Design of Anechoic Chamber Instrumentation and Data Acquisition Module for

Testing and Analysis of the CTHA.

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Abstract

The backbone of wireless communication is an antenna, a device that converts electromagnetic energy to electric energy and vice versa, to transmit and receive the signals. The effectiveness of a communication system depends largely on the effectiveness of the antenna used in them. The effectiveness of an antenna is characterized by its electromagnetic field. Methods to characterize the field of an antenna include testing them on outdoor test ranges or in enclosures insulated against electromagnetic radiation, called anechoic chambers. The objective of this work is to design and build an automated data acquisition system to map the field of physically small antennas such as a Contrawound Toroidal Helical Antenna (CTHA), placed inside an anechoic chamber built and maintained by the Center for Industrial Research Applications (CIRA), West Virginia University. Two antennas, a dipole in the transmitting mode and the CTHA, the antenna under test, in the receiving mode are used in the tests. The automated setup includes a rotator for mounting the antenna, a signal generator and a spectrum analyzer to analyze the signals from the receiving antenna. The rotator, signal generator and the spectrum analyzer are controlled remotely by a Visual Basic program running on a central control computer. The acquired data is presented in a graphical form, representing the field around the antenna.

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Chapter 1 – Introduction

Wireless communication has come a long way from its birth in the days of Henri Marconi. Still, the basic premise has remained the same: an antenna transmits and receives electromagnetic signals. Today's antenna technology is present in all communication devices, including mobile phones, car phones and cordless telephones, which are essentially a combination of a transmitter and a receiver. An important element of these devices is the antenna, which transmits and receives electromagnetic signals.

A radio antenna is described as "A transition device, or transducer, between a guided wave and free space wave, or vice versa, which converts photons to currents, or vice versa" by Kraus [1].

Many kinds of antennas are used in communication devices, the most common ones being whip antennas and dipoles. If the antennas used are highly effective, then these devices work more effectively. A measure of the effectiveness of an antenna is its radiation pattern. "A plot of the actual or the relative field intensity at a fixed distance, as a function of the direction from the antenna, is called an antenna radiation pattern" [2]. Typical graphical representations of the radiation patterns are in polar or rectangular coordinates, and are as shown in Figure 1.1.
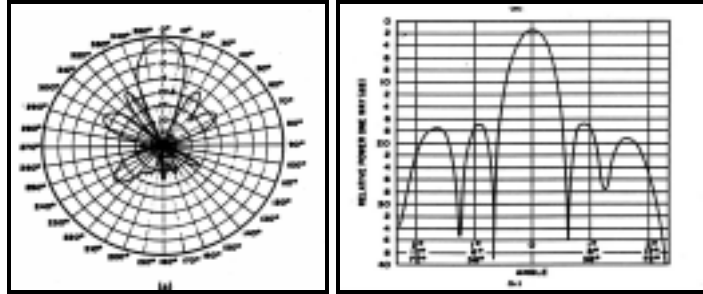
Figure 1.1 Radiation patterns in polar and rectangular coordinates [18]

The radiation pattern depends on the nature of the antenna and is different for different antennas. At one end of the spectrum, an antenna could be highly directional with its beam strength concentrated in a particular direction; at the other end of the spectrum are antennas with isotropic patterns, with the energy distributed uniformly in all directions. In cases related to mobile communications, it is desired that the antenna's radiation pattern be isotropic, i.e. uniform in all the directions, because that characteristic would reduce the directional dependence of the antenna, allowing for better reception and transmission.

In order to check if an antenna radiates as expected, it is necessary to measure its field in the required directions. Standard test procedures described by the Institute of Electrical and Electronics Engineers (IEEE) are followed to map the radiation field of antennas. These tests assume that an antenna is a "passive, linear and reciprocal device" and thus, its properties are the same when it is transmitting or receiving and can be measured in either the transmitting or receiving modes. The tests characterize the antenna by measuring the relative amplitude, relative phase, polarization, and the power gain on the surface of an imaginary sphere whose radius R, the distance from the center of the antenna, is fixed.

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1.1 Field Characterization

There are two ways of characterizing the field of an antenna. The first one is to map the field by concentrating on one frequency and mapping the amplitude variation over the imaginary sphere. The second method, called the swept frequency method, maps the field by sweeping over a spectrum of frequencies.

There are some constraints in mapping the field of an antenna. First, it is impractical to map the field over the continuous surface of the imaginary sphere, so sampling techniques are used to reproduce the field on the surface as closely as possible. A commonly used approach to overcome this limitation is to keep the frequency of operation and polarization fixed and measure the field over the entire range of (Phi) ϕ or (Theta) θ, incrementing one parameter while keeping the other fixed. If the increments are small enough, then for all practical purposes, the field of the antenna is mapped. Second, the field of the antenna might be time varying. This is side stepped by assuming that the field of the antenna is time invariant. Next, the influence of the environment in which the antenna is being tested. The presence of extraneous electromagnetic fields would change the field of the antenna. So, the antenna has to be tested in an environment where such fields are a minimum.

One of the common methods of characterizing an antenna's field is to test it inside an anechoic chamber. An anechoic chamber is an enclosure lined with radiation-absorbing material to minimize reflections and external signals so that the radiation from the test antenna is incident on the receiving antenna. In other words, an anechoic chamber

creates an almost ideal free space environment for testing an antenna. There are two basic types of anechoic chambers, rectangular and tapered anechoic chambers. The choice of the chamber depends on the application. For this work, a rectangular anechoic chamber is used. An illustration of a basic rectangular anechoic chamber available in the market is given in Figure 1.2.
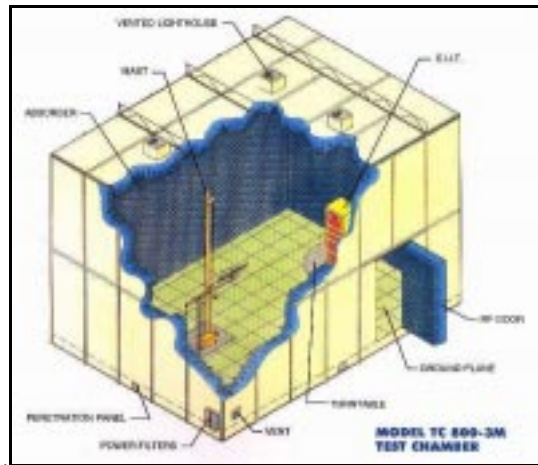
Figure 1.2 Typical anechoic chamber [19]

The radiation absorbing material that is used to line the interior of the chamber is typically pyramidal in shape and the actual picture of the absorbing foam is given below in Figure.1.3. Figure 1.4 depicts several functional anechoic chambers.

Figure 1.3 Typical radiation-absorbing materials

Figure 1.4 Anechoic chambers in use at various test centers

The above pictures show the various applications that the anechoic chamber could be put to. The first two chambers in the first row are at Panashield Incorporated and the pictures that are illustrated here show them put to use to test cars and computers. The third picture in the first row shows an anechoic chamber at the Department of Acoustic Technology, Technical University of Denmark. This is used for free-field reciprocity calibrations of laboratory standard microphones. The first picture in the second row shows an anechoic chamber at the University of Stuttgart, Germany. The next picture in the second row shows an anechoic chamber at the Rayproof Industries. The last picture shows an anechoic chamber at the AIL systems, used for testing the radiation patterns from an aircraft. As illustrated in those figures, the size of anechoic chambers can range from a small room sized unit to a large building.

A positioner is used to control movement of the device under test for accurate measurements. The following pictures in Figure 1.5 illustrate the positioners that are available in the market and used by various testing agencies for varied applications. The

illustrated positioners are made by the RPM – PSI industries. The positioners shown here are very large in size and are used for positioning dimensionally large and heavy objects.

Figure 1.5 Various commercially available antenna positioners[20]

1.2 Objective

The objective of this work is to design an automated instrumentation and data acquisition module for testing and analysis of physically small antennas, more specifically the CTHA, placed inside an anechoic chamber, built at West Virginia University and maintained by the Center for Industrial Research Applications (CIRA).

As evident from Figure 1.5, most positioners are metallic; a design with minimal metal is needed for the same in order to map the field of the antenna. Also, these positioners are big and bulky and are not dimensionally matched with the antennas. Finally, these positioners are expensive and exceed the budgetary limitations of the project. This work involved design and construction of a positioner on which the test antennas could be mounted and a data acquisition module running on a desktop personal computer, for the collection and analysis of the data from the chamber.

1.3 Setup

The anechoic chamber built at West Virginia University is rectangular in shape and has external dimensions of 8ft×8ft×18ft. In order to map the field to the maximum possible accuracy, limited by various constraints, it is important that the chamber does not have any components that might affect the radiation pattern of the antenna under test. This requirement virtually eliminates the possibility of using commercially available positioners since most of them are metallic and have the drive motors built into them as an integral part. This is not desirable as the motors themselves produce their own electromagnetic field, which would alter the field of the antenna. Also most of them are not suited dimensionally for the purpose as the emphasis is to test physically small antennas like the CTHA. It thus becomes important that the material the positioner is made of exerts a minimal influence on the field of the antenna under test. Materials such as fiberglass, Teflon, and certain polymers have a low dielectric strength and thus exert only a negligible influence on the field. In this work, fiberglass is chosen over other materials because it is the least expensive and most readily available of the materials. For driving the positioner, stepper motors with a stepping angle of 0.9 degrees/step are used. A nuLogic drive controller/amplifier is interfaced with a computer and controls the working of the motors through software written specifically for this purpose.

The radiation pattern is acquired by means of a Hewlett Packard spectrum analyzer, model number 8594E. It is interfaced to the same computer that controls the motors through a National Instruments General Purpose Interface Bus (GPIB) card,

model AT-GPIB/TNT. The settings on the analyzer are controlled by software written in Visual Basic using the NI 488.2 specifications.

The setup consists of a spectrum analyzer and a signal generator connected with the GPIB card on the computer. The motion control card is also mounted on the same computer. A single program written in Visual Basic running on the Windows 95 environment controls the entire setup.

