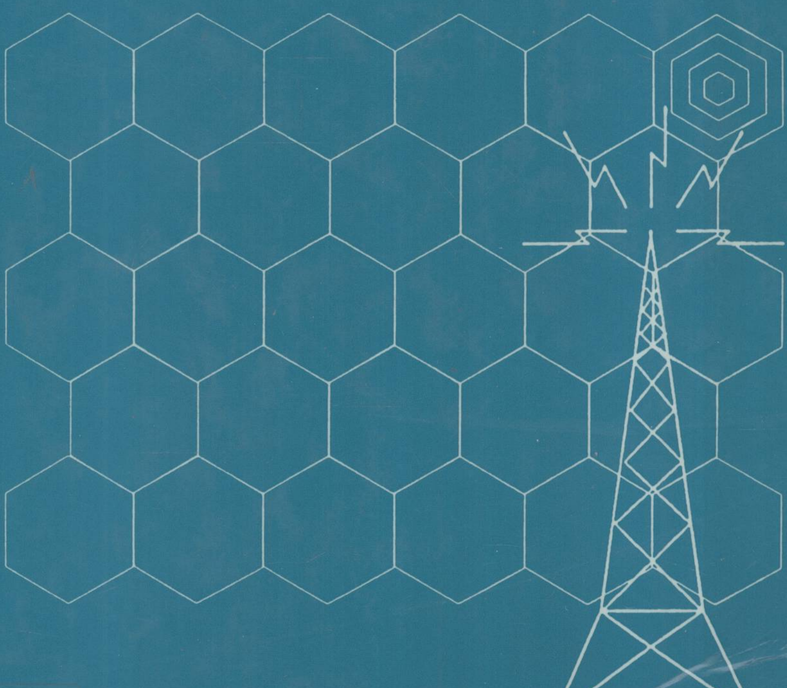
Wireless Personal Communications

Channel Modeling and Systems Engineering

edited by
William H. Tranter
Brian D. Woerner
Theodore S. Rappaport
Jeffrey H. Reed



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WIRELESS PERSONAL COMMUNICATIONS

Channel Modeling and Systems Engineering

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PREFACE

The papers appearing in this book were originally presented at the 9^{th} *Virginia Tech/MPRG Symposium on Wireless Personal Communications*. The *Symposium on Wireless Communications*, which is an annual event for Virginia Tech, was held on June 2-4, 1999. The 1999 symposium was co-sponsored by MPRG, the Division of Continuing Education, University International Programs, and the MPRG Industrial Affiliate Sponsors.

Much of the success of our annual symposium, as well as the success of MPRG's research program, is due to the support of our industrial affiliates. Their support allows us to serve the wireless community through research, education and outreach programs. At the time of the 1999 symposium, the MPRG affiliates program included the following organizations: Army Research Office, AT&T Corporation, Bellsouth Cellular Corporation, Comcast Cellular Communications, Inc., Datum, Inc., Ericsson, Inc., Grayson Wireless, Hewlett-Packard Company, Honeywell, Inc., Hughes Electronics Corporation, ITT Industries, Lucent Technologies, Motorola, National Semiconductor, Nokia, Nortel Networks, Qualcomm, Inc., Radix Technologies, Inc., Salient 3 Communications, Samsung Advanced Institute of Technology, Southwestern Bell, Tantivy Communications, Tektronix, Inc., Telcordia Technologies, Texas Instruments, TRW, Inc., and the Watkins-Johnson Company

As can be seen from the Table of Contents, the papers included in this book are divided into six sections. The first five of these correspond to symposium sessions, and cover the following topics: Propagation and Channel Modeling (4 papers), Antennas (6 papers), Multiuser Detection (3 papers), Radio Systems and Technology (4 papers), and Wireless Data (3 papers). The last section contains invited poster papers (2 papers).

