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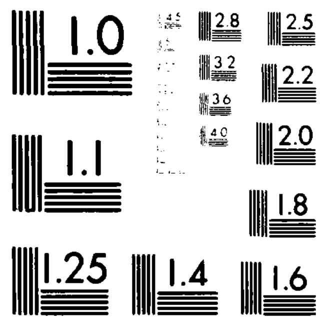


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MEMORANDUM REPORT ARSCD-MR-80001

# RADAR CLUTTER MODELS AT 95GHZ

R. D. HAYES



SEPTEMBER 1980

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
FIRE CONTROL AND SMALL CALIBER
WEAPON SYSTEMS LABORATORY
DOVER, NEW JERSEY



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The purpose of this study was to collect data which have been presented over the past 5 years on radar reflection from material targets and surfaces such as trees, rain and snow for use on the Advanced Fire Control Radar System (AFCORS) Program. Since the data will be used in an air defense application to assist in the prediction of system operation and limitations, only low grazing angles are considered.

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## FIGURES

## INTRODUCTION

The purpose of this study was to collect the data which have been presented (references 1-8) over the past 5 years on the radar reflection from natural targets and surfaces for use on the Advanced Fire Control Radar System (AFCORS) program. Since the data will be used in an air defense application to assist in the prediction of system operation and limitations, only low grazing angles are considered.

## ANALYSIS

### Trees

The amplitude of returns from trees can be described by a log-normal distribution for most of the data recorded. Under some conditions a Weibull distribution was more descriptive and only rarely (about 5% of the data) did a Rayleigh distribution properly describe the data.

Thus the description of a signal with amplitude variations following a log-normal distribution with an average cross-section per unit area, horizontal polarization, is given by

$$\sigma^{0} = -15+15 \log \frac{\theta}{25} -8 \log \lambda /0.32 \quad dB, \; m^{2}/m^{2}$$

and a standard deviation of 5.8 dB (at 95 GHz) would be most appropriate for a radar operating between 0- and 25-degrees grazing angles.

From the reported data, wet foliage produced returns which were 5 dB stronger than dry foliage. The vertically polarized returns were 3 to 4 dB higher than the horizontally polarized returns.

The frequency contained in the noncoherent spectrun of the pulsed radar return has two predominant returns. One component is very narrow in the frequency domain (less than 4 Hz wide), and some 15 to 20 dB greater than the high frequency components. The high frequency components have a slower decay at 95 GHz than at 10 GHz. The 95 GHz spectrum can be modeled from the equation

$$F = \frac{1}{1 + \left(\frac{f}{35}\right)^2}$$

This type of high frequency content has been observed at millimeter wavelengths and even at X-band when narrow antenna beams and short pulse (less than 100 ns) have been employed. The spectral content is much higher than previously observed at low radar frequencies such as L-band, and for radars employing longer pulselengths (1us), where the spectral content was adequately described by a Gaussian function. The half power value of F is a function of wind speed and the value of 35 Hz appears to be appropriate for wind blown trees in the range from 8 to 15 mph. In addition to 95 GHz radar data, 9.4 GHz data have been collected for wind blown trees in full foliage. These data reveal a more rapid decay in frequency components as compared to 95GHz. The equation

$$F = \frac{1}{1 + \left(\frac{f}{9}\right)^3}$$

represents the fast moving components above the D.C. Again, this is a slower decay in frequency components than would be expressed by a Gaussian function with a half power value at 9 Hz. Figure 1 plots the F functions.

Wind blown trees (figure 2) also produce radar returns which decorrelate faster than fixed objects. Measurements at 95 GHz show that trees in a wind of 8 to 15 mph will decorrelate linearly in 10 to 1 ms, respectively. This is an order of magnitude faster than observations made at X-band.

## Rain

Radar backscatter and attenuation are a function of both the radar wavelength and the rain rate. At X-band, the drop size is small relative to the radar wavelength and the scattering characteristics follow the Rayleigh function. At 95 GHz, the droplet size is comparable to a wavelength and the resonant phenomena as described by Mie must be applied. Radar backscatter in rain is indicated in Figure 3.