Chapter 2 – Literature Review

The development of electromagnetic radiation absorbers and anechoic chambers is well documented by Emerson [6]. The first known radiation absorbing material was developed and patented in the 1936 at the Naamlooze Vennootschap Machinerieen in The Netherlands and was a quarter wave resonant type for the 2-GHz region. It used carbon black for dissipation of energy and TiO for achieving a high dielectric constant, which reduced the thickness of the foam. Further improvements on the design and fabrication of such radiation absorbing materials was made during the World War II by researchers in United States and Germany.

Neher [7] improved the accuracy of anechoic chamber test measurements by covering the inner walls of a pyramidal shaped structure with an absorbing material. Neher then showed that the level of the signals that were reflected to a test region at the aperture of the structure was much lower than the reflections from a panel of the same absorber at normal incidence. The fall in the signal level is due to the fact that the pyramidal geometry gives rise to multiple reflections in the direction of the apex of the pyramidal structure. As a result of multiple reflections the signals get absorbed more at each reflecting surface and their amplitude decreases with each reflection to a point where it becomes insignificant at the apex of the pyramidal structure.

Testing and mapping the radiation pattern of antennas is a major part of research work in many cases. Even though the fundamental goal is to measure the electric or the magnetic fields at different points in space, the techniques to do so differ, depending on

the nature of the region under consideration, the representation of the measured data, inclusion or the exclusion of the polarization information. This is in addition to the amplitude of the field at that point in space and some measurements where only the relative field strengths are measured. Tests on antennas could be roughly classified into three categories as diffraction and scattering by obstacles, reflection and transmission at boundaries between materials, termed as "fundamental phenomenon", and the measurement of aperture, near field radiation patterns and current distributions related to antenna design. Diffraction results when the radiation from the transmitting antenna encounters an obstacle in its path to the receiving antenna. The extent of the diffraction is described by the electric or magnetic field strength defined by the amplitude, phase and the polarization at various points in the vicinity of the obstacle. Scattering may be caused by an obstacle placed in the path of the radiation from the transmitting antenna. The effect of this scattering depends on the nature of the obstacle. In addition to the scattering and diffraction of radiation, the effects of transmission and reflection are also important from both the theoretical and practical point of view. Both phenomena occur in everyday use of antennas and so it is important that the effects on the radiation pattern are studied in detail. These are discussed in detail with experiments by Cumming [5].

Anechoic chambers have been used to test the performance of antennas since the late 1940s. Initially the tests were done manually but with time and the advent of computers, automation of these tests was natural.

Conti and Dowling [8] described one such automated antenna test range. The test setup consisted of a central control computer into which commands were entered by

means of punch cards. The computer controlled a two or three axis antenna mount by means of a digital-to-analog converter interfaced to control units capable of precisely moving the antenna mount to desired locations. The received data at the antenna was representative of the amplitude and phase and was presented visually and in digital formats. The central computer controlled the frequency and the polarization of the transmitted signal. The control program was done using a language called FORTH running on the Hewlett Packard operating system DOS-IIIC. This method provided a wide range of automated tools when testing antennas.

Taylor and Passimo [9] describe a very good example of automation of the anechoic test facilities at the Edwards Airforce Base, California. This chamber is very large in size and is designed to test the patterns of aircraft antennas, which, in essence, are the antennas under test. The programming is done using the HP graphical programming language called HP-VEE, where VEE stands for Visual Engineering Environment. The chamber is lined with a radiation absorbing material to minimize the effects of reflections off the walls and to simulate an almost free space environment for testing. The tests are conducted by means of the control program run on a centralized computer capable of coordinating different peripherals connected to the test system. The automation of the test procedure by means of programming in the HP-VEE environment reduced the time taken for the tests by about 80%, the entire procedure was made very user friendly and human factors in the computations were reduced, resulting in greater accuracy in measurements. This strongly argues for automation of the test facilities.

Earle [4] describes the construction and working of a computer controlled anechoic chamber. The chamber works on the principle of reciprocity of an antenna, which states that an antenna's characteristics are the same in the transmitting or the receiving mode. In this case, the antenna is installed on a shaft connected to a rotator that is capable of sweeping 360° about its axis and the field is sampled every 3°. The test is conducted with a transmitted signal of frequency 1 GHz, modulated by a 1 kHz message signal. The position of the rotator is tracked by means of a wiper that is connected to a potentiometer and the voltage signal from the potentiometer is converted into a digital signal by means of an A/D converter and fed into the control computer. The set up has an antenna interface circuitry consisting of an envelope detector, a band pass filter and a linear rectifier. The envelope detector eliminates the negative amplitude components of the received signal while the band pass filter makes sure that frequencies other than the 1KHz message signal are filtered. The rectifier circuit converts the peak-to-peak variations to corresponding dc signals in the voltage range 0 – 5 volts and feeds the 0804 successive approximation analog-to-digital converter. Testing begins with an initialization procedure followed by the antenna data acquisition procedure. The user can choose between two modes of acquiring data from the system. The first procedure records the data continuously and then displays it as a percentage of the highest recorded signal. Also, sounds are generated with the pitch proportional to the recorded amplitude values. In the second procedure, data is acquired at intervals of 3° as the shaft rotates and the information is stored in a relative data array that is initialized during the initialization procedure and continues till the rotator sweeps 360°. The recorded data is plotted in

rectangular coordinates as well as a polar plot to be displayed either on the screen or printed.

Yan et. al [10] discuss another example of automation of the anechoic chamber for test purposes. This article discusses the use of movable probes in anechoic chambers. It consists of a movable test probe that can scan a planar area 1.5 m×1.5 m via stepper motors and can be placed inside the anechoic chamber. The main objective of this work was to calculate the far field radiation pattern from near field data. The setup consists of a pair of stepper motors that are driven by a central computer to move the probe antenna over the planar surface. The measuring equipment is a vector network analyzer also interfaced to the computer. The backbone of communication between the central control computer and the network analyzer for data transfer and instructions is the IEEE 488 interface supported by a General Purpose Interface Bus (GPIB) with data transfer rates of up to 1 megabyte per second. The antenna under test built at the C-CORE, operates at a frequency of 1.29 GHz and the test probe is a monopole with a length of 0.1λ and is mounted on the stepper motor drive to be positioned anywhere in the planar test region. From the near field data collected, the far field patterns are generated by means of Fourier transforms.

Myers [11] describes in detail an automated antenna test facility developed by the Emerson electric company. The chamber is split into three sections with one section to house the chamber and two to contain the upper and lower control rooms. The lower control room contains the signal generating equipment, controllers and the central control computer. The upper control room has facilities to move the antennas to the desired

positions. The signal generation revolves around a Hewlett-Packard 8409B-network analyzer and the generated signal is pulse modulated by an external pin diode switch. The chamber is designed to cover a wide range of frequencies and involved four antennas mounted on a carousel with an aluminum support structure and for anechoic walls. The alignment of the antennas is achieved by means of a theodolite aligned with the center of the chamber.

The test setup is controlled by means of a software program written in HP Enhanced BASIC language. The communication between the computer and the network analyzer is by means of the IEEE 488 bus and the data acquisition from the test antenna is by the RS 232C interface at a speed of 300 baud. The rotation is achieved by means of a stepper motor also controlled by the computer through a 16 bit parallel interface.

The best description of an automated antenna test facility can be found in the article by Geen and Smith [12] where the design of a small low cost anechoic chamber is described. The chamber can be dismantled and moved from one place to another with ease. The chamber is designed to operate in the range of 18-30 GHz, which effectively reduces the size of the chamber to manageable dimensions of 2.25 m×1.20 m×1.20 m. The length-to-width ratio is maintained at an approximate 2:1 ratio to provide good electrical performance without much increase in the cost of absorbing material. The chamber is built on a wooden skeleton with aluminum sheets providing the external walls to provide mechanical strength. The sides of the chamber are constructed individually and can be joined by means of hinges and allow the walls to swing 180° to provide a good view of the interior of the chamber. The walls of the chamber are covered with

pyramidal shaped radiation absorbing material to simulate a near free space environment. The chamber is characterized by using the VSWR technique with a standard gain pyramidal horn antenna serving as the reference antenna. The test setup is as illustrated below.
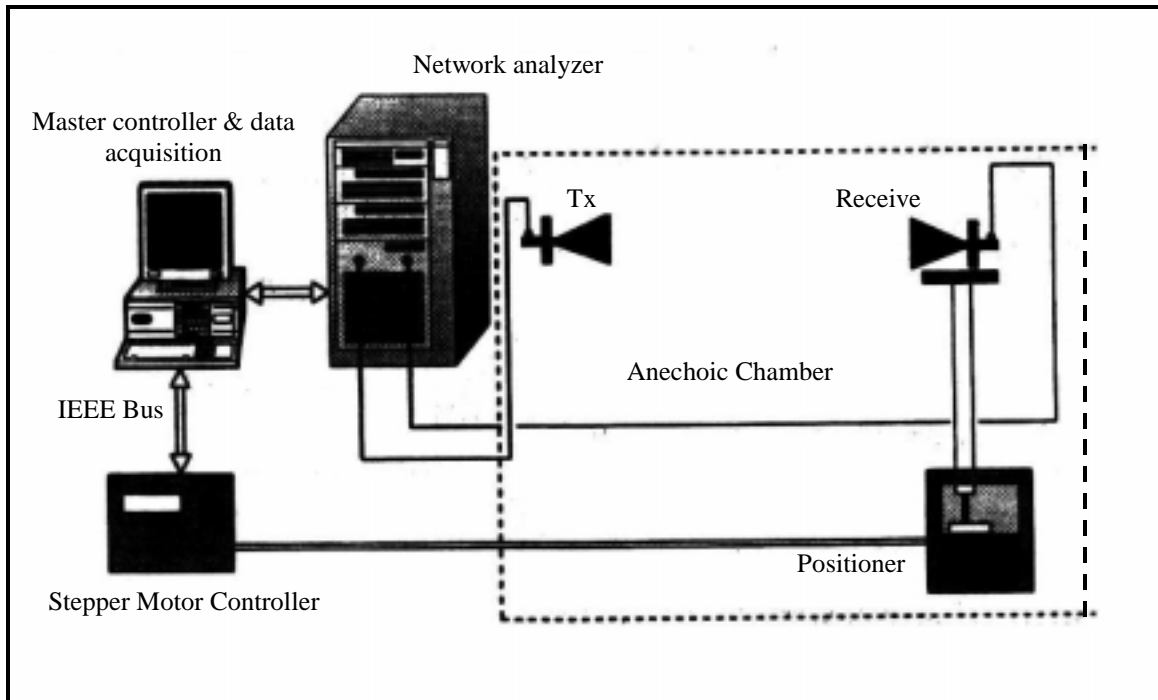
Figure 2.1 Antenna radiation pattern measurement setup [12]

The automated antenna pattern measurement setup consists of a personal computer that serves as the central controller, a vector network analyzer and control circuitry. These components are interconnected by means of the IEEE 488-interface bus. The operator can control all the operating parameters of the setup including the antenna position and data collection. The reference antenna as well as the antenna under test is connected to the network analyzer. The reference antenna is capable of longitudinal and rotational motion. The antenna positioner on whom the test antenna is mounted is capable

of providing only the azimuth plots and the elevation plots are obtained by turning the antenna through 90° about the axis of rotation of the positioner.