The first group of papers deals with Propagation and Channel Modeling. The first paper, *Very Near Ground RF Propagation Measurements and Analysis*, by Thad Welch, Michael Walker, and Ray Foran, treats the propagation characteristics of a cordless phone antenna when the antenna is placed near the ground. A situation like this might exist if an incapacitated person, lying on the ground, has access to a cellular or cordless phone. Results of their study show that a significant decrease in signal strength (as much as 12 dB) can occur if a person using the phone falls from a sitting to a prone position. The second paper in this section, *Identification of Time-Variant Directional Mobile Radio Channels*, is co-authored by R. S. Thoma, D. Hampicke, A. Richter, G. Sommerkorn, A. Schneider, and U. Trautwein. Their paper describes a broadband channel sounder which allows a full statistical analysis of the Doppler-delay-azimuth statistic of mobile radio channels. The measurement procedure uses processing based on the ESPRIT algorithm. The third paper in this section is co-authored by B. L. Johnson, Jr., P. A. Thomas, D. Leskaroski, and M. A. Belkerdid, and is entitled *Propagation Measurements and Simulation for Wireless Communication Systems in the ISM Band.* They use both deterministic and stochastic models to study propagation coverage in the 2.4 GHz ISM band for an area in South Florida. The result of their study is a Hata-Okumura model implemented in Mathcad™. The results show that Mathcad™ is a practical tool for simulating propagation coverage. The next paper in this group was contributed by Dave Crosby, Steve Greaves and Andy Hopper. This contribution, entitled *A Theoretical Analysis of Multiple Diffraction in Urban Environments for Wireless Local Loop_Systems*, studies the use of simulation to study multiple diffraction effects in wireless local loop systems. They show that the average path loss characteristic can be separated into two regions, which gives rise to a two slope model. They show that the diffraction is well approximated by a log-normal distribution.

The second section of this book, Antennas, consists of six papers. The first paper, *Active Microstrip Antenna for Personal Communication System* by M. Wnuk, W. Kolosowski, M. Amanowicz, and T. Semeniuk, describes the development of a microstrip antenna having a radiation pattern which limits the electromagnetic field emitted towards a user's head. The second paper, *Co-located, Dual-band, Multi-function Antenna System for the GloMo Universal Modular Packaging System* by J. S. McLean, J. A. LaCoss, J. R. Casey, E. Guzman, G. E. Crook, and H. D. Foltz, discusses the packaging system for the ultra-high density handheld data terminal. A multi-function antenna, allowing simultaneous operations of two or more radio systems is described. The system was configured to minimize co-site interference. The third contribution is entitled *Self-Calibration Scheme for Antenna Arrays Using the Combined Array Signal* was written by Mark Wiegmann. The calibration employs a beamforming network and a single receiver. A simulation study showed good performance of the calibration algorithms. H. Novak contributed the fourth paper in this group. His paper, entitled *Switched Beam Adaptive Antenna Demonstrator for UMTS Data Rates*, describes the development of a switched beam adaptive antenna system. His system supports data rates in excess of 1 Mbit/s. The fifth paper in the antenna section is entitled *UMTS Radio Network Simulation with Smart Antennas* and was co-authored by B. O. Adrian and S. Haggman. Their simulation study shows substantial capacity improvements in a DS-CDMA network using smart antenna technology. The sixth and final paper in the group of papers dealing with Antennas is entitled *Methods for Measuring and Optimizing Capacity in CDMA Networks Using Smart Antennas,* and was co-authored by S. D. Gordon, M. J. Feuerstein, and M. A. Zhao. The contribution of this paper presents a technique for estimating the forward link capacity of a CDMA system. Their model slows a 27% improvement in capacity over a conventional antenna system.

