VERY NEAR GROUND RADIO FREQUENCY PROPAGATION MEASUREMENTS AND ANALYSIS FOR MILITARY APPLICATIONS

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Abstract - **We analyze, using a 2-ray model, the effects associated with placing a man-portable radio transceiver very near the ground (3 - 28 cm). A significant decrease in signal strength occurs when a soldier drops from the crouched position to the prone position. As much as a 16.8 dB decrease in signal strength was observed. This effect is more pronounced at short ranges, even without obstructions in the signal path. The Rician *k* factor generally decreases as antenna height is lowered. The assumed 2-ray propagation model is only appropriate when the Rician *k* factor is much greater than zero.**

I. INTRODUCTION

A number of indoor and outdoor military scenarios can be proposed that require two soldiers to communicate via man-portable radios. While others have investigated the issue of carrier frequency selection for communication systems with a low antenna height, e.g. [1], we will investigate the effects associated with the scenario where one of these soldiers is lying on the floor or ground. We will call this geometry *very near ground* RF propagation (all antennae less than 1 meter in height).

If we assume that a soldier is lying on his stomach or back with access to a portable radio, then a single antenna radio system could have the tip of its antenna very near the ground plane (floor or ground). Depending on the physical construction of the radio, the antenna could be vertically, horizontally, or inverted-diagonally[1] relative to the ground plane. The proximity of the antenna to the ground plane suggests that a significant performance degradation may exist [2]. Indeed, it is already known that a *dipole's* impedance and field pattern fluctuates with varying height above the ground plane. Additionally, these effects are more pronounced if the antenna has a horizontal orientation.

[1]The term inverted-diagonally refers to a diagonal orientation where the antenna's feed point is above the antenna's tip.

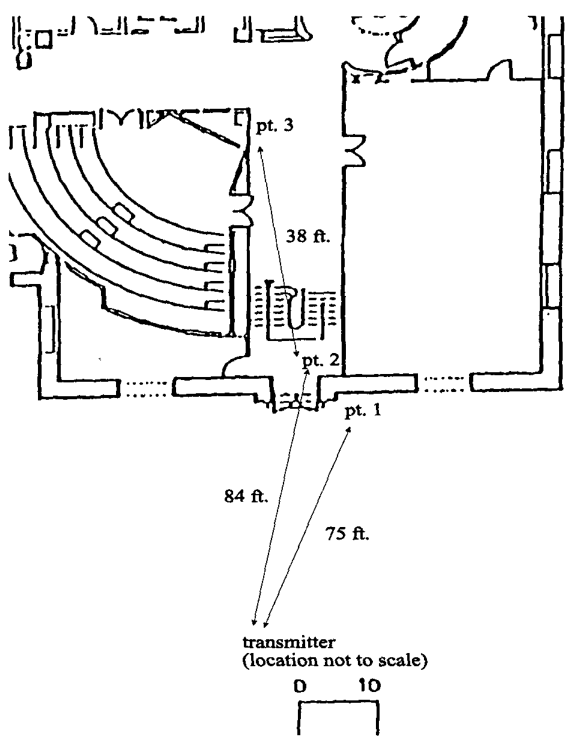

Fig. 1. Measurement geometries.

We will consider the geometries shown in Fig. 1. A photograph from near the transmitter's location is provided as Fig. 2. In Fig. 1, a fixed communication station (the first soldier, which is labeled "transmitter," (see Fig. 3)) is communicating with a second soldier who is either outside a building (labeled "pt. 1"), just inside a building (labeled "pt.

Fig. 2. Exterior photo of the building.

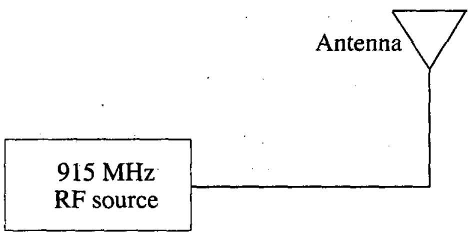

Fig. 3. Transmitter block diagram.

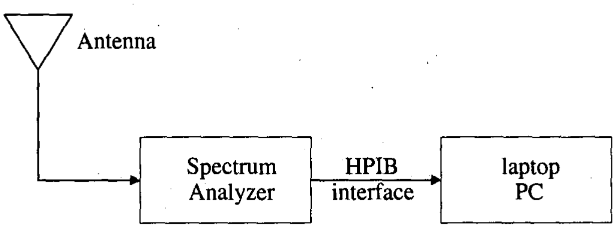

Fig. 4. Receiver block diagram.