Chapter 3 – Computer Interface Procedures

This chapter discusses the tools that are available to control the positioner and also to interface the RF instrumentation with the computer.

Establishing an antenna test facility is one of the first steps in characterizing the antenna itself. The process involves the selection of appropriate RF instrumentation, data acquisition systems, positioning systems and an overall controller. In addition, appropriate testing environments for both near field and far field characterization need to be created.

As mentioned in the first chapter, antennas can be tested in either the transmitting mode or in the receiving mode. So, for testing purposes, two antennas are needed, one for transmitting and the other for receiving. To excite the transmitting antenna a source of RF energy is needed and depending on the type of antennas that are being tested, the requirements of the source vary. The signal generator used in this project is GPIB compatible and can be operated remotely by a computer.

The next component of the test setup is the receiver. There are two kinds of receivers that could be used with the test setup, scalar receivers and vector receivers. A scalar receiver is one that is capable of making only the amplitude measurements while the vector receiver can make both the amplitude and phase measurements. Vector receivers are more expensive than the scalar versions, but are much more accurate and rugged. For most antenna tests, phase measurements are not needed, so, scalar receivers are sufficient for obtaining gain measurements.

Spectrum analyzers and scalar network analyzers are typical scalar receivers. They offer much more dynamic range and sensitivity as compared to simple crystal detectors. Though they can make only amplitude measurements, they are extremely accurate and cost about one third of a phase coherent receiver.

3.1 Motion Control

The next step involves the control of the operation of the motors that position the antenna mounted on the table. ValueMotion motion control board manufactured by National Instruments is used for that purpose. These boards are capable of providing fully programmable motion control for up to four axes at the same time with additional provisions for I/O for limit and home switches. These boards can be used for point-to-point positioning, velocity profiling, and event based motion profiling. The board that is used in this project is a 4 Axis Open Loop Stepper board (PC- Step-4OX) and is capable of controlling up to four stepper motors at the same time. Detailed description of the board can be found in the reference [18].

3.1.1 Visual Basic Example for Motion Control

An example program, which illustrates the concepts of motion control using the command set provided with the board, is given below.

```
Private Sub MnuMotors_Click  ()
' Initialize the motors...
   ' Set Position Mode.
      'Set the motion in the Absolute mode of operation.
        Status = set_pos_mode (1, 3, 0)
        Status = set_pos_mode (1, 4, 0)
   ' Set Stop Mode
      ' A value of 2 is for setting the stop mode
```

```
            ' in the halt mode...
            Mode = 2
            Status = set_stop_mode (1, 3, Mode)
            Status = set_stop_mode (1, 4, Mode)
        ' Set the limit switches polarity.
            ' Set the entire limit & home switches in the non-inverting mode.
            Status = set_lim_pol (1, 4095)
        ' Enable limits.
            ' Enable all limit & home switches.
            Status = enable_limits (1, 4095)
        ' Initialization steps that have to be executed
        ' before operating the motors.

        ' Load Steps/Rev
            steps = 720
            Status = store_steps_rev (1, 3, steps)
            Status = store_steps_rev (1, 4, steps)
        ' Load acceleration.
            Status = load_accel (1, 3, 1)
            Status = load_accel (1, 4, 1)
        ' Load RPM.
            rpm = 10
            Status = load_rpm (1, 3, rpm)
            Status = load_rpm (1, 4, rpm)
        ' Load the MotorInit form to find home.
            Load Form8
    End Sub
```

The above program is written in Visual Basic and is a part of a larger program that is used to interface motion control with the Interface Bus applications. The purpose of this module is to initialize the motion control board so that the trajectory of the positioning system could be controlled remotely by computer. The initialization procedure for the basic per axis or board level operation has to follow a certain sequence recommended by the manufacturer, which is given below. As a ValueMotion stepper board is used in this application, the procedure pertaining to this board only is given here. The initialization procedure for other boards could be found in the ValueMotion software reference manual, published by National Instruments.

The motion control board responds to many other commands and features that could be used to enhance the performance of the system. Detailed descriptions of such functions could be found in the Motion Control software reference manual [17].

3.2 GPIB introduction

The National Instruments GPIB board on the computer controls both the signal generator and the spectrum analyzer. The user inputs the desired settings on these instruments through a controller program and sends these commands to the respective instruments through the GPIB cable. The instruments respond to these by sending back the pertinent information to the central control computer.

3.2.1 Visual Basic Example for GPIB Application

A simple example written in Visual Basic illustrating the use of the Interface Bus in controlling the working of a signal generator is given. In this example, only a few functions of the entire command set are made use of. In most of the applications, this is the case.

```
Private Sub cmdSigGenerator_Click ()
Text1.Text = ""
Text5.Text = ""
   'Check for the status of ud1. If ud1 is 0 then initialize the
   'Board, else continue with other things...
  If ud1 = 0 Then
     Screen.MousePointer = vbHourglass
     ibfind "gpib0", ud1
     ibsic ud1
     ibrsc ud1, 1
     ibsre ud1, 1
     ibdev 0, 19, 0, 13, 1, 0, ud3
     Screen.MousePointer = vbDefault
        If ud3 = -1 Then
```

```
            Msg = "Error In Initializing"
            Style = vbOKOnly
            Title = "Signal Generator"
            Response = MsgBox (Msg, Style, Title)
         Else
            Msg = "Signal Generator Initialized"
            Style = vbOKOnly
            Title = "Signal Generator"
            Response = MsgBox (Msg, Style, Title)
         End If
       Else
       ibdev 0, 19, 0, 13, 1, 0, ud3
       ibwrt ud3, "*TST?"
         If ud3 = -1 Then
            Msg = "Error In Initializing"
            Style = vbOKOnly
            Title = "Signal Generator"
            Response = MsgBox (Msg, Style, Title)
         Else
            Msg = "Signal Generator Initialized"
            Style = vbOKOnly
            Title = "Signal Generator"
            Response = MsgBox (Msg, Style, Title)
         End If
       End If
    End Sub
```

In the above program, the commands that are italicized and are bold are GPIB commands that are used to initialize the signal generator. More specifically, these commands are a part of the NI 488.2M-command set supported by the AT-GPIB/TNT Interface Bus board, made by National Instruments.

In this chapter the tools for motion control and interfacing the RF instrumentation to the computer were identified. A Motion Control interface card and its associated software, manufactured by National Instruments was used to control the motors that drive the positioner. The interfacing of the signal generator and the spectrum analyzer to the computer was achieved through the GPIB protocols, as illustrated in the above example.

More details on the GPIB protocol can be found in reference [16] and the command set used to control the motors through the Motion Control card can be found in the function reference manual from National Instruments [17].

Chapter 4 – Design

This chapter deals with the design and the working of the measurement system, including the instrumentation, data acquisition system, and the position controller. As mentioned before, the system consists of the positioner placed inside the anechoic chamber and a data acquisition and control module outside it. The positioner, as the name suggests, positions the antenna under test. Once the antenna under test is at the desired position, the amplitude measurements are made by means of the data acquisition module. The antenna is then moved to another position and new measurements are made. This process is repeated till the antenna's field is sampled. The resulting plot is representative of the field of the antenna under test.

4.1 Setup

In order to map the field to the maximum possible accuracy, limited by various constraints, it is important that the chamber does not have any components that might affect the radiation pattern of the antenna under test. This requirement virtually eliminates the possibility of using commercially available positioners since most of them are metallic and have the drive motors built into them as an integral part. This is not desirable as the motors themselves produce their own electromagnetic field, which would alter the field of the antenna. Also most of them are not suited dimensionally for the purpose as the emphasis is to test physically small antennas like the CTHA. It thus becomes important that the material the positioner is made of exerts a minimal influence on the field of the antenna under test. Materials such as fiberglass, Teflon, and certain

polymers have a low dielectric constant and thus exert only a negligible influence on the field. In this work, fiberglass is chosen over other materials because it is the least expensive and most readily available of the materials. For driving the positioner, stepper motors with a stepping angle of 0.9 degrees/step are used. A nuLogic drive controller/amplifier is interfaced with a computer and controls the working of the motors through software written specifically for this purpose.

The radiation pattern is acquired by means of a Hewlett Packard spectrum analyzer, model number 8594E. It is interfaced to the same computer that controls the motors through a National Instruments General Purpose Interface Bus (GPIB) card, model AT-GPIB/TNT. The settings on the analyzer are controlled by software written in Visual Basic using the NI 488.2 specifications.

The setup consists of a spectrum analyzer and a signal generator connected with the GPIB card on the computer. The motion control card is also mounted on the same computer. The entire setup is controlled by one program written in Visual Basic running on the Windows 95 environment.