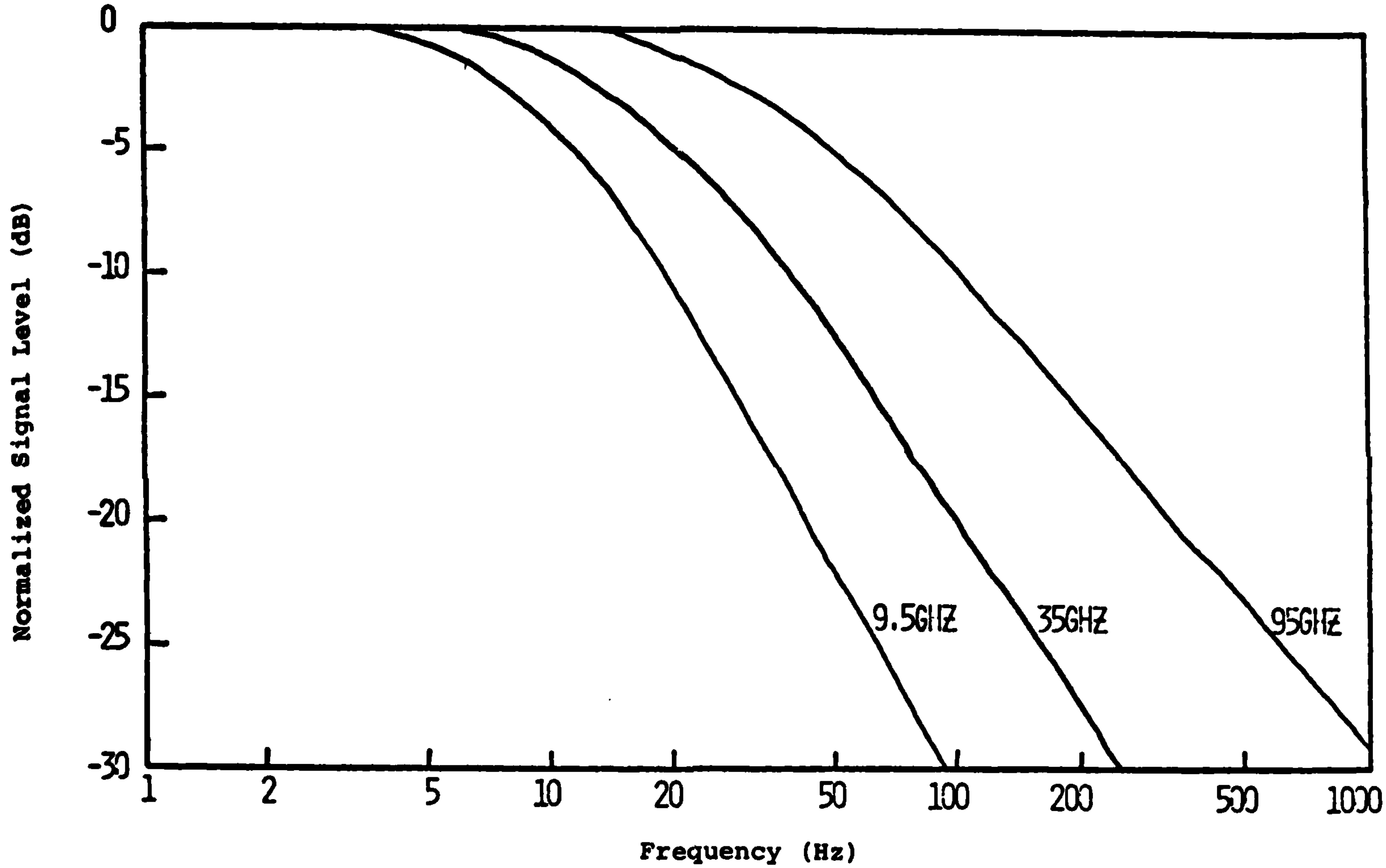



Figure 1. Normalized frequency spectra of the return from deciduous trees.