2"), or inside a building in an interior hallway (labeled "pt. 3"). The first soldier will always remain in the crouched down or kneeling position. This will place the transmitting antenna's tip 1 meters above the ground. The second soldier will be in a crouched down or prone position. Antenna orientation, while the second soldier is crouched down, will always be vertical. Antenna orientation while the second soldier is prone will be either vertical, horizontal, or inverted-diagonally. This will place the receiving antenna's tip, 28, 15, or 3 centimeters above the ground, respectively. The fixture that holds the receiving antenna is designed to accurately model a small hand-held radio being held to the soldier's ear.

The signal strength data sets gathered, Fig. 4, at each of the three locations will be used for a comparison of the system performance with user elevation and antenna orientation as the only variables. At each of the locations the mean signal strength and the Rician k factor will be calculated.

II. Analysis

An analysis of the radiating antenna can explain some of the effects seen in the measurements below. The ground can be modeled as an infinite planar boundary. This is a reasonable assumption because the antenna heights and radiation distances are so small compared to the radius of the earth and the measurement sites were essentially flat in the immediate area [3]. When an antenna radiates in the presence of an infinite, planar boundary, some of the energy will propagate directly to the receiver and some will reflect off of the boundary to the receiver. The reflected energy can be modeled as if it is coming from an image source located at the same distance below the boundary as the height of the actual antenna above the boundary, but propagating through free space the entire distance. In the case of a perfectly conducting boundary, all of the energy is reflected and the magnitude of the image will be identical to the source. When the antenna is polarized horizontally, there will also be a 180° phase shift. The reflection coefficient, the ratio of reflected energy to incident energy, is constant and equal to either +1 or -1. The only effect of the perfectly conducting boundary on the total antenna pattern is the multiplication of an array factor term corresponding to a two-element array with a separation of twice the original source's height. When the medium below the boundary has a finite conductivity, as the ground actually does, the reflected energy can still be modeled as being radiated from an image source, but the net effect changes in several ways. For a finite conductive surface, the reflection coefficient will be complex. The magnitude will almost always be less than one and there will be an additional phase component added. Both the magnitude and phase of the reflection coefficient will also be a function of angle, frequency and polarization. The effect on the total antenna pattern is the multiplication of a term that accounts for the difference in distances between the source and the receiver and the image and the receiver as well as the image's magnitude and phase.

The power pattern resulting from the summation of the original and image source's radiation in the vertical case is shown below, Fig. 5. The effect of the antenna element's own pattern is not included. Both data sets were normalized to the maximum value of the perfect conducting case. Thus, the power pattern for the finite conducting case is reduced in two ways; because it will never reach the same maximum and because of the altered pattern shape.

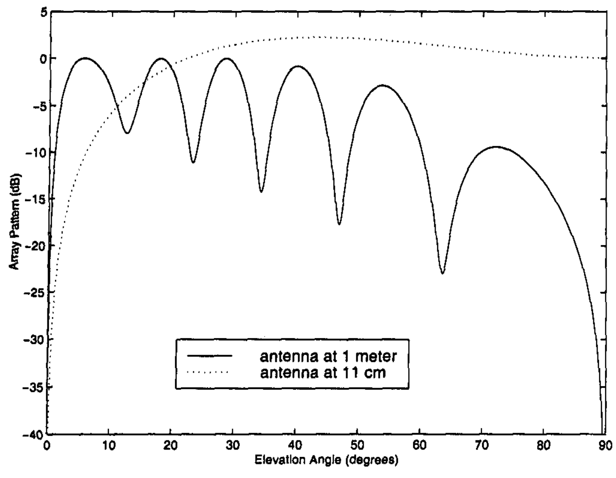

Fig. 5. Array pattern for the vertically oriented antenna.

