RADIO PROPAGATION MEASUREMENTS IN COAL MINES AT UHF AND VLF *

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ABSTRACT

Radio propagation measurements were conducted in a coal mine at UHF (200 to 1000 MHz) and VLF (1 to 50 kHz) to characterize the transmission loss of intra-mine paths. The basic experimental parameters included frequency, polarization, path orientation and distance. Further tests evaluated the performance of roof-bolt vs. loop antennas at VLF and parasitic reflectors at UHF.

Measurement results are summarized in a series of transmission loss curves. Examples are presented to show the use of these curves in predicting the performance of radio communication systems in mines.

INTRODUCTION

This paper summarizes a coal mine communication field test project conducted by Collins Radio as part of a continuing study of coal mine communications for the Bureau of Mines. The measurement and analysis effort centers on the propagation characteristics of radio signals in a working coal mine environment. The intent of the resulting data is to provide basic propagation loss characteristics in a form convenient for establishing requirements and evaluating alternate approaches for an integrated mine communications system. The goal of such a system is to satisfy both operational and emergency communication needs in the mine.

Field testing was conducted during the last week of November, 1972, at a coal mine operated by Inland Steel Company, near Sesser, IL. The mine has a vertical shaft entry with 750 feet of overburden and is located

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in the Illinois No. 6 seam. At present, the mine is 8,000 feet North-South by 13,000 feet East-West with an ultimate size 3 miles North-South by 7.5 miles East-West. All tunnels and haulage ways are 14 feet wide by 7-8 feet high with pillars running 60 feet by 74 feet. Roof bolts are 6 to 9 feet in length and secured by expansion achors. The roof bolts are placed on 4 foot centers throughout the mine.

The test area extended along a 4450 foot segment of the main west entry. The tunnel in which measurements were taken was the same as used for haulage of men and supplies via battery-operated, rubber tire vehicles. This tunnel also contained a 7200 VAC, 3-phase prime power cable suspended from the roof. A cross section of the tunnel is shown in figure 1. Measurements of corner attenuation were made along cross-cuts at right angles to the main tunnel. A typical corner geometry is shown in figure 2.

UHF TESTS

At UHF, transmission loss along the main tunnel and around corners was measured as a function of frequency, polarization and distance. All UHF tests utilized a 20-watt source and $\lambda/4$ ground plane antennas for transmission and standard $\lambda/2$ dipole antennas for reception. At each receiverpoint, a series of measurements was made to determine local signal strength variation over a range of several wavelengths. Horizontal and vertical polarization measurements were conducted to determine the extent of signal depolarization. Measurements were continued along the main tunnel and around corners at appropriate intervals determined by the rate of signal attenuation. Measurements were continued outward from the transmitter until no further signal could be detected. Transmission loss measurement accuracy is ± 2.5 dB based on receiver and antenna calibration tolerances.

The observed signal attenuation along the main tunnel is shown in figures 3, 4, and 5 for 200, 415, and 1000 MHz respectively. Attenuation is plotted as the power transfer ratio between isotropic antennas (basic transmission loss) for the indicated polarizations. Transmission loss may be combined directly with equipment parameters to establish communications performance.

Significant propagation characteristics are:

a) Attenuation (in dB) increases nearly linearly with increasing distance.

b) Horizontal polarization produces significantly lower transmission loss at a given distance than does vertical polarization. Cross polarization produces a loss intermediate between horizontal and vertical.

c) Transmission loss decreases significantly at a given distance as the frequency is increased from 200 to 1000 MHz.

Linear attenuation (in dB) versus distance is a characteristic of waveguide propagation; the tunnel geometry also suggests a guided mode of propagation. From the slope of the attenuation curves, attenuation rates have been determined as shown in figures 3-5. The values for 200 MHz are considered to be very approximate because they are based on a small number of data points. For comparison, Farmer and Shephard[1] report a value of 12 dB/100' at 160 MHz for straight passageways underground and in buildings.

