the same properties as the real data.

#### RECEIVED SIGNAL COMPLEX TIME RECORD

The received signal is the sum of the direct wave and all of the scattered waves. The direct wave is attenuated by shadowing on the direct path, and is received at a frequency equal to the transmitted frequency plus or minus a Doppler shift obtained from the vehicle speed and the angle between vehicle velocity and the direct signal arrival angle. The scattered signals arrive from angles all around the receiver (Campbell 1989), so they are received at a spread of frequencies between a maximum (vehicle moving directly toward a scatterer) and minimum (vehicle moving directly away from a scatterer). The total power in the scattered waves is about 17 dB below the unattenuated direct wave (Stutzman and Barts 1988, Campbell 1989).

One application of this program is to explore the effects of different antennas and vehicle velocities on existing data bases. For example, the Vogel and Goldhirsh data were collected using crossed drooping dipole antennas. The fade statistics would be different if other antennas had been used. This program allows post processing of the Vogel and Goldhirsh data to see what they would have obtained with a different antenna, for example a 13 dB patch array.

Another application of this program is to explore the characteristics of received signals in environments that have not been measured. For example, in dense foliage, the direct wave might be attenuated by an average of 17 dB. Then the total signal is made up of equal parts, direct and scattered waves. The fade statistics will be dominated by multipath effects, and the signal arrival angle will be uniformly

distributed around the vehicle. A feedback type antenna aiming system would be lost in such an environment. The benefit obtainable from various antenna systems, such as gain, space diversity, and adaptive array, in this environment would depend on the modulation and coding used in the system.

To study signal environments that have not been measured, it is necessary to synthesize data having the correct properties. If the engineer specifies a carrier frequency, vehicle speed and direction relative to the direct wave and ratio of direct to total scattered wave power, the program can generate an appropriate complex time record with the properties of a signal received on an omni directional antenna. Shadowing effects may be included by making the ratio of direct to scattered wave power a function of time. The data may be generated using either the simple model developed by Campbell or a more correct scattering theory model (Wang, 1991). Once the basic time record is generated, it may be modified with different antenna patterns.

#### ANTENNA EFFECTS

The antenna system operates on the distribution of signal arrival angles. Antenna effects may be studied by multiplying the Doppler spectrum by the antenna pattern. This is equivalent to a convolution of the complex time record with the Fourier transform of the antenna pattern. For example, the Fourier transform of an omni directional antenna pattern is a delta function. Convolution with the complex time record leaves it unchanged. The Fourier transform of a narrow Gaussian beam antenna is a wide Gaussian. Convolution with the complex time record will tend to remove rapid fluctuations in the complex time record. This agrees with our intuition that narrow beam antennas may be used to reduce multipath effects.

To study the benefit of a narrow beam antenna, the antenna must be aimed in the direction of the direct signal arrival. Conversely, the effects of antenna aiming errors may be studied by purposely introducing an offset in the antenna pattern. The effect of an antenna aiming error is not only to reduce the received signal strength, but also to decrease the ratio of direct to scattered signal power available to the receiver. When an antenna aiming error is present, the signal strength goes down and the multipath effects go up.

The antenna patterns may be entered either as analytical functions or as ASCII flat files. A catalog of useful antenna patterns will be included in the software.

#### MODULATION AND CODING

In order to design robust modulation and coding for the

transmitted signals, the fade rates, fade durations and Doppler spectrum must be known. Each of these depends on the ratio of direct to scattered signal level, the antenna pattern, the vehicle velocity and direction and any antenna aiming errors. If feedback is used to aim the antenna, it may be useful to use different modulation on the antenna aiming pilot than for error free speech and data. Entirely different antenna systems may be optimum for intelligible real time speech and maximum data transfer.

The input and output files of SATLAB will be ASCII flat files and MATLAB .MAT files, allowing data transfer to and from other programs and industry standard signal analyzers (the latest Tektronix models communicate with MATLAB). This will permit simulating the entire signal environment, including the source, modulation and coding, multipath channel, antennas and demodulation and decoding in the laboratory.