4.2 Anechoic Chamber

A rectangular anechoic chamber was built for the purpose of testing the CTHA and some physically small antennas such as dipoles for frequency ranges in the region of 900 MHz and above, and the Contrawound Toroidal Helical Antenna (CTHA) at the Center for Industrial Research Applications (CIRA), West Virginia University. A rectangular chamber was chosen because the pattern generated by the CTHA is nearly isotropic, has circular polarization characteristics at certain frequencies and a rectangular

chamber minimizes the reflections from the walls, reducing the effects of interference. The chamber is made of wooden walls, has external dimensions of 8ft×8ft×18ft and doors that allow the user to mount antennas at the transmitting and the receiving ends. The transmitting antenna is placed at a distance of 0.66m (2 feet) from one wall and at a height of 1.33 m (4 feet) from the floor of the chamber and the test antenna was placed in a similar way at the other end of the chamber. The interior of the chamber is lined with the radiation absorbing foam, pyramidal in shape and 1 foot thick, supplied by EMC Test Systems. This foam is glued to the wall with special glue, which does not affect the field. The chamber houses the positioner on which the test antenna is mounted. The anechoic chamber at West Virginia University is shown in figures 4.1a and 4.1b.

Figure 4.1a Anechoic chamber at West Virginia University

Figure 4.1b Anechoic chamber at West Virginia University

4.2.1 Positioner

The design and the fabrication of the positioner and interfacing this with the controller are the next step in the project. As mentioned in Chapter 1, the need for designing and fabricating a new positioner, rather than procuring one from the market is due to the fact that most of the available positioners are almost entirely made of metal. This results in the positioner affecting the field of the antenna under test. So, to design a positioner that has a minimal effect on the field of the antenna under test, various parameters are to be considered before selecting the material for the positioner. In most of the other test facilities, thin threads suspend the antenna under test. This, would eliminate the effect of dielectrics on the field of the antenna under test, also eliminates the capability to automate the test facility. So, a compromise was reached by designing a positioner that would allow automation and at the same time exert minimal influence on

the field. Materials that have a low dielectric constant, such as Styrofoam with a dielectric constant of 1.05, exert the least influence on an electromagnetic field. Although this is true, a downfall of Styrofoam is that it is not easily machinable and thus cannot be shaped to meet the design requirements. Other materials that would exert minimal influence on the field are polymers like TEFLON and Plexiglas or composites like fiberglass. TEFLON has a low dielectric constant in the frequency range of operation of the anechoic chamber, but does not have adequate mechanical properties and is expensive. Plexiglas and fiberglass both satisfy the requirements, but the best material suited for this purpose is fiberglass as it is easily available, inexpensive and easily machinable.

The positioner can be divided into two components as the rotator and the table. The rotator supports the table and revolves about its axis, and supports the table on which the antenna is mounted. The table on the other hand is pivoted on the rotator and is capable of tilting about the pivot. A combination of this tilt and the rotation of the rotator result in a sphere being described by a reference point on the table. If the antenna under test were placed on the table, then a reference point on the antenna would describe a sphere with its center coincident with the center of the table. The table is positioned in such a way that its center lies exactly on the axis of rotation of the rotator.

The rotator is made of fiberglass tubing with outer diameter of 1" and an inner diameter of 0.75" and is 4' in length. The rotator is positioned within a sleeve that is made of fiberglass and provides physical support to the frame of the rotator. The rotator assembly is shown in Figure 4.2. The table, made of Plexiglas, is rectangular in shape and has dimensions of 2"× 2"×0.25", and is mounted on the rotator using plastic pivots. The

table has evenly spaced holes in a rectangular grid so that antennas of different shapes and sizes can be mounted on it. A pair of plastic bevel gears with a ratio 1:4 is used to tilt the table. The larger bevel gear is actually cut in half and is fixed to the table. A fiberglass shaft runs through the middle of the rotator and culminates in the smaller gear. These two gears are coupled to achieve the tilting motion of the table. The shaft that runs through the center of the rotator is coupled directly to a motor that is controlled by the computer. The tilt motion is contained within the allowable mechanical limits by means of limit switches that are connected to the motion control board on the computer. There are two limit switches that indicate the two limits of motion. One of these is designated as the home switch and the other as the forward limit switch. These switches are positioned in such a way that the table is in the horizontal position, with the normal to the plane of the table coincident with the axis of rotation of the rotator. The computer sets the tilt angles of the table. Mechanical limitations on the movement of the table restrict the tilt angles to about +85 to –85 degrees from the home position of the table. Double-ended stepper motors are used for motion control through the computer. The position of the table is tracked by mounting gears on the other end of the shaft of the motor. A pair of gears in the ratio 1:4 is used for this purpose. The smaller gear is mounted on the motor while the larger one is fixed on to a reference frame that also houses the limit and home switches. The larger gear has a lever fixed on it in such a way that it trips the home switch, the forward, or the reverse limit switch.

The entire setup for the tilt motion is mounted on a reference frame that rotates with the rotator assembly, as it turns. The rotary motion is achieved by means of a stepper motor, remotely controlled by the motion control board on the computer. The motor used

here is similar to the one used for tilting the table. The rotator assembly is actually mounted on a metallic turntable, which is then coupled to the motor with a belt and pulley. As in the case of the table, there is a lever mounted on the turntable that trips the home and limit switches. The motion of the rotator setup is tracked with these switches.

Mechanical drawings of the positioner and the related components of the rotator assembly are given in the following pictures. Figure 4.2 shows the entire rotator assembly.
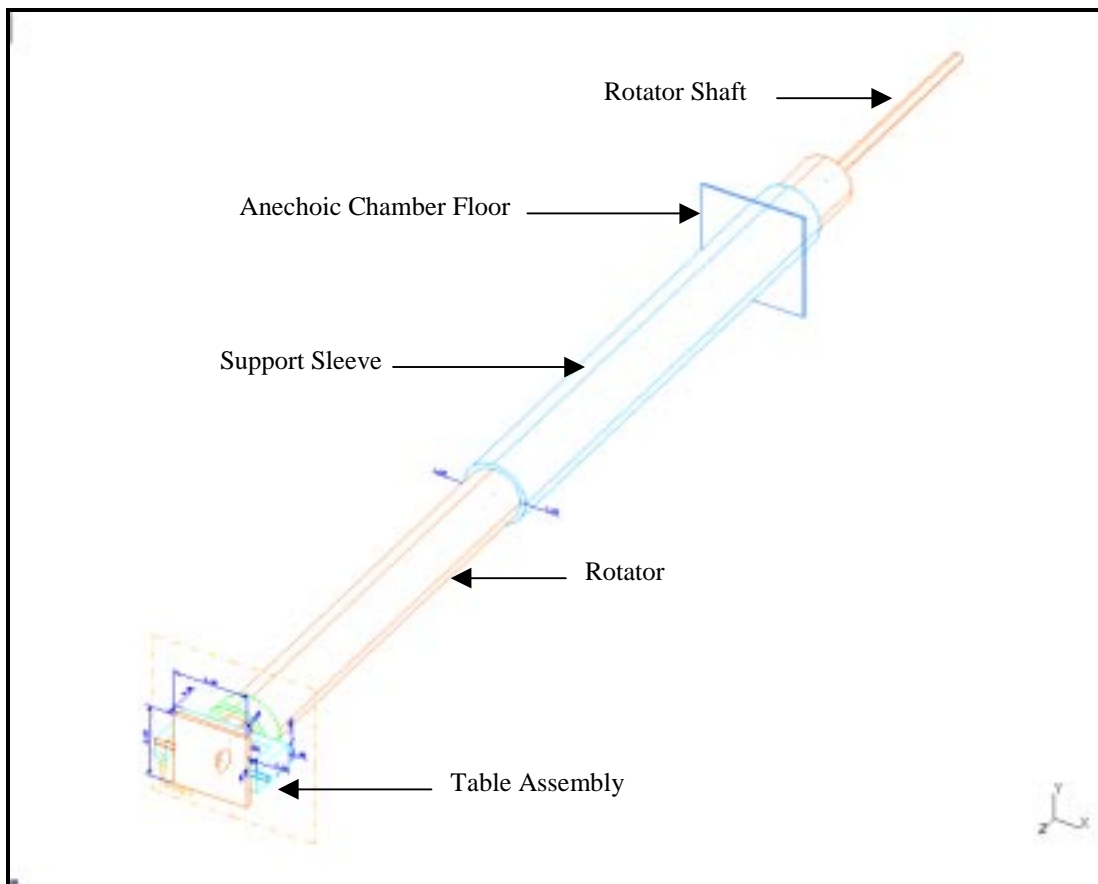
Figure 4.2 Positioner assembly

Figure 4.3 gives a magnified view of the top of the rotator and shows the arrangement of the table, table support, pivots and the bevel gear arrangement. Figure 4.4