The third group of papers presented here deals with Multi-Detection. There are three papers in this section. The first of these, *Adaptive Radio Resource Control via Cascaded Neural Networks for Sequenced Propagation Estimation and Multi-User Detection in Third-Generation Wireless Networks* by W. S. Hortos, makes use of a neural network approach to predict radio propagation characteristics and multi-user interference, and to evaluate their impact on wireless networks. The neural network architecture proposed by the author is used to allocate network resources and optimize quality-of-service. The second paper in this section is by M. Golanbari and G. E. Ford. Their contribution, entitled *Successive Interference Cancellation for Interception of the Forward Channel of Cellular CDMA Communications*, considers successive interference cancellation techniques to simultaneously detect cochannel signals in an IS-95 CDMA system. A host of channel impairments are considered. They show performance that tracks the performance of the optimum receiver. In addition, their receiver is near-far resistant. The third and final contribution dealing with multi-user receivers, co-authored by A. Boariu and R. E. Ziemer, is entitled *A New Muliuser Detector for Synchronous CDMA Systems in AWGN Channels.* Boariu and Ziemer introduce a decorrelating decision-feedback multiuser detector based on Cholesky factorization. Simulation results show that the Cholesky-iterative decoder outperforms the standard decorrelating decision feedback detector.

The fourth group of papers in this book treat a variety of technology issues relating to the implementation of radio systems. There are four papers in this group. The first of these, entitled *Modeling Study to Determine the Realistic Constraints of the Wireless Land Mobile Radio Narrowband CAI Interface Specified in the TIA-102 Standard,* is contributed by S. E. Bartlett and K. M. Syed. They describe the result of a channel performance study focusing on the interoperability of the common air interface of the TAI-102 narrowband standard for public safety land mobile radios. Then next paper is by N. L. Marran and is entitled *Over-the-Air Subscriber Device Management Using CDMA Data and WAP.* This contribution illustrates how wireless service providers and their customers can benefit by the deployment of OTA services.

The third paper in this group is entitled *Hyperactive Chipmunk Radio* and was co-authored by G. H. McGibney and S. T. Nichols. The chipmunk radio modulates voice signals in a manner that causes radio waves to behave in the medium as sound waves behave in an acoustic medium. The result is that radio signals inherit many of the desirable characteristics of acoustic voice signals including resistance to both flat and frequency selective fading. The final paper in this section, *Turbo Code Implementations on Fixed Point DSP's*, by E. Cress and W. J. Ebel, considers the implementation of turbo decoding algorithms on the TMS3206201 fixed point DSP architectures.

The fifth group of papers presented in this book deals with wireless data systems. There are three papers in this group. The first of these, *TCP with Adaptive Radio Link*, by D. Huang and J. J. Shi, treats the performance of circuit-switch based TCP over a wireless link. They propose an adaptive radio link protocol to maintain TCP performance under a variety of channel conditions. The following paper, *Reducing Location Update and Paging Cost in a PCS Network* by P. G. Escalle, V. C. Giner and J. M. Oltra, deals with mobility tracking strategies. They propose a new technique that is a hybrid between global and local strategies. The last paper in this section, *Performance Enhancement for TCP/IP on Wireless Links*, by J. S. Stadler, J. Gelman, and J. Howard, discuss the reasons for reduced levels of TCP/IP performance, and describes two techniques for improving performance. Both of the new techniques have been prototyped and tested and both show nearly optimal performance.

The final section of this book contains two invited posters. The first of these, *Development and Implementation of an Adaptive Error Correction Coding Scheme for a Full Duplex Communications Channel,* was co-authored by J. W. Waterston, S. Wooten, W. Bennett, and T. B. Welch. They consider an adaptive coding strategy in which the rate of a n = 63 BCH code is adjusted according to channel conditions. They show an increased throughput for a slowly fading Rayleigh channel. The second paper in this set of papers, *Simulink Simulation of a Direct Sequence Spread Spectrum Differential Phase Shift Keying SAW Correlator* by S. M. Nabritt, M. Qahwash, and M. A. Belkerdid, considers the use of a SAW-based demodulator for direct sequence spread spectrum signals. Simulation results agreed well with results obtained from the hardware implementation.