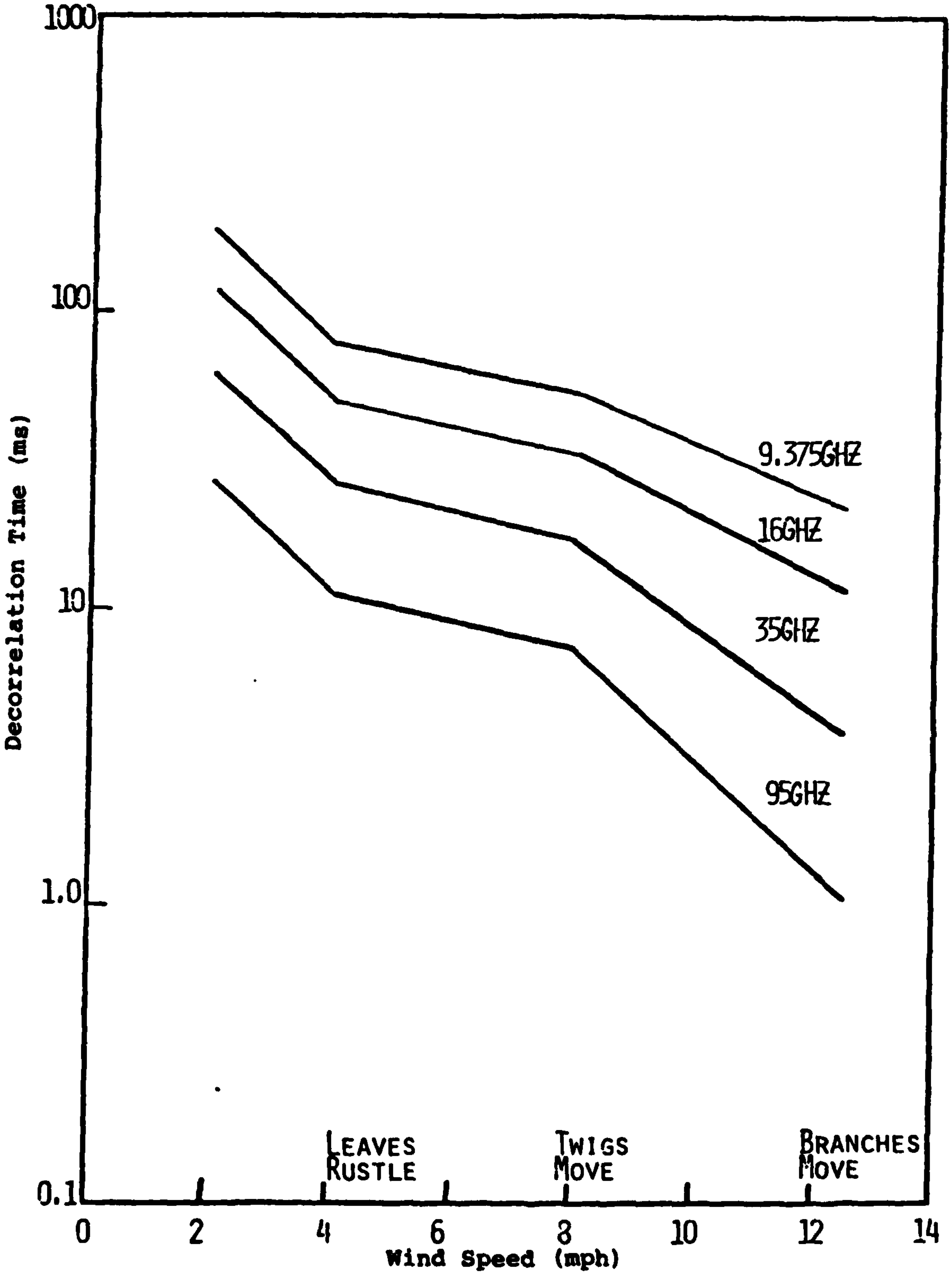



**Figure 2. Decorrelation time of radar backscatter from trees.**

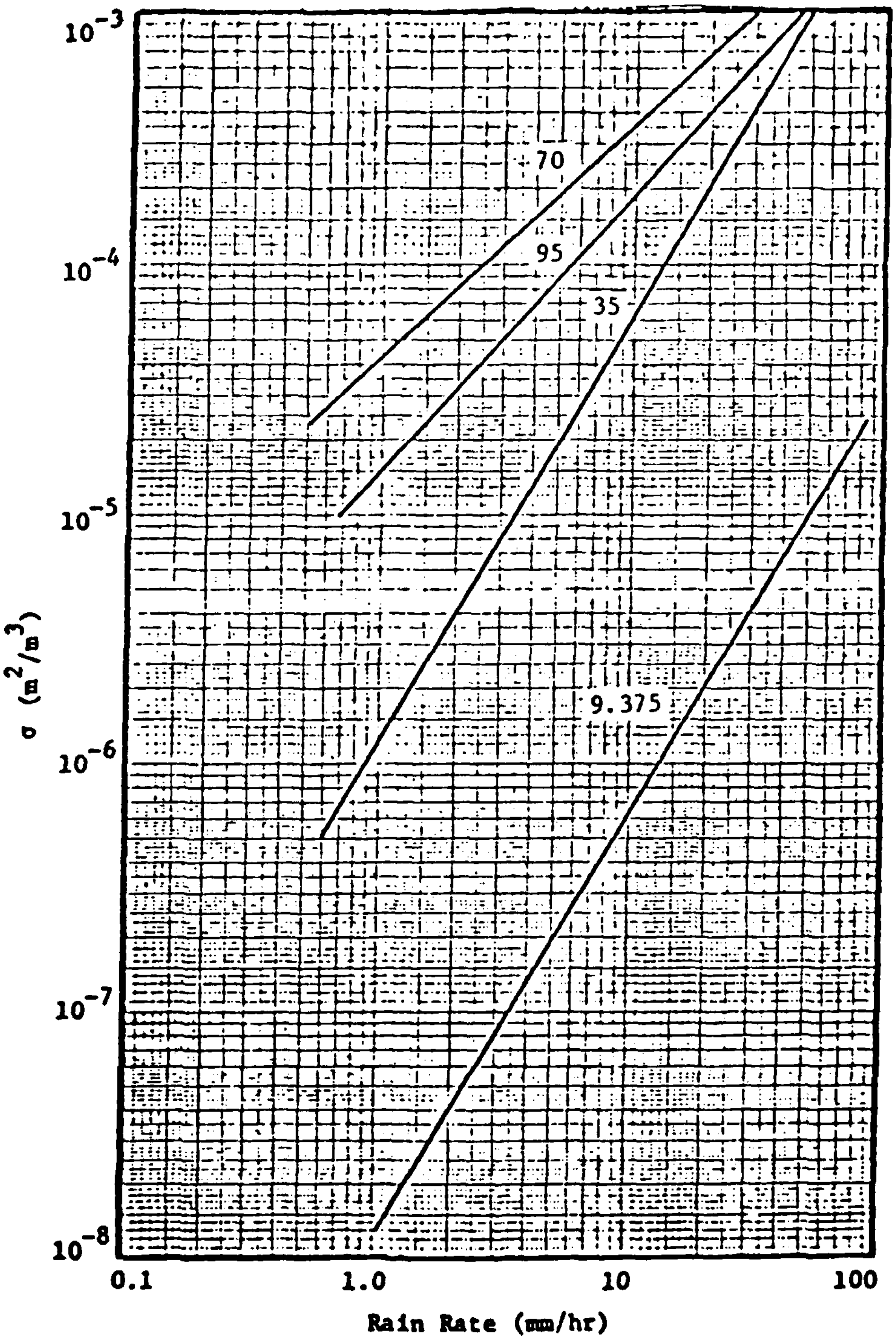



Figure 3. Least mean square fit to radar backscatter data, VV polarization.

The measured backscatterfor rain has been reported as

$$\sigma_V = 1.03 \times 10^{-8} \times R^{1.79} \; m^2/m^3, \; 9.4 \text{ GHz}$$

$$\sigma_V = - \times 10^{-5} \times R^{.925} \; m^2/m^3, \; 95 \text{ GHz}.$$

About these average values, there is a ± 5 dB variation about the 95 GHz data as a result of variation in drop size, regardless of rain rate. The variation at 9.4 GHz is less than that observed at 95 GHz. On the average the backscatter $\sigma_v$ for horizontal polarization is larger than $\Delta$ for vertical polorization. The backscatter at both polarizations is also drop size dependent with a result that the overall effect is minor in choosing between horizontal and vertical polarization. Decorrelation time of radar backscatter from rain as a function of frequency is shown in figure 4.

Attenuation of microwaves and millimeter wave radars is a result of sbosrption and scattering. As such, the attenuation is a function of rain droplet size and shows a variation during measurements very similar to variations in the measured backscatter. Average attenuation values can be determined from the equations

$$\alpha = 0.00919 \times R^{1.16} \quad \text{dB/km one way, 9.r GHz}$$

$$\alpha = 1.6 \times R^{0.64} \quad \text{dB/km one way, 95 GHz}$$

Figure 5 shows how the spectra from trees and moderate rain can limit the Doppler return from moving targets at slow speeds. For example, a vehicle moving at 5 mph in a 5 mm/hr rain will be limited to less than 20 dB signal-to-clutter improvement in the Doppler domain. The Gaussian curve on this figure has the same half power width as the rain spectrum (160 Hz), and if used as a model for the width of rain frequency components, would predict a high signal to rain clutter, thuspermitting better detection than if the measured data were employed and leads to an optimistic detection in adverse weather.