#### EXAMPLE

Figure 1 shows a typical Doppler spectrum that might have been received by a 1.5 GHz receiver with an omni directional antenna moving at highway speeds with roadside trees. The vertical scale is in dB, with the receiver noise at -20 dB and the direct signal received at +40 dB. The direct signal to noise ratio is about 60 dB, so receiver noise is not significant in this example. The horizontal axis is the frequency of the downconverted received signal in Hz. The scattered signals are displayed as a uniform spectrum between the minimum and maximum Doppler shifts.

Figure 2 shows the effect of receiving this same signal with a dipole antenna. The nulls of the dipole are toward the front and rear of the moving vehicle, so the minimum and maximum Doppler shifted scattered signals are attenuated. The dipole received spectrum is the solid line and the original omni spectrum is the dotted line. Note that the antenna has no effect on the receiver noise.

Figure 3 shows the effect of receiving this same signal on a 10 dB gain array. Once again the original omni signal is shown as a dotted line. The direct signal is now 10 dB stronger than for the omni case, and the scattered signals at arrival angles near the direct signal are also stronger, but by less than 10 dB. The scattered signals at angles far from the direct signal are greatly attenuated. Since the receiver noise is not affected by the antenna, the direct signal to noise ratio is now 70 dB.

Figure 4 shows the IF voltage as a function of time for each of these three cases. The signal from the dipole is offset by +2 and the signal from the omni is offset by -2. Note that the signal from the 10 dB gain array is not only stronger, it has smaller fluctuations than the signals from