A successful symposium, and consequently the papers contained herein, result from the significant efforts of a dedicated team of people. First, thanks go to those who submitted papers and attended the symposium. Without a strong technical program, the symposium could not continue to prosper. We also thank the MPRG support staff and graduate students. The efforts of Jenny Frank, who took the lead in organizing the symposium and tending to the vast quantity of details associated with the symposium, are gratefully appreciated.

We also acknowledge the support of our technical co-sponsors. These include the IEEE Communications Society, the IEEE Virginia Mountain Section, and the Virginia Tech Student Joint-Chapter of the IEEE Communications and Vehicular Technology Societies.

Blacksburg, Virginia

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Brian D. Woerner
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TABLE OF CONTENTS

Very Near Ground RF Propagation Measurements and Analysis

Thad B. Welch[†], Michael J. Walker[‡], and Ray A. Foran[†]

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Abstract - *We analyze and measure the effects associated with placing a cordless phone antenna, with three different orientations, very near the ground (3 - 28 cm). A significant decrease in signal strength occurs when a user falls from the sitting position to the prone position. As much as a 12 dB decrease in signal strength can occur. This information, if available to an injured cordless phone user, could allow for a successfully completed 911 call.*

1. INTRODUCTION

When and where available, the traditional *plain old telephone service* (POTS) provides *almost guaranteed access* to 911 and other emergency services. With an increase in cellular and cordless phone usage, more people are relying on these products for both their routine and emergency communication needs. While cellular and cordless products offer increased mobility, challenges associated with the mobile radio channel prevent them from providing *almost guaranteed access* to emergency services. A number of indoor and outdoor emergency scenarios can be proposed. 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 of antenna height and orientation on system performance. Specifically, we will investigate the scenario of an incapacitated person lying on the floor or ground. If we assume that this scenario exists and that an individual is lying on their back with access to a cellular or cordless phone, then a single antenna phone system would have the tip of its antenna very near the ground plane (floor or ground). Depending on the physical construction of the phone, the antenna could be vertically, horizontally, or diagonally (inverted) oriented 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 fluctuates with varying height above the ground plane. Additionally, this effect is more pronounced if the antenna has a horizontal orientation.

We will consider an indoor scenario where the fixed base station is communicating with a cordless phone which is either in the same room, in an adjacent hallway, or in a distant hallway. At each of the locations, the signal strength will be measured for both the sitting and prone system user. Antenna orientation will also vary from vertical to horizontal, and to diagonal (inverted). Data gathered at the three locations will allow for a comparison of system performances with user elevation and antenna orientation as the only variables. An analysis of the antenna pattern and impedance will also be conducted to help explain the reception difficulties.

We will consider the geometries shown in Figure 1. In Figure 1, a fixed base station labeled "trans" communicating with a system user who is either inside the same room (labeled "pt. 1"), just outside the room in a hallway (labeled "pt. 2"), or further down the same hallway (labeled "pt. 3"). The base station will always remain in the same position. This will place the transmitting antenna's tip 1 meter above the ground.

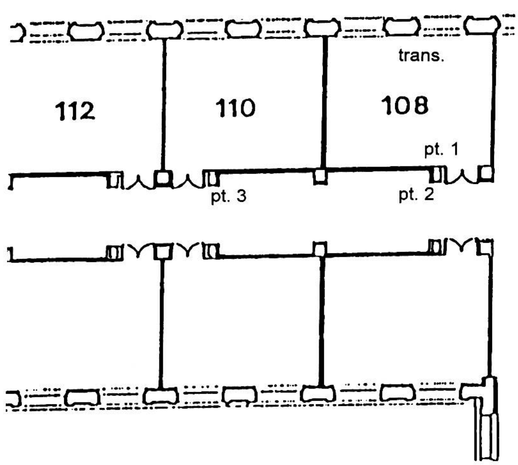

Fig. 1. Measurement geometry.