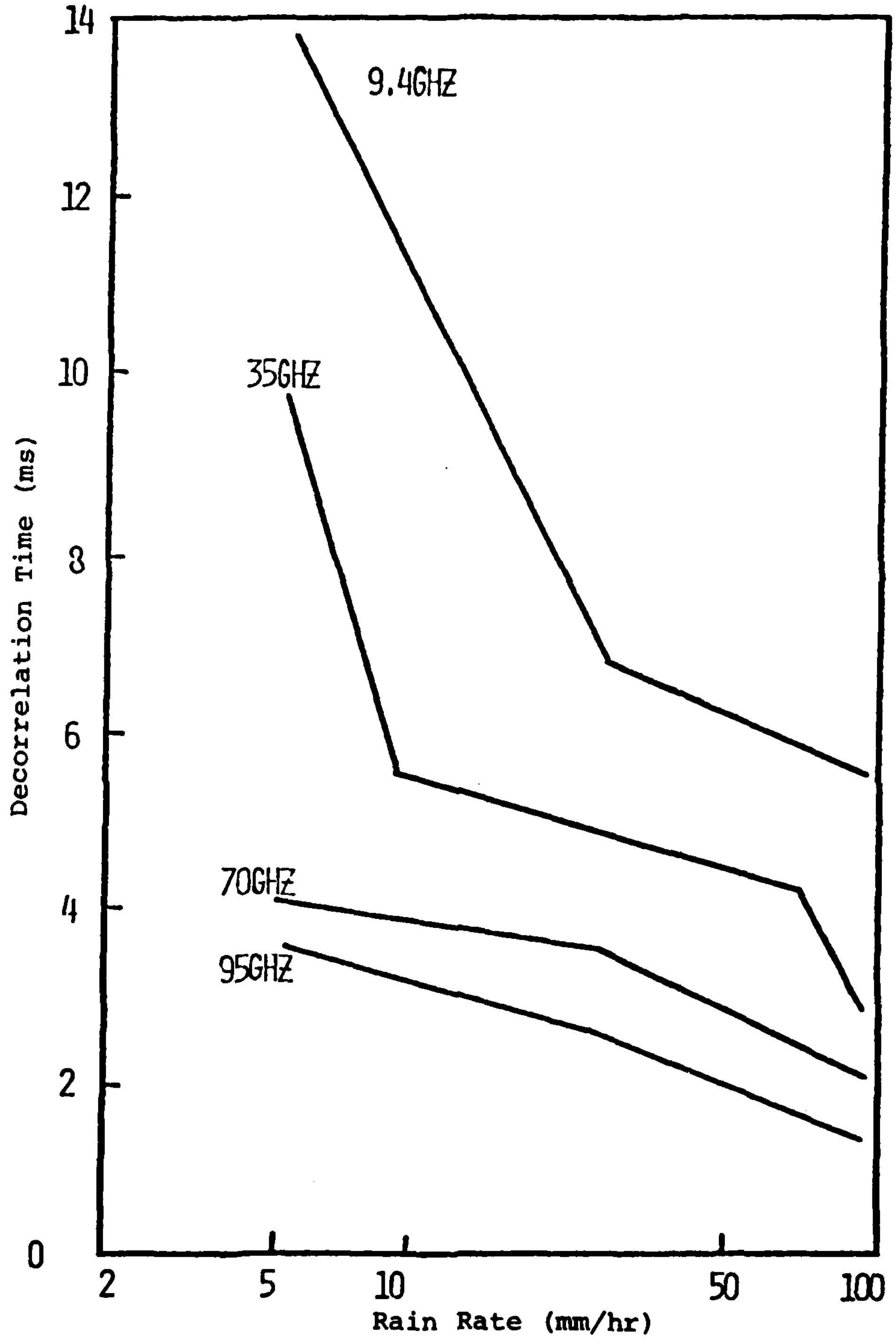


Figure 4. Decorrelation time of radar backscatter from rain.