shows the bevel gear arrangement on top of the rotator shaft. These gears are used to tilt the table to the desired position. Figure 4.5 shows the table assembly in close detail and Figure 4.6 shows the rotator, rotator support and rotator shaft.
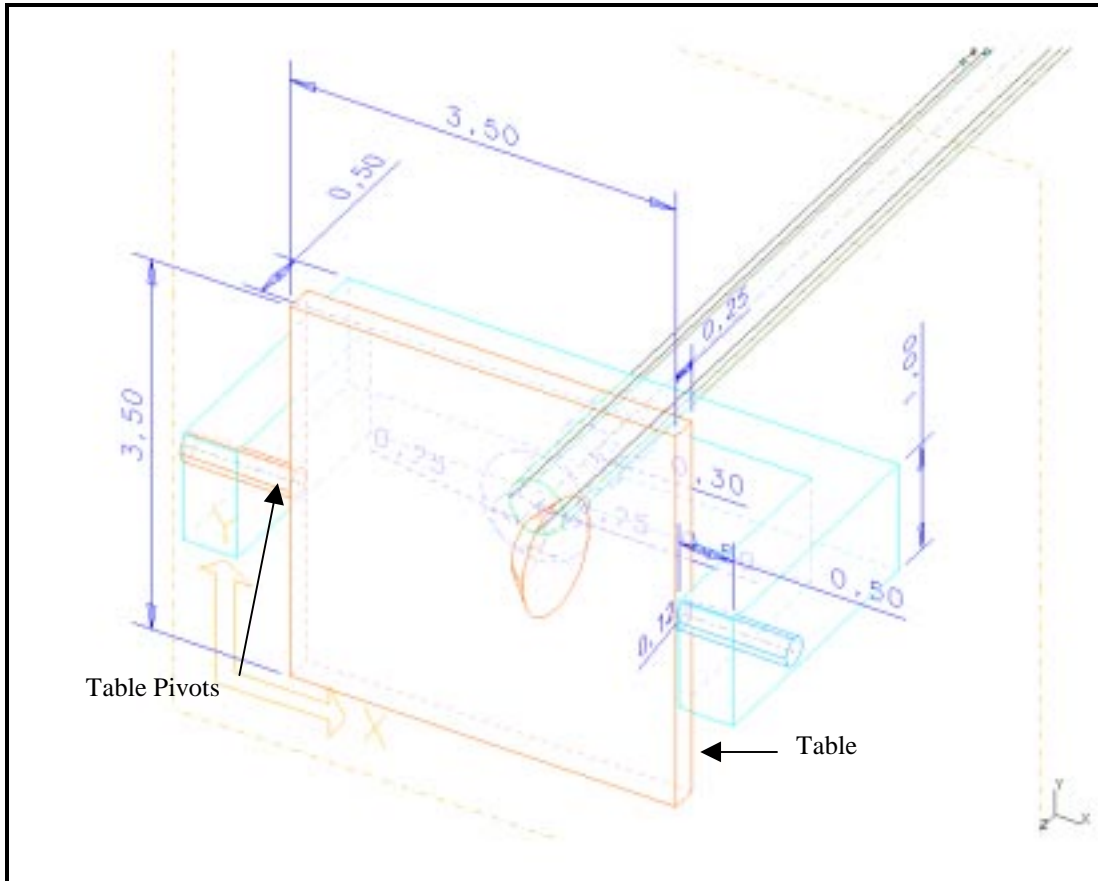
Figure 4.3 Close up view of the top of rotator
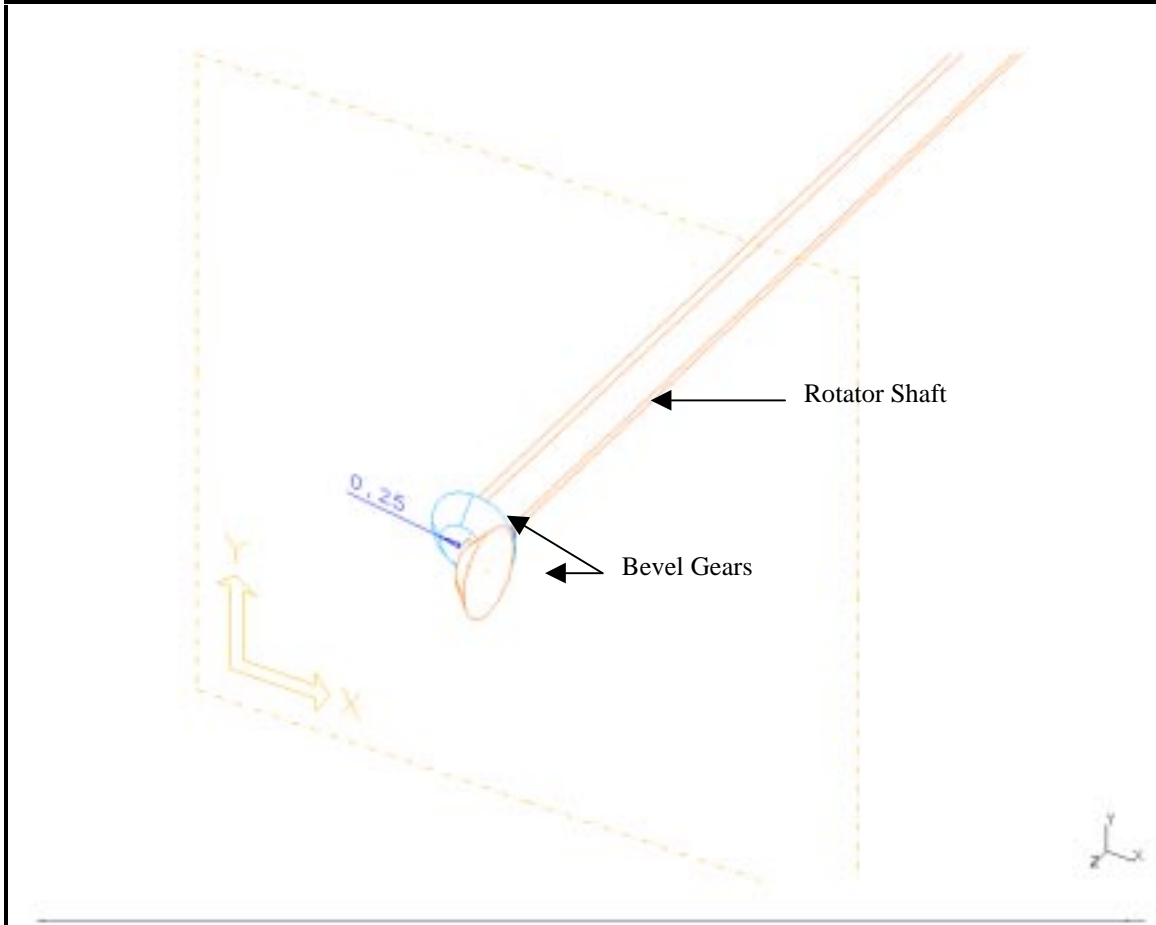
Figure 4.4 Bevel gear arrangement on the shaft
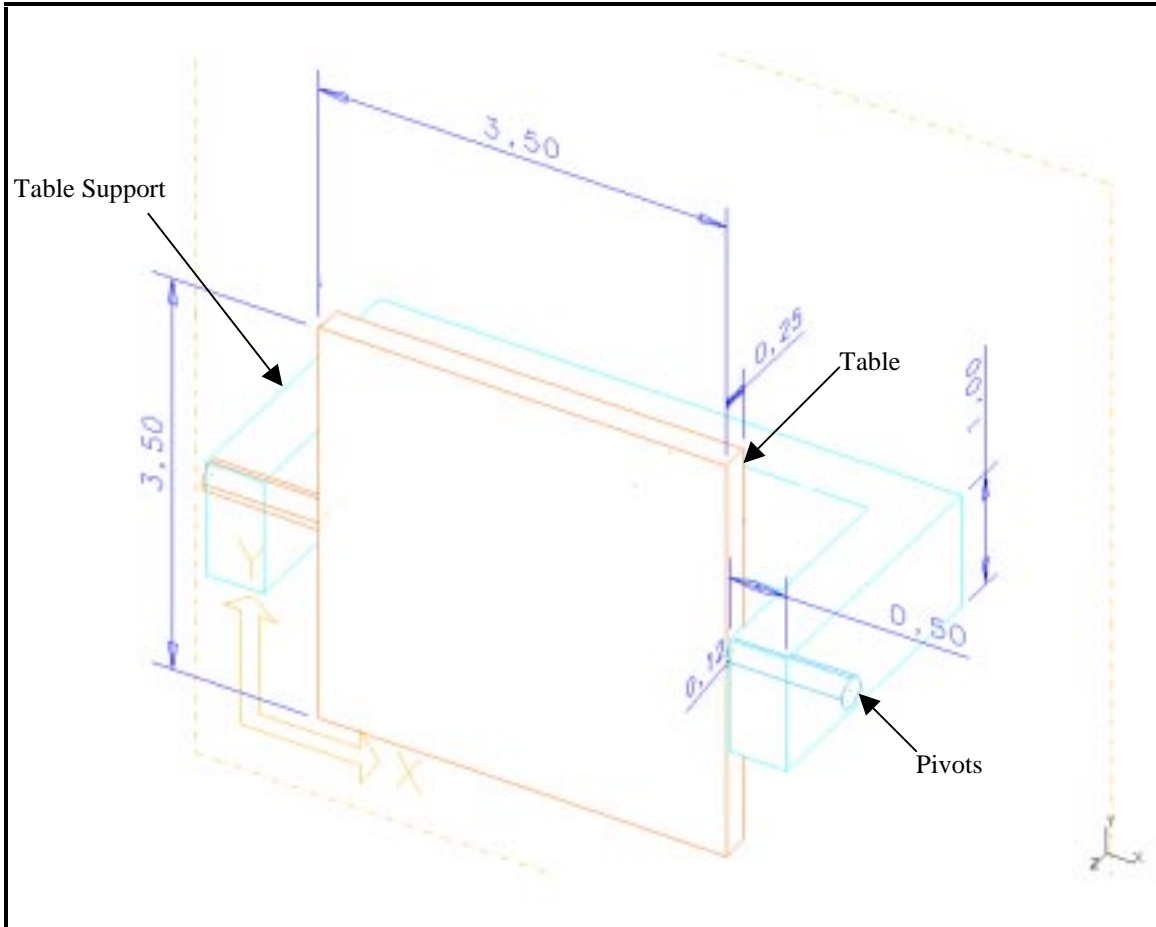
Figure 4.5 Close up of table and supports
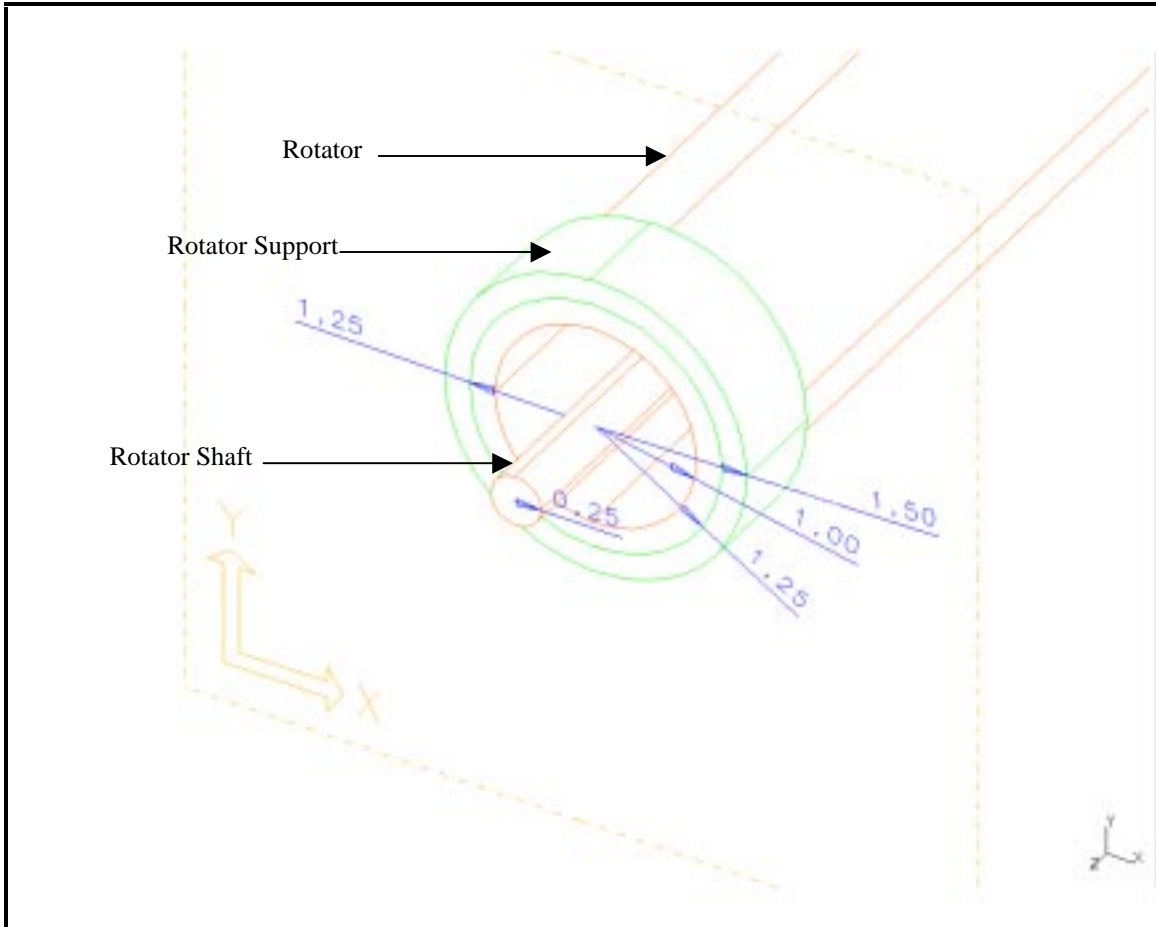
Figure 4.6 Close up of the shaft, rotator and support