DIRECT SIGNAL PLUS UNIFORM ARRIVAL ANGLE SCATTERED SIGNALS

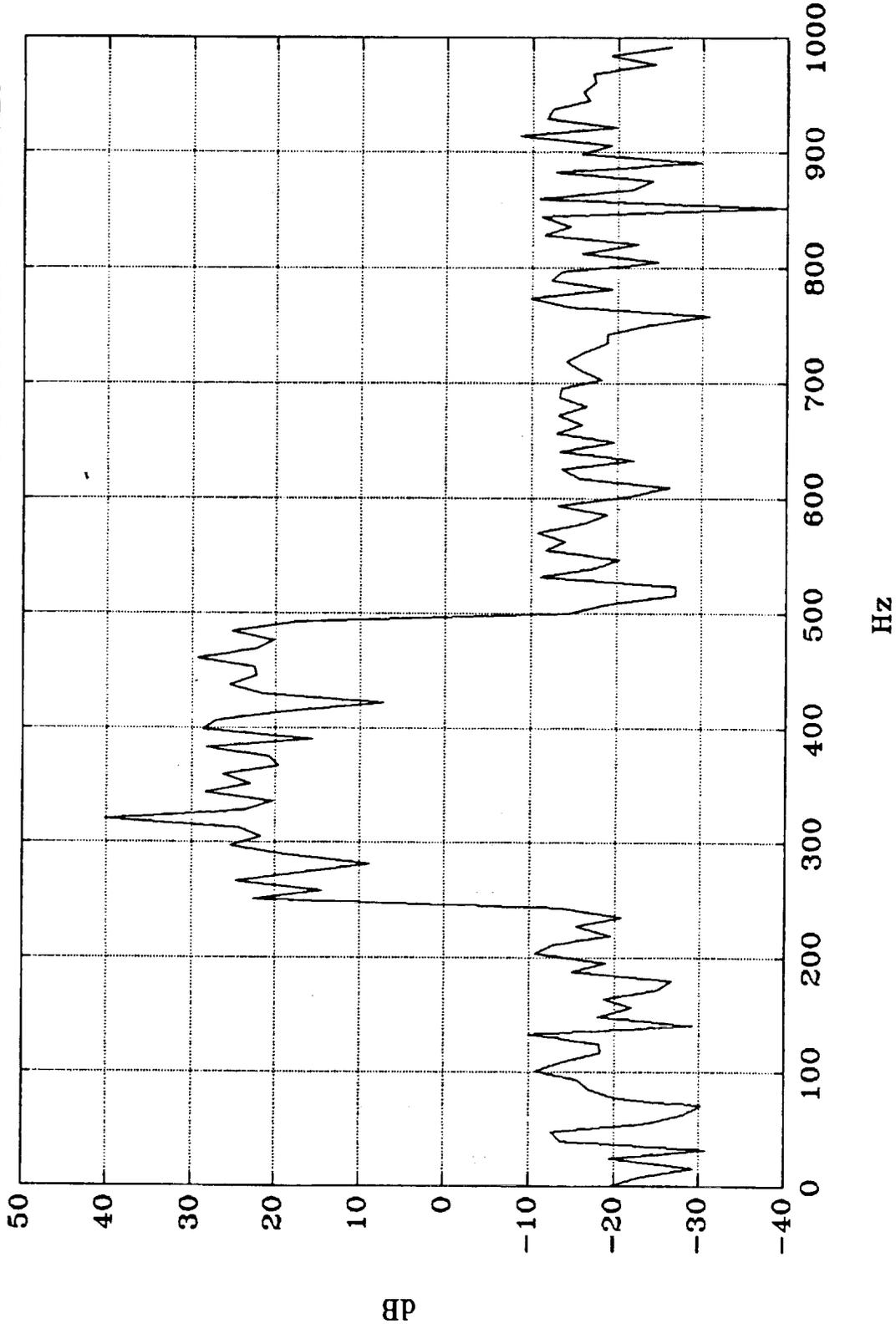


FIGURE 1

IF SPECTRUM RECEIVED ON OMNI DIRECTIONAL ANTENNA