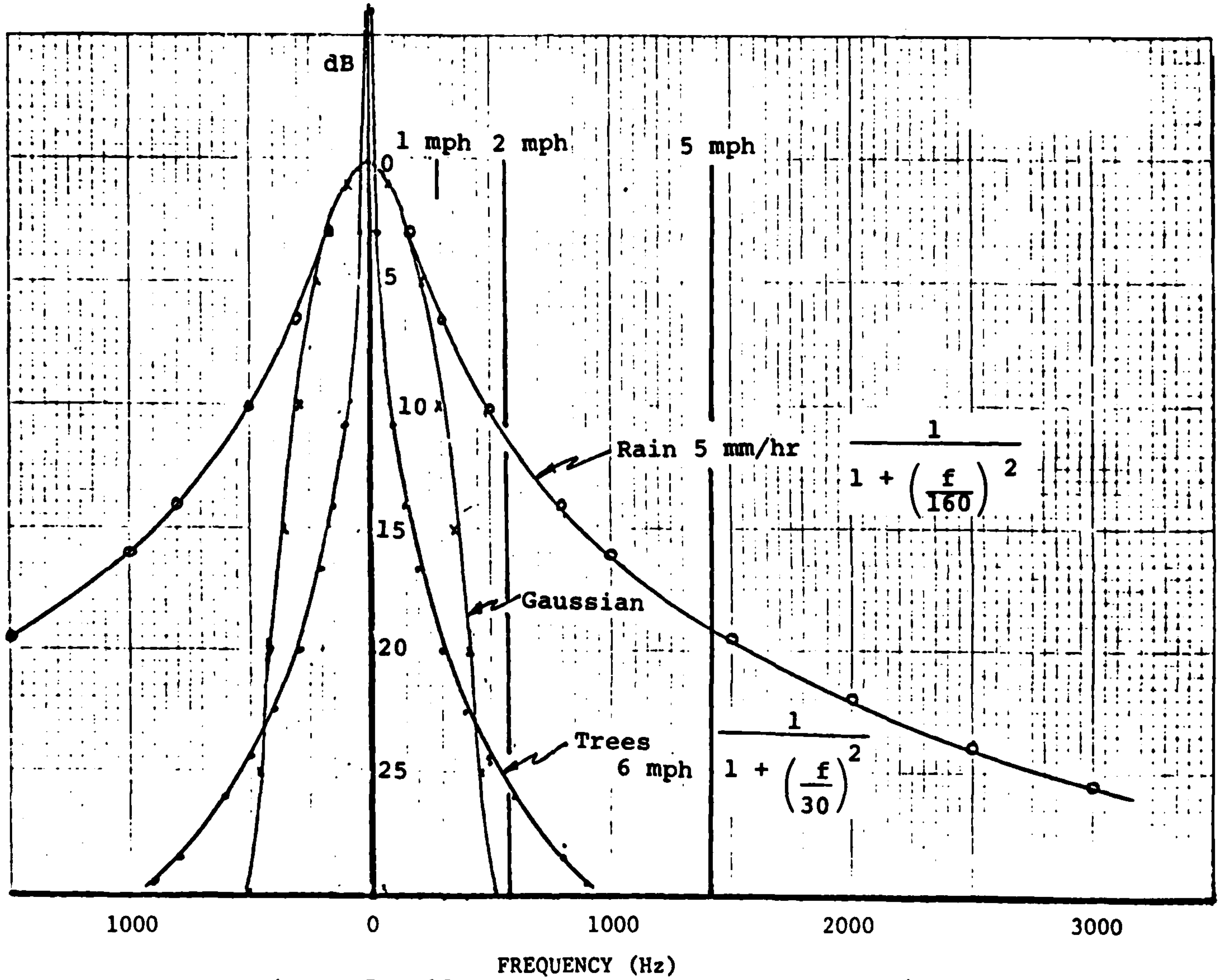



Figure 5. 95 GHz noncoherent spectrum, rain, and trees.

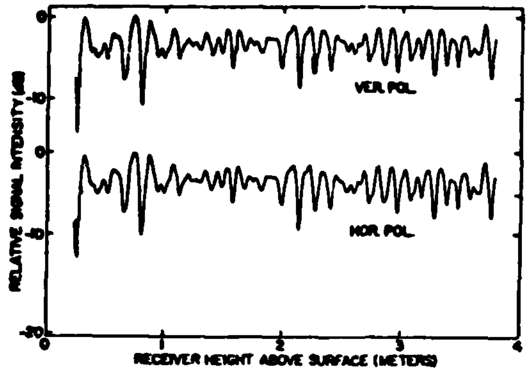
This modulation of the carrier signal is caused by scattering within the radar cell of resolution. Thus, the spectra are repeated around the PRF. Care must be taken not to use a high Puls Repatition Frequency (PRF) which permits the "negative frequency" spectra from clutter to raise the effective noise level in the Doppler Filters. Another observation to make is that the radial motion of a rain storm creates a Doppler in addition to the internal motion represented in Figure 5. As a matter of fact, the same 1/f2 (95 GHz F function) spectra is wrapped around the Doppler of the actual storm movement. This can lead to further limitations for target detection in adverse weather.