With the main tunnel measurements as a reference, data were also obtained around corners. Observed corner attenuation is shown in figures 6, 7, and 8 for 200, 415, and 1000 MHz, respectively. Corner attenuation is plotted in dB relative to the horizontally polarized signal level observed in the center of the main tunnel. Significant propagation characteristics are:

a) Signal attenuation immediately around a corner is considerable at all three frequencies.

b) Complete signal depolarization is observed around the corner.

Because of the high attenuation of a single corner, propagation around multiple corners is expected to be even more severely attenuated. Consequently, the signal existing at any point can be reasonably assumed to have followed the path including the least number of corners. The transmission loss at any point along a cross tunnel can then be estimated by adding the attenuation from the appropriate curve in figure 6, 7, or 8 to the transmission loss corresponding to the distance along the main tunnel back to the transmitter.

One possible UHF communications system consists of a 20-watt base station and 1-watt walkie-talkie. As shown in Table 1-A, the base to walkie-talkie link has a "range" of 156 dB wherein satisfactory communications can be obtained. Communications coverage can thus be determined by comparing the predicted transmission loss to the 156 dB limit.

VLF TESTS

At VLF, the transmission loss and field strength were measured as a function of frequency, distance, and antenna orientation. All VLF tests utilized a 7-watt source with roof bolt (line source) antennas for transmission and standard loop or roof bolt antennas for reception. The line source antenna was established by clamping a pair of wire leads to two roof bolt heads separated by 52 feet. At each receive point, signal strength readings were made for two orthogonal positions of the roof bolt antenna and three orthogonal positions for the loop. The entire measurement sequence was then repeated for a second orientation of the transmit antenna. Measurements were conducted at three points spaced at intervals determined by the rate of signal attenuation. Transmission loss measurement accuracy is ± 2 dB based on receiver calibration tolerance.

Observed signal attenuation for intra-mine roof bolt-to-roof bolt antennas is shown in figure 9. Attenuation is plotted as the power transfer ratio between the roof bolt antenna terminals. Transmission loss may be added directly to transmitter power to determine the received signal level (available power into matched load). Significant propagation characteristics are:

a) Minimum transmission loss occurs for the end-to-end antenna orientation.

b) Transmission loss is relatively flat versus frequency.

c) The attenuation rate is approximately 5 dB/100' averaged over all frequencies and antenna orientations.

The available measurements do not fully characterize the propagation behavior. In particular, measurements over a greater range of distance, frequency and roof bolt spacing are desirable. However, the range of a roof bolt voice radio system can be estimated from measured data. For a 25-watt transmitter and other parameters as shown in Table 1B, the "range" of a typical system is 158 dB. Assuming that the curves of figure 9 extrapolate at 5 dB/100, 158 dB transmission loss then occurs at a distance of 1200 to 1400 feet, depending on antenna orientation.

Observed field strength for intra-mine roof bolt-to-loop antennas is shown in figure 10. Field strength is shown as the magnetic field intensity in dB/μA/m. This quantity is chosen rather than transmission loss to facilitate trade-off studies involving loop parameters such as size and weight. Field strength measurement accuracy is ±2 dB based on receiver and loop calibration tolerances.

Significant propagation characteristics are:

a) Maximum field strength occurs with the vertical magnetic dipole oriented along the axis of the roof bolt antenna.

b) Field strength is relatively flat versus frequency.

c) The attenuation rate is approximately 4 dB/100' averaged over all frequencies and antenna orientations.

The range of a roof bolt-to-loop voice bandwidth radio system can be estimated from measured data. Assuming the equipment parameters listed in table 1B and a 30-inch diameter, 20-turn loop for receiving, the required field strength is -14dB/μA/m at 50 kHz and +20 dB/μA/m at 1 kHz. Further assuming that the curves of figure 10 extrapolate at 4 dB/100', the minimum useful field strengths are reached at approximately 1500 feet at 50 kHz and 800 feet at 1 kHz when the loop is oriented as a VMD.