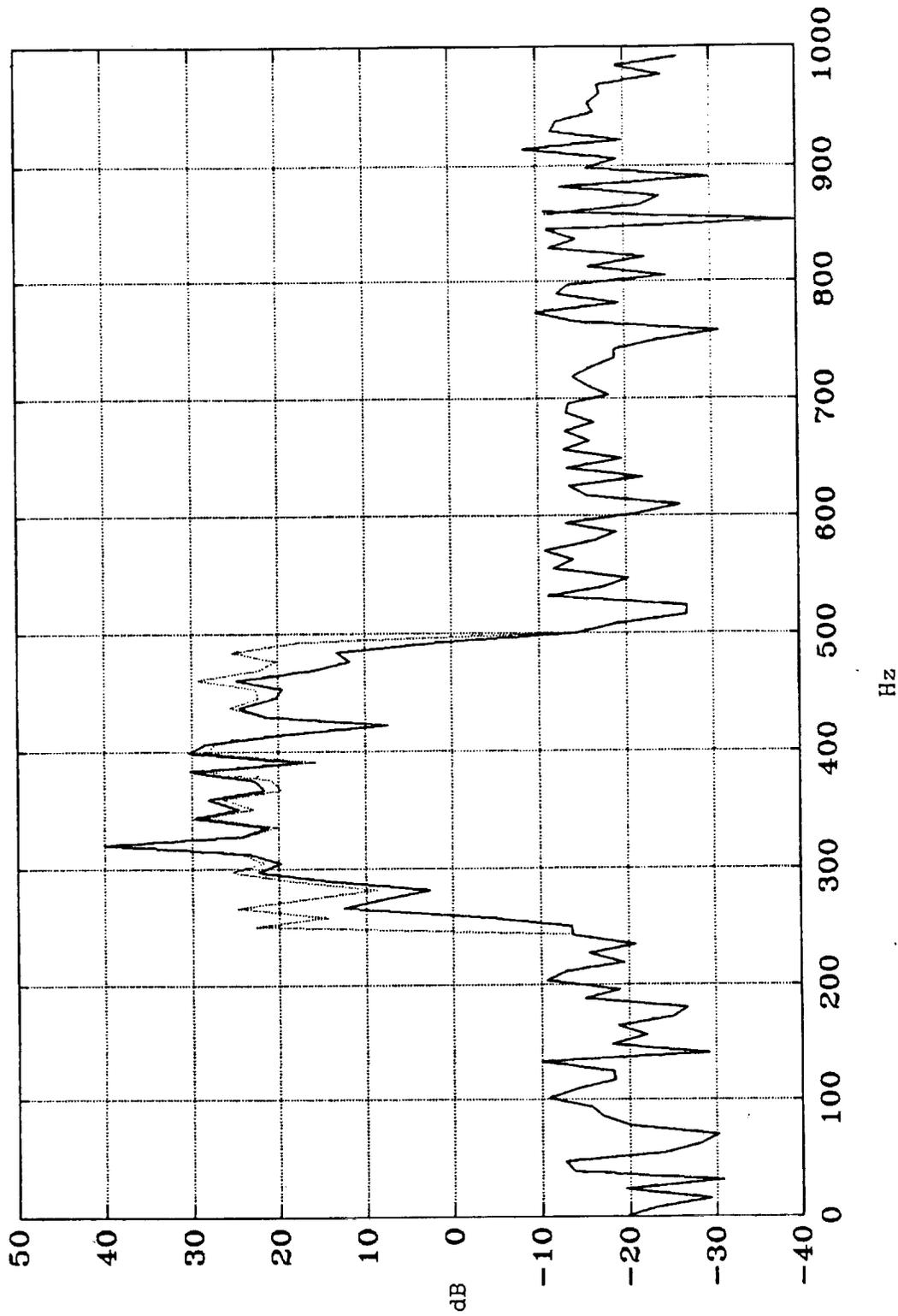


FIGURE 2  
 IF SPECTRUM RECEIVED ON DIPOLE (SOLID)  
 AND OMNI DIRECTIONAL ANTENNAS (DOTTED)