Floor of the Anechoic Chamber ——————
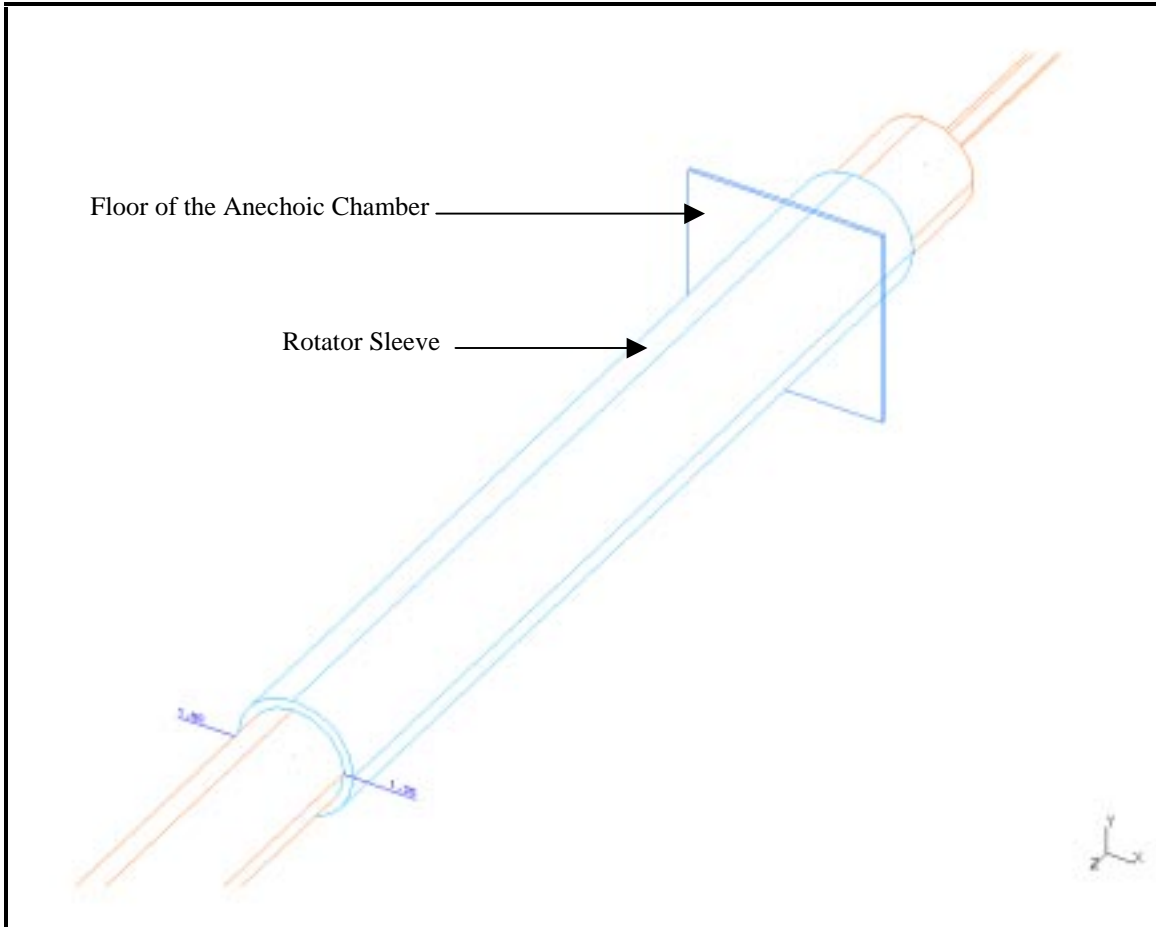
Rotator Sleeve ——————

Figure 4.7 Close up view of rotator support sleeve, floor and shaft

In Figure 4.7, the lower portion of the rotator assembly is shown. The rotator shaft can be clearly seen, extending out from the rotator.
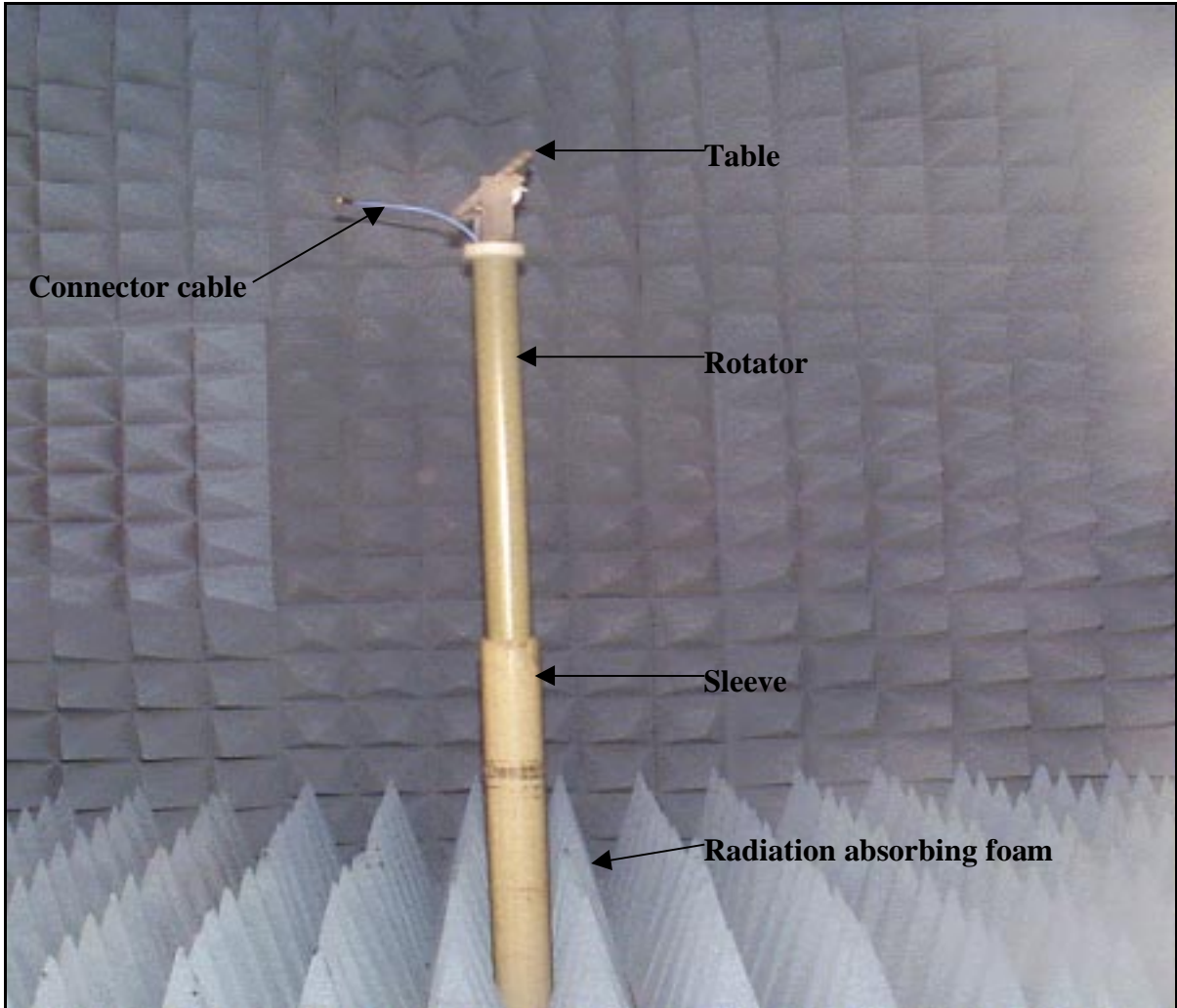
Figure 4.8 Rotator assembly placed inside the anechoic chamber

Figure 4.9 shows the setup of the drive motors and the location of the limit switches on the rotator.