ACKNOWLEDGEMENT

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REFERENCES

1. Farmer, R. A., and N. H. Shephard, "Guided Radiation. . .The Key to Tunnel Talking," IEEE Transactions on Vehicular Communications, pp 93-102, March, 1965.

TABLE 1 COMMUNICATION LINK CALCULATIONS

(A) UHF, 2-WAY FM RADIO

Transmit Power,	P_t	=	+13 dBW
Transmit Antenna Gain,	G_t	=	0 dBi
Receive Antenna Gain,	G_r	=	0 dBi
Receive Sensitivity*,	P_r	=	-143 dBW

System "Range" $= P_t + G_t + G_r - P_r$

$= 156$ dB

*0.5uV for 20 dB quieting

(B) VLF, SSB RADIO

Transmit Power,	P_t	=	+14 dBW
External Noise,	N_e	=	-194 dBW/Hz
Receiver Noise,	N_r	=	-194 dBW/Hz
Total Noise	N_s	=	-191 dBW/Hz
Required SNR*	SNR_o	=	+47 dB-Hz

System "Range" $= P_t - N_s - SNR_o$

$= 158$ dB

* Articulation index = 0.3

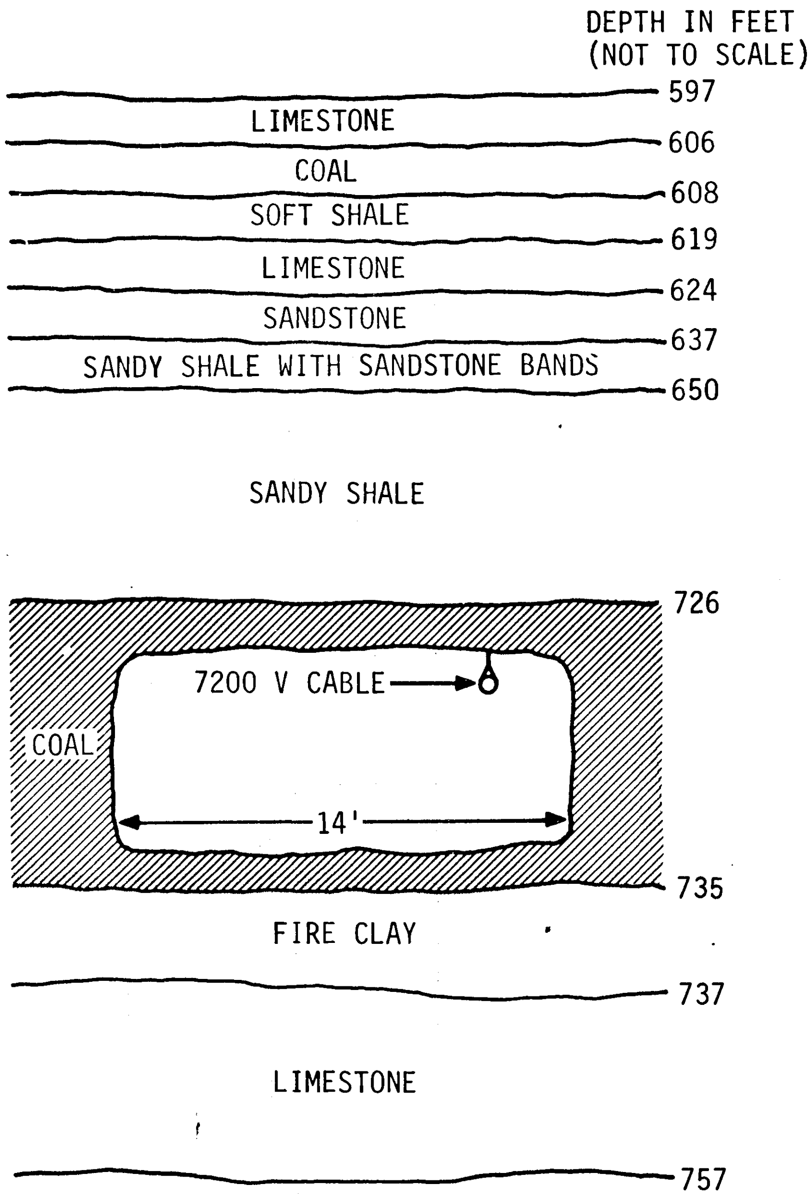

FIG. 1 - TUNNEL CROSS SECTION

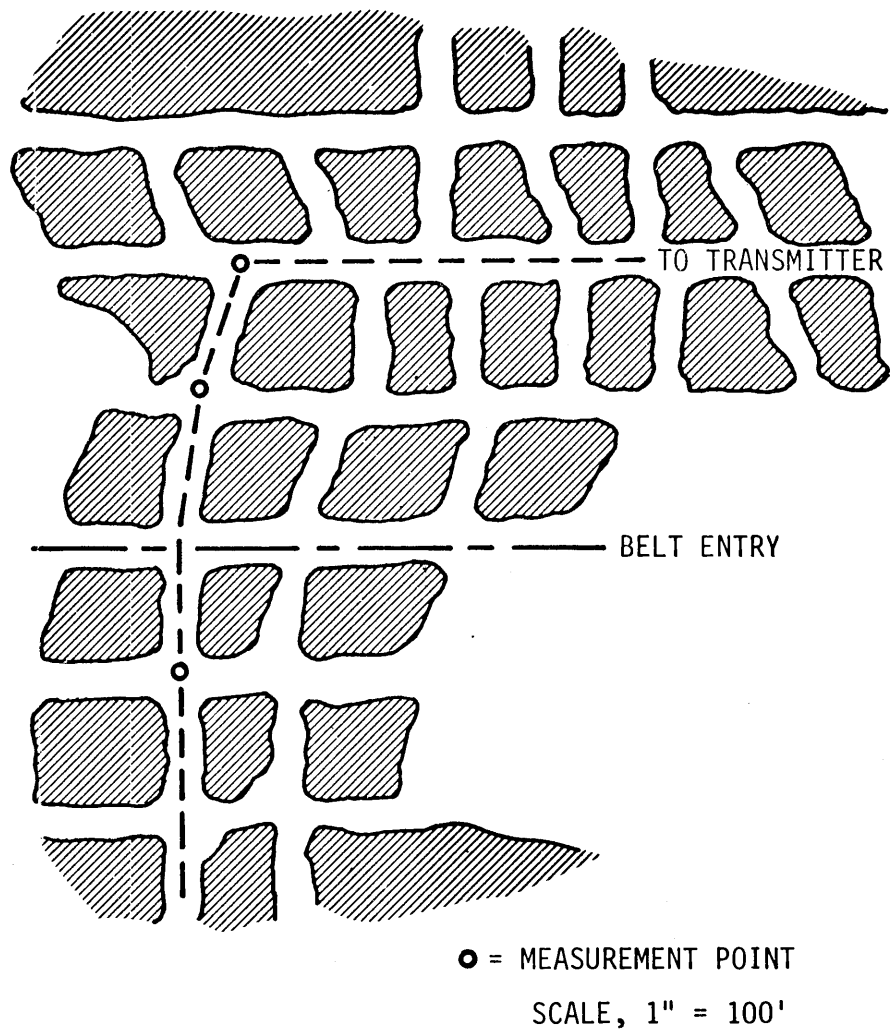