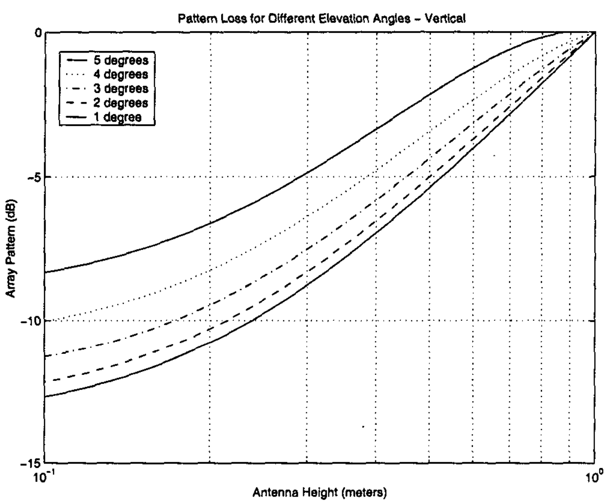

Fig. 6. Normalized (at 1 meter) array pattern for the vertically oriented antenna (< 5 degrees).

The effect below 5 degrees is shown in Fig. 6. This very small angle of arrival (< 5 degrees) is what we anticipate for our geometries. From this plot we predict a 5-12 dB power reduction due to the loss effects of the finite conductivity of the ground in the angular region of interest.

In the case of horizontal polarization, the pattern effect is minimal above about 20 degrees and really only extends the angle at which the pattern drops to zero from about 15 degrees to 10 degrees, slightly increasing the coverage at these grazing angles

The power pattern resulting from the summation of the original and image source's radiation in the horizontal case is

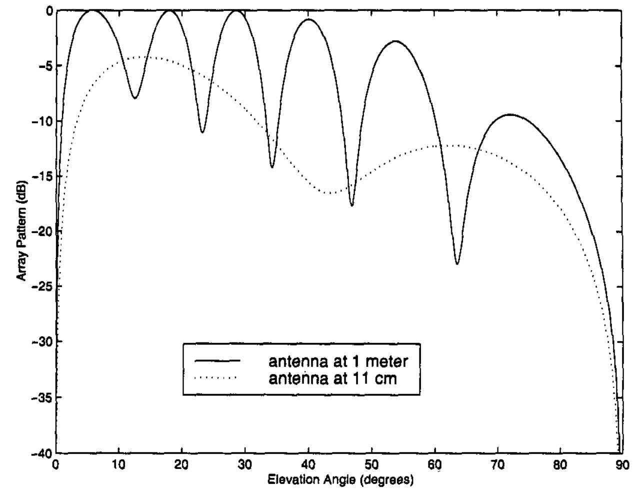

Fig. 7. Array pattern for the horizontally oriented antenna.

shown in Fig. 7. Notice that there is an additional dependence on the azimuthal direction to the receiver. Again, the effect of the antenna element's own pattern is not included and all data is normalized to the maximum value of the perfectly conducting case.

There is another effect that was not thoroughly analyzed but deserves to be mentioned. The presence of an infinite, planar boundary beneath a radiating antenna also alters the antenna's input impedance. If an antenna is connected to a system that is tuned to deliver maximum power based on the antenna's impedance in free space, this change will cause a mismatch and reduce the total radiated power. Using data calculated for dipoles, the effect of this mismatch on vertically oriented antennas is very small. However, the effect on horizontally oriented antennas can be losses on the order of 5-10 dB [4]. We hope to analyze this effect more rigorously in future efforts.

III. Data Gathering and Reduction

At each of the three previously defined points, the receiving antenna fixture is moved approximately 20 wavelengths. The 20 wavelength measurement track is used to be consistent with the results of [5]. During this motorized movement of the antenna, the spectrum analyzer gathers signal strength data and recorded this data, via the HPIB, to the attached laptop PC (see Fig. 4). At each of the three points, four data sets are gathered. These four sets correspond to the four elevation and antenna orientations combinations of concern(crouched down with a vertical antenna, prone with a vertical antenna, prone with a

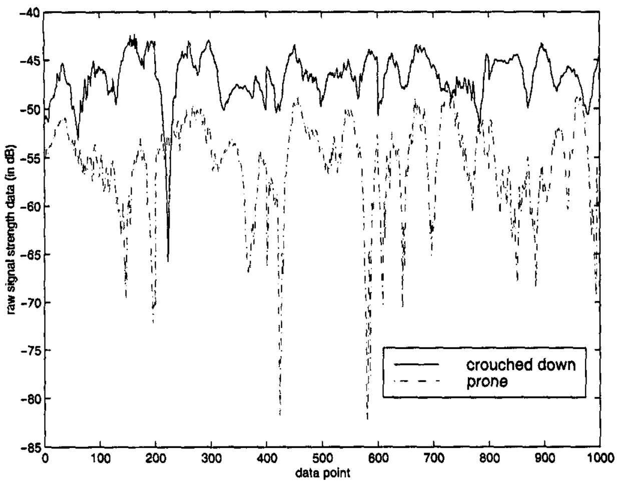

Fig. 8. Point 1 signal strength data for a vertically oriented antenna.

horizontal antenna, and prone with a inverted-diagonally antenna). At each of the points 2000 signal strength measurements are gathered into a data set.