The system user will be sitting on the floor or in a prone position. Antenna orientation, while the system user is sitting on the floor, will always be vertical. Antenna orientation while the system user is prone will be either vertical, horizontal, or diagonal (inverted). This will place the receiving antenna's tip, 28, 15, or 3 centimeters above the ground, respectively (11, 15, or 16 centimeters above the ground for the antenna's feed point). The fixture that holds the receiving antenna was designed to model a hand-held cordless phone being held to the system user's ear.

2. 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.

$$R_V = \frac{\eta_1 \cos\theta_i - \eta_2 \cos\theta_t}{\eta_1 \cos\theta_i + \eta_2 \cos\theta_t}$$

$$R_H = \frac{\eta_1 \cos\theta_t - \eta_2 \cos\theta_i}{\eta_1 \cos\theta_t + \eta_2 \cos\theta_i}$$

$$\eta_1 = \sqrt{\frac{\mu_0}{\varepsilon_0}}$$

$$\eta_2 = \sqrt{\frac{j\omega\mu_0}{\sigma + j\omega\varepsilon_0\varepsilon_r}}$$

$$j\omega\sqrt{\mu_0\varepsilon_0}\sin\theta_i = \sqrt{j\omega\mu_0(\sigma + j\omega\varepsilon_0\varepsilon_r)}\sin\theta_t$$

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. 2. 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. From this plot we predict a 5-10 dB power reduction due to the loss effects of the finite conductivity of the ground in the angular region of interest.

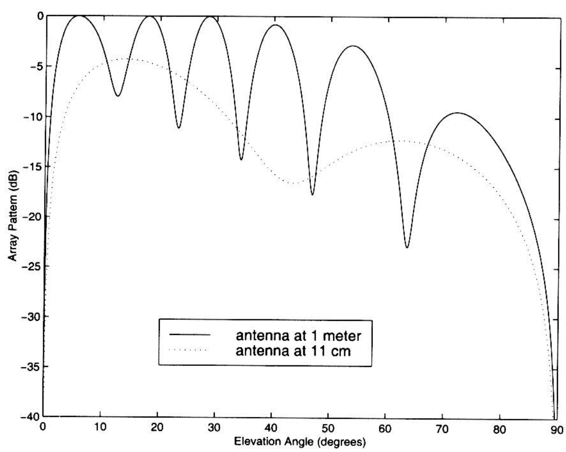

Fig. 2. Array pattern for the transmitter at 1 meter elevation, 10 meter separation, over a reinforced concrete slab (vertical antenna orientations).

The power pattern resulting from the summation of the original and image source's radiation in the horizontal case is shown below, Fig. 3. 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. From this plot we predict a negligible reduction, if not a small gain, in the power pattern for the horizontal case.

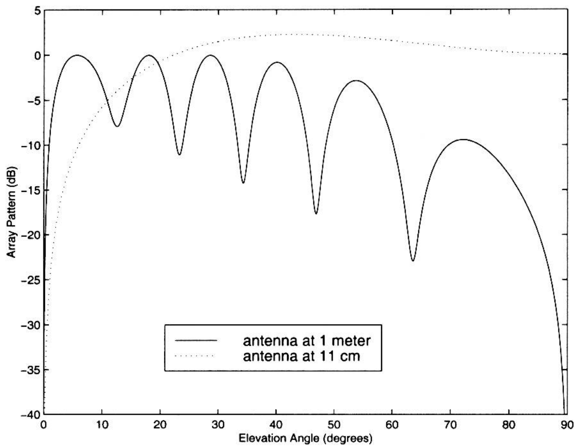

Fig. 3. Array pattern for the transmitter at 1 meter elevation, 10 meter separation, over a reinforced concrete slab (vertical antenna orientation - transmitter and receiver (1 meter elevation), horizontal antenna orientation - receiver (11 centimeters elevation)).