FIG. 2 - TYPICAL CORNER GEOMETRY

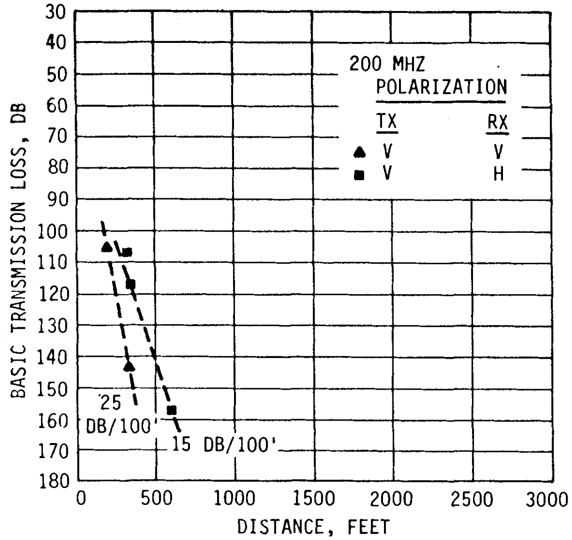

FIG. 3

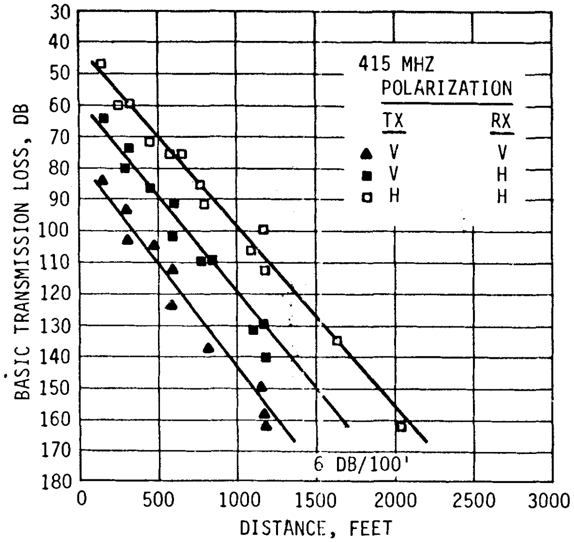

FIG. 4

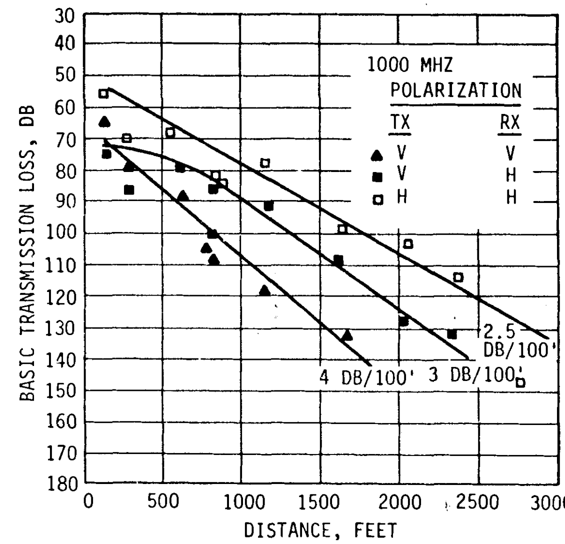

FIG. 5

UHF TRANSMISSION LOSS ALONG STRAIGHT TUNNEL

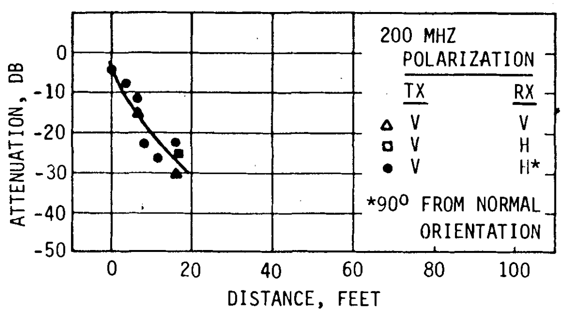

FIG. 6

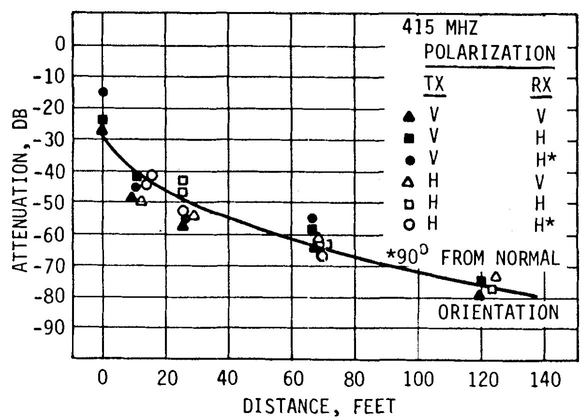