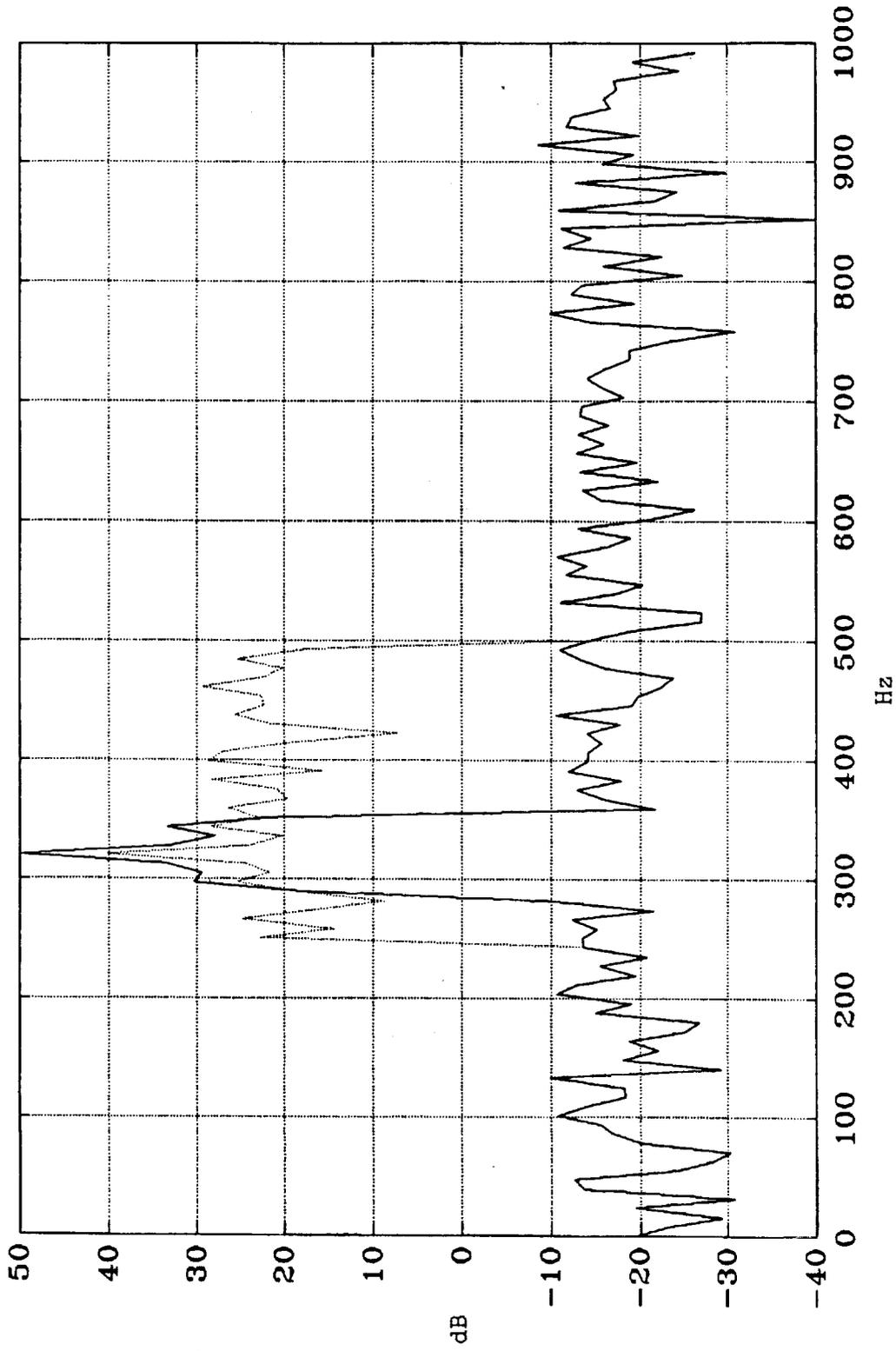


FIGURE 3  
 IF SPECTRUM RECEIVED ON 10 DB GAIN ANTENNA (SOLID)  
 AND OMNI DIRECTIONAL ANTENNA (DOTTED)