Snow

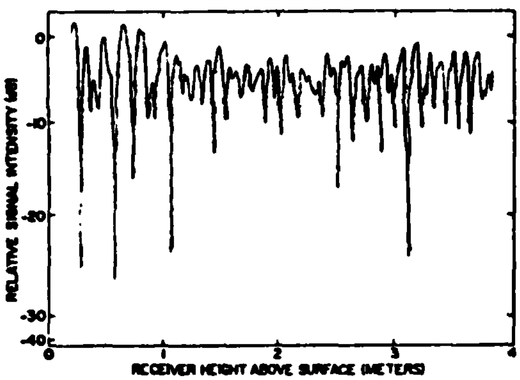
Attenuation of signals through fresh falling dry snow has been observed to be very small at C-, X-, and Ku-bands. This is somewhat expected since dry snow comprises a small amount of ice crystal structure, but consists mostly 8 air, in given volume. Wet sonw has been observed to attenuate signals in about the same magnitude as light rain. Calibrated data are insufficient to permit comparison with theoretical calcualtions.

Backscatter returns from snow covered ground, (figure 6) is a function of the snow surface roughness and free-water content of the sonw. Since the attenuation through metamorphic snow is high (greater than 100 dB/meter) at frequencies of 9 GHz and higher, then there is no effect of the earth surface when 0.15 meters or more snow is present on the ground. For frozen metamorphic snow, the magnitude is comparable to the backscatter from short grass at 35 GHz. Backscatter at 95 GHz is some 8 dB higher than at 35 GHz and is comparable to returns from short grass at 95 GHz. At all frequencies from 10 to 100 GHz, the radar backscatter is a function of the grazing angle. The presence of as little as 3% free water in the surface layer caused a decrease of 10 to 15 dB in the backscatter. Thus, the difference between day and night is dramatic.

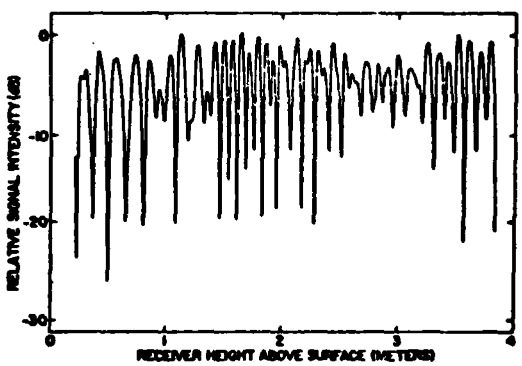
Measurements at 35, 95, and 140 GHz show that at low grazing angles there is as much as a 25 dB variation in the forward scattering signal. This has been identified in a multipath environment and represents a source of tracking error when near horizontal line-of-sight geometry is encountered.




RELATIVE SIGNAL INTENSITY VS RECEIVER HEIGHT: 98 GHz. Vertical and Horizontal Polarization. No Snow Cover.




RELATIVE SIGNAL INTENSITY VS RECEIVER HEIGHT: 98 GHz. Vertical Polarization. Dry New Snow (5 to 8 cm).




RELATIVE SIGNAL INTENSITY VS RECEIVER HEIGHT: 98 GHz. Vertical Polarization. Sleet (8 cm).

From: Dr.D.T.Hayes, EASCON , Oct.1979

Figure 6. 98 GHz low angle grazing multipath signal variations.

## RECOMMENDATIONS

The following areas are recommended fpr further investigation:

1. Undertake a multifrequency, multipolarization, high resolution measurement program at millimeterwave frequencies to characterize forward scatter multipath in various types of terrian.

2. Undertake a multifrequency millimeterwave measurement program to characterize propagation phenomena through various precipitants-dust, aerosols, etc.

3. Carry out measurements of drop size distribution in order to obtain better attenuation model of rain.

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