FIG. 7

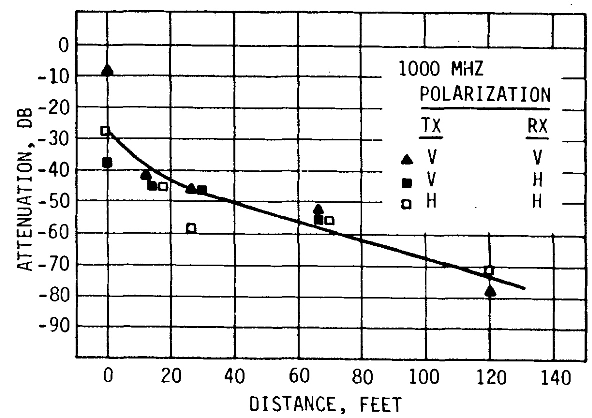

FIG. 8

UHF ATTENUATION OF SINGLE CORNER

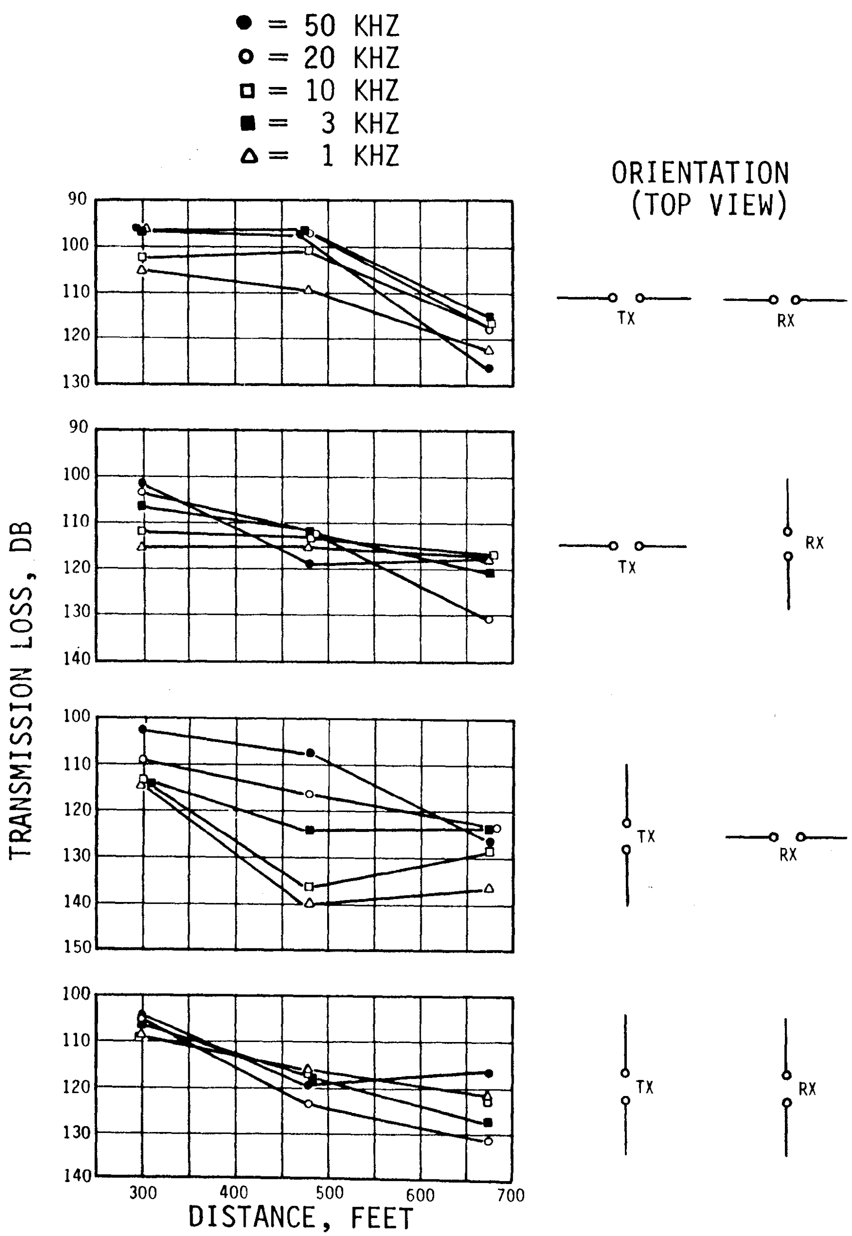

FIG. 9 - VLF TRANSMISSION LOSS FOR ROOF-BOLT ANTENNAS

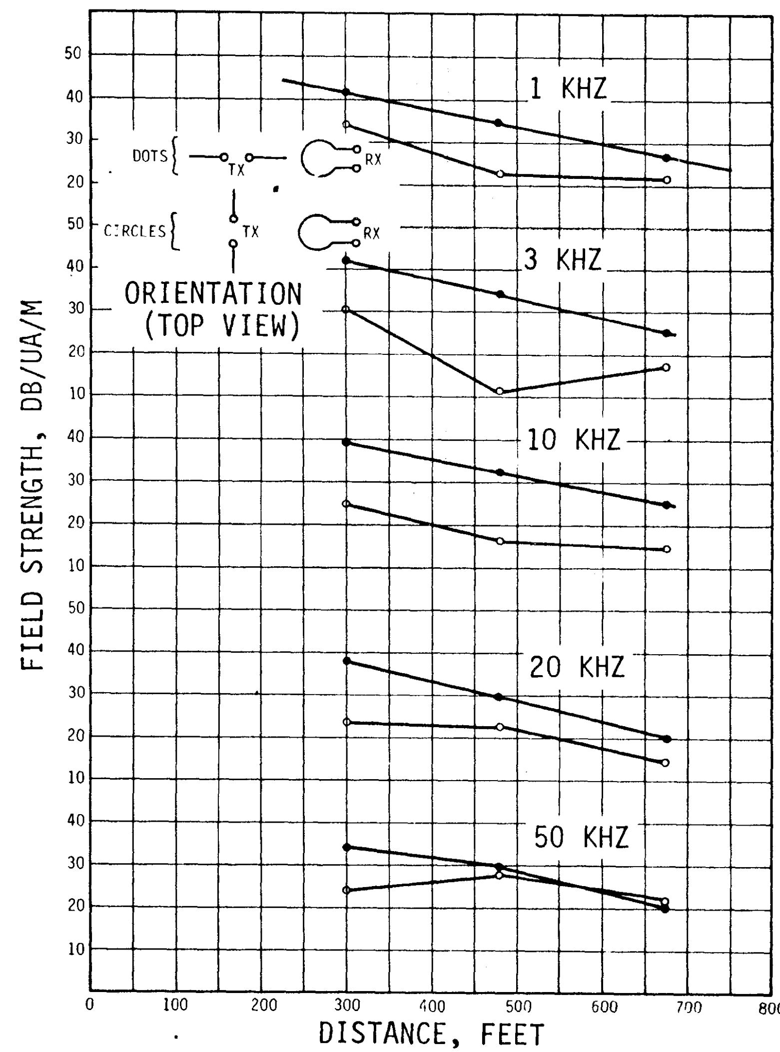

FIG. 10 - VLF FIELD STRENGTH FOR ROOF-BOLT ANTENNA