The signal strength data from point 1 is provided in Fig. 8. For clarity, only the data associated with the crouched down position with a vertical antenna and the prone position with a vertical antenna are provided. Using the cumulative distribution function (CDF) technique discussed in [6], the Rician *k* factor for the data sets can be calculated. For point 1,

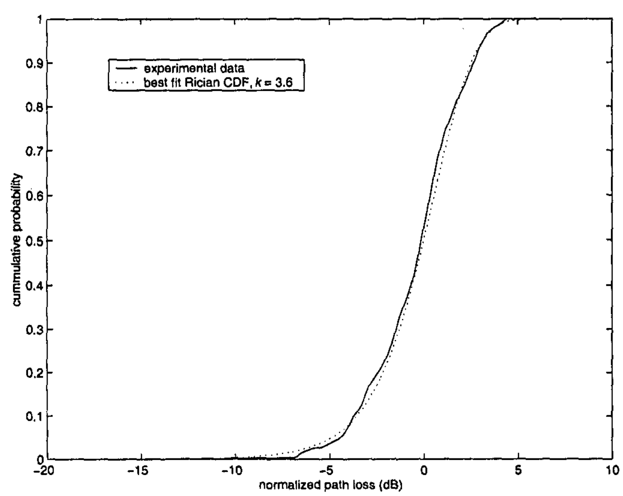

Fig. 9. Best fit Rician CDF for point 1, prone, vertical orientation.

prone position with a vertical antenna, the CDF with the *best fit* for a Rician CDF is provided in Fig. 9. Table 1 provides the measured average path loss, an estimate of the Rician *k* factor, and the mean-squared error (mse) associated with this best fit. We are using a mse of < 0.0005 to indicate an extremely good fit [7].

At point 1 we can see a 12.1 to 16.8 dB decrease in average signal strength as the soldier drops from a crouched position to a prone position. At point 2 we see a 7.6 to 8.2 dB decrease in average signal strength as the soldier drops from a crouched position to a prone position. The path-loss range varies very little with antenna orientation changes. Despite a metal framed glass doorway, the Rician *k* factor remains small for all antenna positions. At point 3 we see a 4.8 to a 6.4 dB decrease in average signal strength as the soldier drops from a crouched position to a prone position.

TABLE I
DATA POINT MEASUREMENT RESULTS

data pt. number	antenna orientation	average loss(dB)	Rician *k* factor	mean squared error (mse)
1	crouched - vertical	-23.9	3.6	0.0002236
1	prone - vertical	-35.0	2.6	0.0003893
1	prone - horizontal	-39.4	2.2	0.0001672
1	prone - inv. diag.	-40.7	0.6	0.0002075
2	crouched - vertical	-35.0	0.9	0.0004607
2	prone - vertical	-43.1	1.3	0.0001072
2	prone - horizontal	-43.2	0.0	0.0004935
2	prone - inv. diag.	-42.6	0.0	0.0002964
3	crouched - vertical	-47.5	1.3	0.00006764
3	prone - vertical	-53.4	0.0	0.00009271
3	prone - horizontal	-53.9	0.0	0.0002121
3	prone - inv. diag.	-52.3	1.3	0.00008677

IV. CONCLUSIONS

A significant decrease in signal strength occurs when a soldier drops from the crouched position to the prone position. As much as a 16.8 dB decrease in signal strength was observed. This effect is most pronounced at short ranges, even without obstructions in the signal path. The Rician *k* factor generally decreases as antenna height is lowered. The assumed 2-ray propagation model is only appropriate when the Rician *k* factor is much greater than zero.

This type of analysis and propagation information should be useful to the designers, manufacturers, and end users of both military and civilian radios since this data clearly demonstrates that the *path loss* link budget term needs to consider the significant effect of both the transmit and receiver antenna heights.

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