Figure 4.9 Motor and limit switch assembly on the rotator

Figure 4.10 is a close up view of the table on which the antennas are mounted for testing. The blue cable connects the antenna to the spectrum analyzer. There are holes drilled in a grid fashion on the table and are used to hold antennas to the table and also allows the user to fix antennas of various sizes on to the table. The figure also shows the plastic pivots about which the table can rotate. This can be used to tilt the table and sample the field of the antenna for different values of the elevation angle θ.
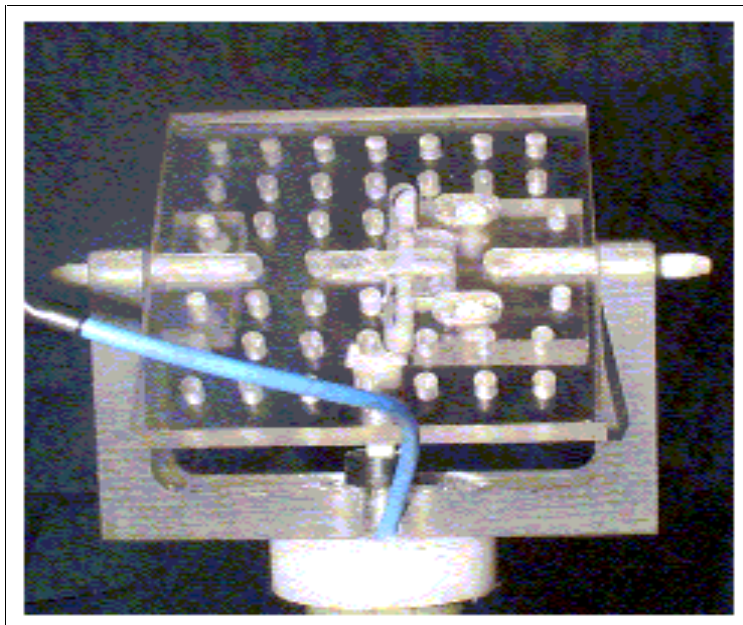
Figure 4.10 Table for mounting antenna under test

4.3 Software

A software code was written in Visual Basic to coordinate the functions of the components of the system. The program is composed of different forms that perform a particular function by themselves.

Form #1; the Interface form is the main form from where the user can access other utilities in the program. This form can take in the name of the user, the description of the test from the user and also the memory location where the data file is to be stored. The parameters that are set on the spectrum analyzer, signal generator and the motion controller are displayed on this form to provide the user an easy lookup of the operating conditions.

Other forms are used to initialize the components of the system and to set the various parameters on them like the marker frequency on the spectrum analyzer, the frequency on the signal generator, and the sampling interval on the position controller. The details of the program including the Visual Basic code and the forms are provided in Appendix B.

Chapter 5 - Experimental Results

This chapter discusses the results that were obtained from the tests conducted in the chamber and how they compare to the results predicted from numerical modeling.

The anechoic chamber that was used to conduct the tests is located at the WVU hangar and is designed to operate in the frequency range above 900 MHz range, which corresponds to a wavelength of approximately 0.33m. The chamber thus accommodates more than ten times the wavelength, a requirement for a plane wave assumption on the aperture of the test antenna. The tests were conducted using a standard dipole constructed to resonate at 901 MHz and the CTHA tuned to resonate at 901 MHz. A dipole resonating at 901 MHz was used as the transmitting antenna. The input energy was fed to the transmitting dipole from a signal generator and the signal at the receiving antenna was fed to a spectrum analyzer. The positioning of the antenna is achieved by means of a position controller. A central computer controls all these components. The signal generator and the spectrum analyzer are connected to the computer by means of the HPIB cable and the GPIB interface card on the computer.

The antenna used in the experiments is the center fed half wave dipole. The length of the transmitting and the receiving dipoles was calculated using the relationship $c = \nu\lambda$, where, c is the speed of light in vacuum/air, ν is the frequency of operation, and λ is the wavelength of the radiated energy.

For an operating frequency of 901 MHz, the wavelength of the radiation is

$$\lambda = 3{\times}10^8 / 901 \times 10^6 \text{ meters}$$

$$\Rightarrow \lambda = 300/901 \text{ m}$$

$$\Rightarrow \lambda = 0.33296 \text{ meters.}$$

The dipole is designed in such a way that its length is equal to half the wavelength of the desired frequency. Since the wavelength is $\lambda = 0.3296$ m, the effective length of the dipole becomes $\lambda/2$ which is 0.16648 meters. At this length, an ideal dipole resonates at 901 MHz.

5.1 Experimental Procedures

The experimental procedure is described in the following paragraphs. The GPIB card on the computer is initialized as soon as the program is started up on the computer. The first input from the user is to initialize the motion control card. The motors are then initialized wherein the limits of motion of the motors driving the rotator, namely the forward limit switch and the home positions are found. This range of motion signifies the sweep of the rotator. The limit switches that signify the limits of motion are set in such a way that a sweep of almost 360° is achieved in the ϕ plane. Once the motors are initialized, the spectrum analyzer and the signal generator are then initialized. Once the signal generators and the spectrum analyzer are initialized, they lose their front panel control and can be controlled only from the central computer.

The signal generator displays a message "RMT TALK" or "RMT LSN" which signifies that the instrument is in the remote talk or the remote listen mode. In the talk mode, the instrument is capable of transmitting data and information about its state over to the computer and while in the listen mode, it receives the instructions from the

computer. On the spectrum analyzer a message "RL" or "RT" is displayed signaling that the instrument is in Remote Talk or Remote Listen mode. As in the case of the signal generator, these states signify the ability of the instrument to relay information and accept instructions to and from a remote controller.

After initializing the instruments, the next step is to set the instruments to the desired operating states. From the pull down menu, "Options" the user sets various parameters on the positioner, the signal generator and the spectrum analyzer. This can proceed in any order. For the motors, the user has the option of setting the number of data points at which the field is sampled. The choices are $0.9°$, $1.8°$ and $4.5°$ between the data points. Depending on the separation between the data points, the speed of the rotator also varies and so does the time taken to complete one test.

The user is given the choice of setting the parameters on the spectrum analyzer in two ways. One, the center frequency and the span can be set and two, the start and the stop frequencies can be set. Once these parameters are set, the marker is set to concentrate on the desired frequency in the range set by the start/stop frequency or the center frequency/span options. The program ensures that the marker is set before the motion of the rotator is started.

The next step is to set the signal generator. On the signal generator, the user can set the frequency of the signal to be fed to the transmitting antenna and its power level. The power level can be set as an absolute power or a power level relative to a reference power level. The user also has the option of setting the modulation on the input signal to the transmitting antenna.

Once the parameters are set on the instruments, the setup is ready to make the measurements. To start the testing process, the user has to click on the "Start" button on the interface window. This starts the motion of the positioner and the data acquisition process. Once the positioner reaches the first data position as defined by the user, the controller sends a command to the spectrum analyzer to record the amplitude of the field at that position. The recorded information is stored in a memory array in the computer. The positioner then moves till it reaches the next data position and the controller sends a command to the spectrum analyzer to record the amplitude at that position, which is then stored in the memory. The whole process is repeated till the forward limit switch is tripped. Once the forward limit switch is tripped, the motion stops momentarily and then starts in the backward direction and the data acquisition procedure is repeated till the home switch is tripped on the way back. This data is stored in a separate array.

Once this test process is completed, depending on whether the user wants to take a look at the data in graphical form or not, a rectangular plot of the acquired data is displayed. After this, the "write" button is enabled and the acquired data can be written to the file specified in the interface window. Once the data is written to the file, the array of memory locations in which the data was stored becomes free to be used again without losing any information. Clicking on the "start" button can start the test procedure again. This would repeat the whole process for the same separation between the data points or for a different separation.

The experiments involved acquiring the data at 0.9°, 1.8° and 4.5° separation five times each. Before the actual data was acquired, the chamber was tested to check the level of noise signals in it. This too was repeated five times. The experimental data was

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then averaged and plotted in Microsoft Excel to get the representative patterns on the azimuth plane corresponding to $\theta = 90°$ and $\phi = 0°$ to about $355°$. The number of data points in different runs is not exactly the same. This can be attributed to the inherent drawback in the limit switches that they are not tripped at exactly the same position every time. But this does not make a major difference in the sample set as the number of data points differ by only a very small number.

In the case of $0.9°$ separation, the number of data points vary from 393 to 395 in the forward direction covering a range of angles from $353.7°$ to $355°$ and from 398 to 399 in the reverse direction covering a range of angles from $358.2°$ to $359.1°$. The next case is the $1.8°$ separation where the number of data points vary from 197 to 198 covering a range of angles from $354.6°$ to $356.4°$ in the forward direction and 199 to 200 points covering a range of angles from $358.2°$ to $360°$ in the reverse direction. The last case is the one with 4.5 degrees between each data point. Here, the number of data points remain the same at 79 covering a range of angles from $0°$ to $355.5°$ in the forward direction and from 79 to 80 in the reverse direction covering a range of angles form $0°$ to $360°$.

Tests were conducted to determine whether the home position is the same every time the tests were conducted. A laser pointer was attached to the table and a white board was placed at the transmitting end. The position of the laser point on the board was marked as a reference. The positioner was made to run at $0.9°$, $1.8°$ and $4.5°$ separation between the data points and the home position as indicated by the laser pointer marked. The tests were run ten times at each sampling interval. From the tests it was recorded that the maximum separation between the home positions after each run was about 1 cm. This

separation at a distance of about 11 feet (335.28 cm) gives a difference of 0.17° angular separation between the home positions. This could be neglected as it is only about 0.047% of 360°.

5.1.1 Dipole Tests

The data obtained from the tests conducted on the 15th of December 1998 in the chamber are plotted here to support the claim that the data acquisition system is capable of obtaining repeatable sets of data from the chamber. The first set of plots represents the data in rectangular coordinates while the next set represents the same in polar coordinates. The patterns for various configurations of the dipoles at 1.8° separation between each data point are represented here.

The following two plots, Figure 5.1 and Figure 5.2, give the patterns in the rectangular and polar coordinates in the azimuth plane when the antennas are in Vertical - Vertical orientation.