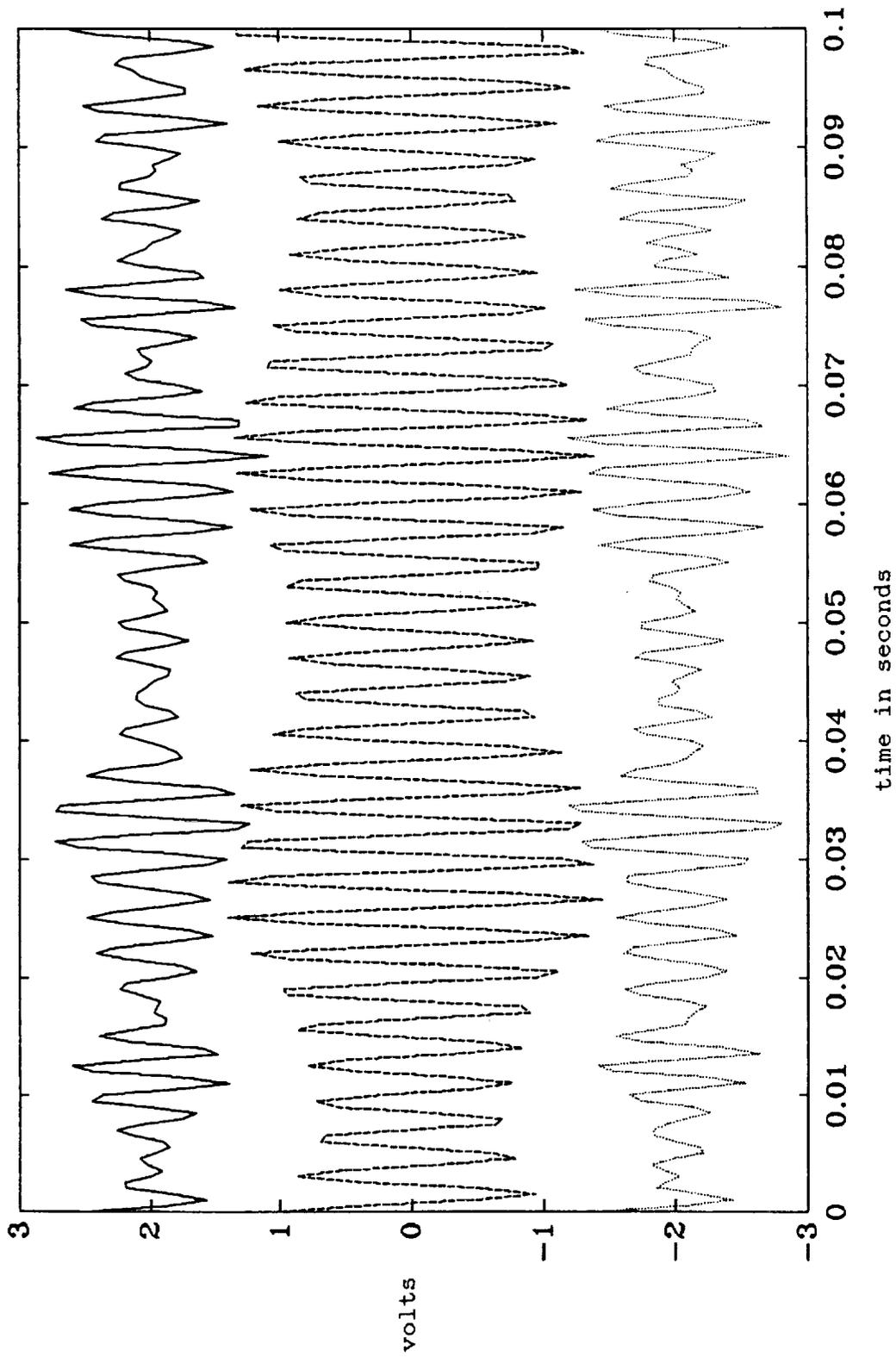


FIGURE 4  
 RECEIVED TIME RECORD SIGNALS ON DIPOLE (UPPER TRACE)  
 10 DB GAIN ANTENNA (MIDDLE TRACE)  
 AND OMNI DIRECTIONAL ANTENNA (LOWER TRACE)