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.

3. DATA GATHERING AND DATA REDUCTION

At each of the three data gather points the receiving antenna fixture was moved approximately 20 wavelengths. The 20 wavelength measurement track was used to be consistent with the results in [5]. During this motorized movement of the antenna, the spectrum analyzer gathered signal strength data and recorded this data, via the HPIB, to the attached laptop PC. At each of the three points, four data sets were gathered. These four sets correspond to the four elevation and antenna orientations combinations of concern (sitting on the floor with a vertical antenna, prone with a vertical antenna, prone with a horizontal antenna, and prone with a diagonal (inverted) antenna). At each of the points 2000 signal strength measurements were gathered into a data set.

Using the cumulative distribution function (CDF) technique discussed in [6], the Rician *k* factor for the data sets can be calculated. Tables 1, 2, and 3, provide the average path loss, path loss standard deviation, an estimate of the Rician *k* factor, and the mean-squared error (mse) associated with this best fit for these three data points. We are using a mse of less than 0.0005 to indicate an extremely good fit [7].

At point 1 we can see a 2.4 to 4.6 dB decrease in average signal strength as the system user falls from a sitting position to a prone position. At point 2 we can see a 0.9 to 3.4 dB decrease in average signal strength as the system user falls from a sitting position to a prone position. At point 3 we can see a 3.3 to 4.6 dB decrease in average signal strength as the system user falls from a sitting position to a prone position.

data point 1	average path loss	path loss std dev	Rician *k* factor	mse
sitting vertical	-12.2 dB	5.8 dB	0.0	0.0000896
prone vertical	-16.8 dB	6.4 dB	0.0	0.000696
prone horizontal	-14.6 dB	5.3 dB	0.0	0.000577
prone diagonal (inverted)	-15.2 dB	5.8 dB	0.0	0.000111

Table 1. Point 1 data analysis.

data point 2	average path loss	path loss std dev	Rician *k* factor	mse
sitting vertical	-16.2 dB	5.3 dB	1.2	0.000237
prone vertical	-19.6 dB	5.7 dB	1.1	0.000356
prone horizontal	-17.1 dB	5.2 dB	1.2	0.000518
prone diagonal (inverted)	-18.8 dB	5.7 dB	0.8	0.0000802

Table 2. Point 2 data analysis.

data point 3	average path loss	path loss std dev	Rician *k* factor	mse
sitting vertical	-20.2 dB	5.1 dB	1.4	0.000305
prone vertical	-24.6 dB	4.8 dB	2.0	0.000312
prone horizontal	-23.5 dB	6.0 dB	0.0	0.000409
prone diagonal (inverted)	-24.8 dB	4.8 dB	1.1	0.000312

Table 3. Point 3 data analysis.

All of this data was taken in Maury Hall on the United States Naval Academy. This building houses the Department of Electrical Engineering and is very convenient for this type of data collection effort. We were very concerned about the structural differences between this building and a traditional home, since Maury Hall was build in the early 1900's with exterior walls made of stone and brick totaling over 3 feet thick and with floors that are almost two feet thick made of concrete and brick. Despite the massive structural difference, similarities can be found with modern construction techniques on the interior partitioning walls. Maury was last renovated in the mid-1970's, during which partitioning walls were replaced by sheet rock over steel stud construction. A comparison between the data taken in Maury Hall and a data taken in a more traditional home was still needed. To allow for this comparison, similar measurements were taken in a private residence. Point 4 was the first of the two residential measurements taken. This point was in the same room as the transmitter, 3.6 meters away. Point 5 was the second of the two residential measurements taken. This point was in a nearby room, 10 meters away. Tables 4 and 5, provide the average path loss, path loss standard deviation, an estimate of the Rician *k* factor, and the mean-squared error (mse) associated with the best fit for these two data points.