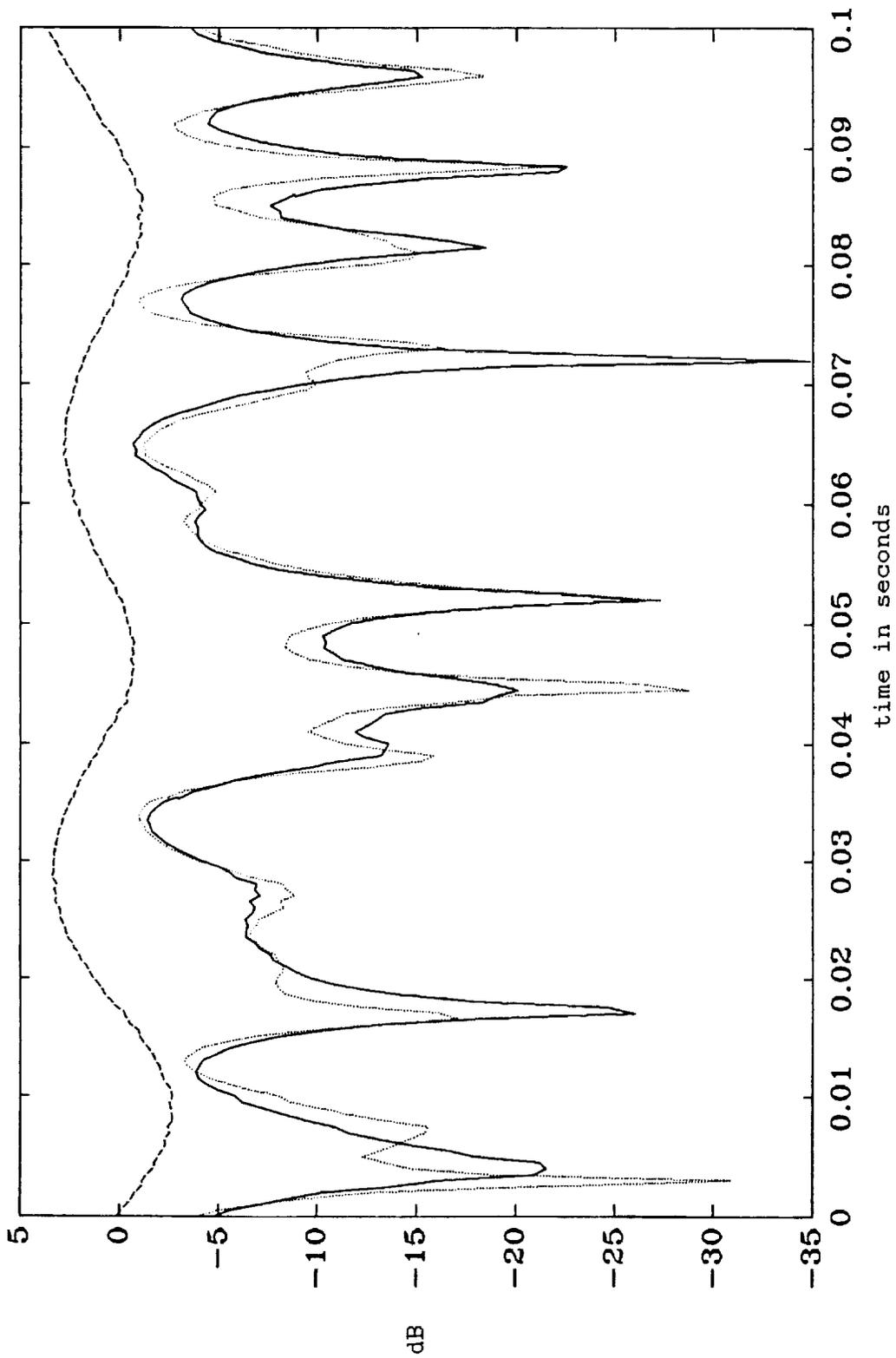


FIGURE 5

RECEIVED SIGNAL ENVELOPE USING DIPOLE (SOLID) 10 DB GAIN

(DASHED) AND OMNIDIRECTIONAL (DOTTED) ANTENNAS

the other two antennas.

Figure 5 is the received signal envelope as a function of time. Note the characteristic multipath rapid fading in the signals received on the omni and dipole antennas. The signal received on the 10 dB gain antenna is not only stronger than the other signals, it also has much less fading.

This example clearly illustrates the effect of different antenna patterns on the fade statistics of strong signals in a multipath environment. By modifying the signal parameters (signal to noise ratio, ratio of direct to scattered signals etc.) other signal environments may be studied.

## CONCLUSIONS

The proposed software package will be a useful tool for studying mobile radio signals in environments with direct and scattered waves. The interrelated effects of carrier frequency, vehicle speed, antenna gain and antenna pattern, antenna aiming errors, direct to scattered signal ratio, shadowing and receiver noise are all included. By modifying one parameter, the engineer may observe the effect on all the other signal characteristics.

This program will either generate synthetic data using one of several available models, or use actual received data files. The engineer may modify measured data to see the effect of different antennas.

## REFERENCES

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## CLOSING REMARKS ON THE NASA PROPAGATION PROGRAM

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ABSTRACT--Several remarks on the current state of the NASA Propagation Program are offered.

### 1. INTRODUCTION

The Science Review of the NASA Radio Propagation Program that was held in September 1986 yielded 14 principal recommendations. It is perhaps worthwhile to reflect on those recommendations now in light of the current evolution of the program.

### 2. REMARKS

Almost five years have elapsed since the Science Review of the NASA Propagation Program (Booker et al., 1987). In reviewing the 14 Principal Recommendations of the report, one observes that some of the recommendations have become obsolete and some have been most successfully implemented; they seem to have been accorded the respect that they deserved. The recommendations were applied to focus the program, not hinder its flexible evolution.

This latter aspect appears to be quite important considering the current broadbased coverage of propagation topics within the program. While much of NASA's early propagation work concerned higher frequencies, at the time of the science review the emphasis was on low-frequency mobile-satellite effects related to the MSAT-X program.

It is gratifying to observe that the current program covers a variety of topics. K-band slant-path propagation with the Olympus and ACTS satellites emphasizing requirements of emerging systems (e.g., low-availability applications); EHF radiometry, including cloud attenuation; continuing development of the NASA handbooks based on theoretical and empirical inputs; and a look ahead to K-band mobile propagation are being addressed. The attendance at NAPEX XV is proof of the recommended national and international cooperation. I am impressed with the current program.

### REFERENCE

1. H.G. Booker, G. Brussaard, K.S. McCormick, and D.V. Rogers, "Science Review of the NASA Radio Propagation Program," Report STC-2127, Science & Technology Corporation, Hampton, Virginia, February 1987.

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