Figure 5.1 Rectangular plot of data from Test 1 to Test 5, forward direction, 1.8 deg separation, Ver-Ver configuration

Figure 5.2 Polar Plot of data from Test 1 to Test 5, Forward direction, 1.8 deg separation, Ver-Ver
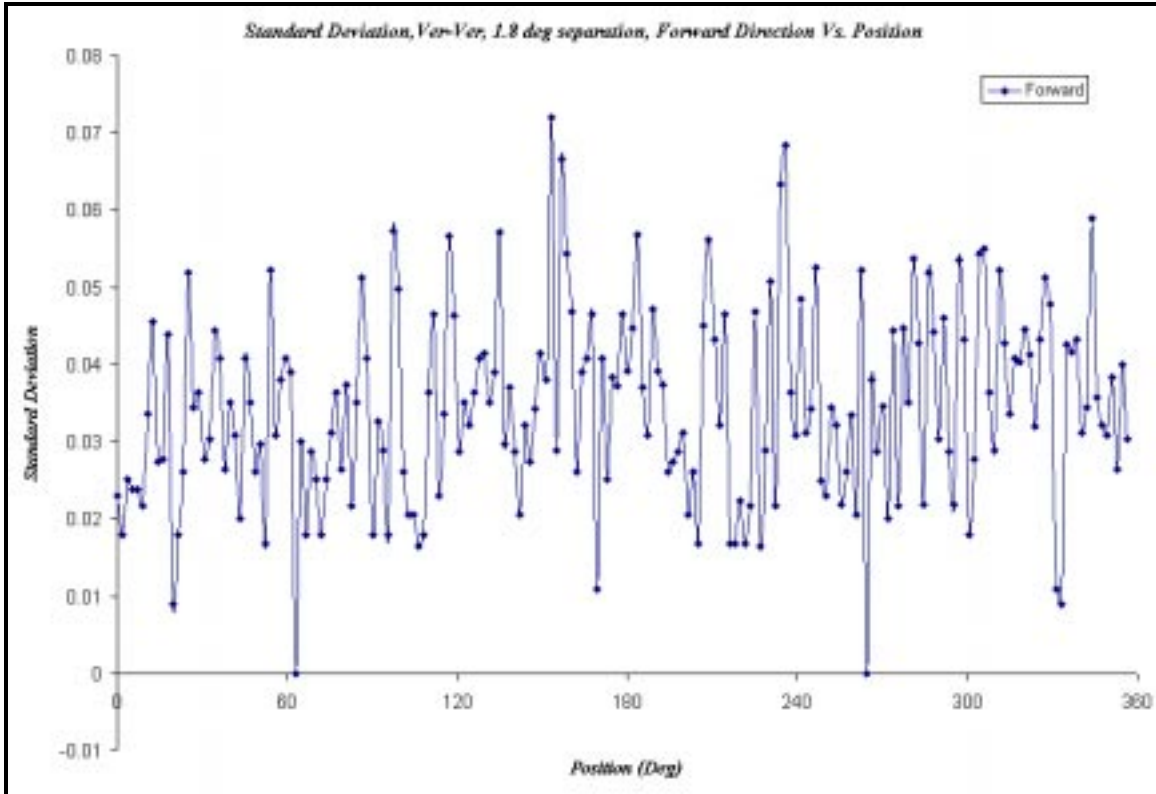
configuration

Figure 5.3 Standard deviation, Ver-Ver, 1.8 deg separation, forward direction

The standard deviation of the amplitudes at each data point for the tests is plotted and shown in figure 5.3. The standard deviation is in the range between 0 and 0.07. This corresponds to 0% and 0.21% of the mean value of the amplitudes around the antenna. This is very small and so, the data sets can be said to be repeatable.

The next two plots Figure 5.4 and Figure 5.5 give the representative patterns when the antennae are in Vertical - Horizontal orientation. Figure 5.6 gives the standard deviation of the amplitude at each data point.
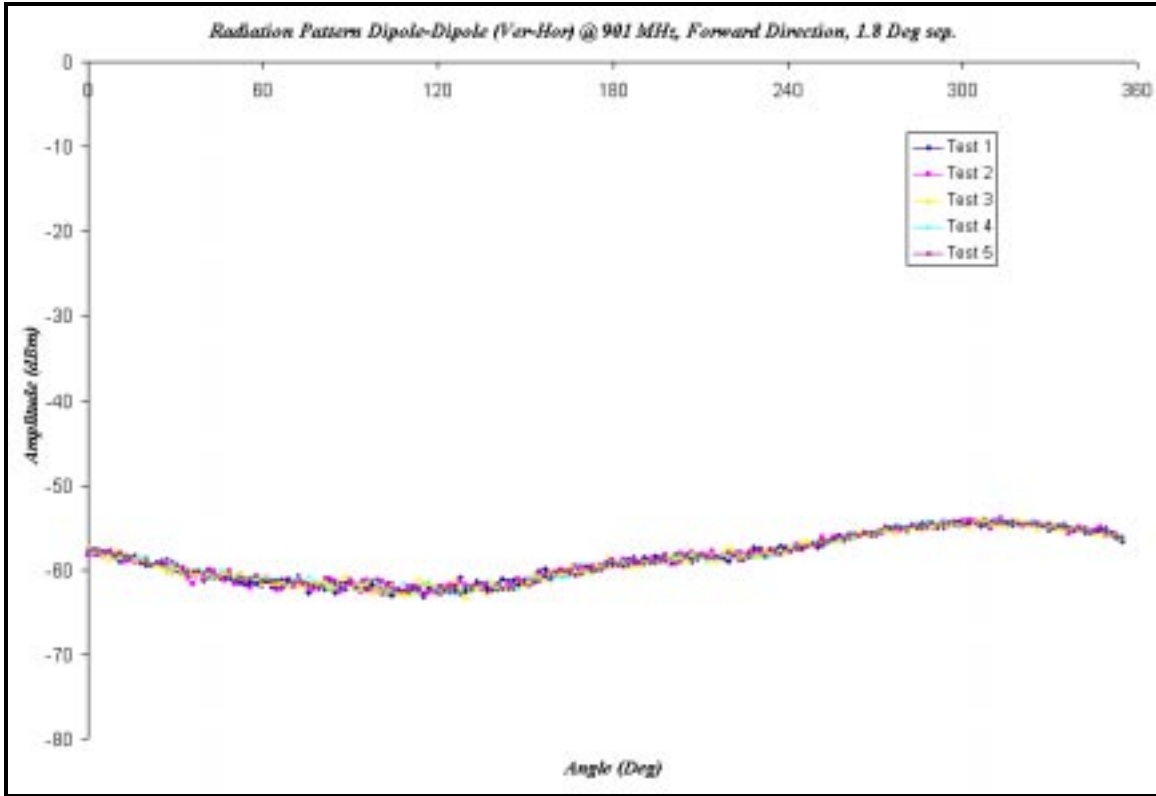
Figure 5.4 Rectangular plot of data from Test 1 to Test 5, forward direction, 1.8 deg separation, Ver-Hor configuration
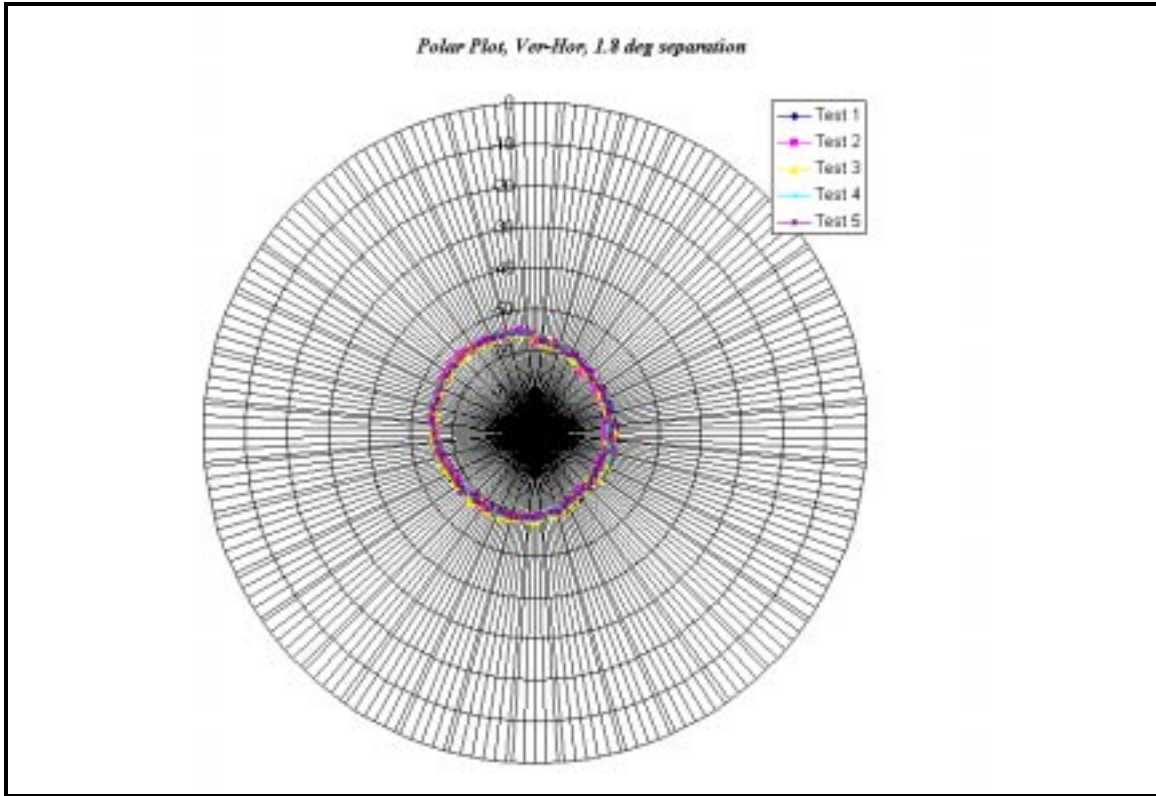
Figure 5.5 Polar plot of data from Test 1 to Test 5, forward direction, 1.8 deg separation, Ver-Hor
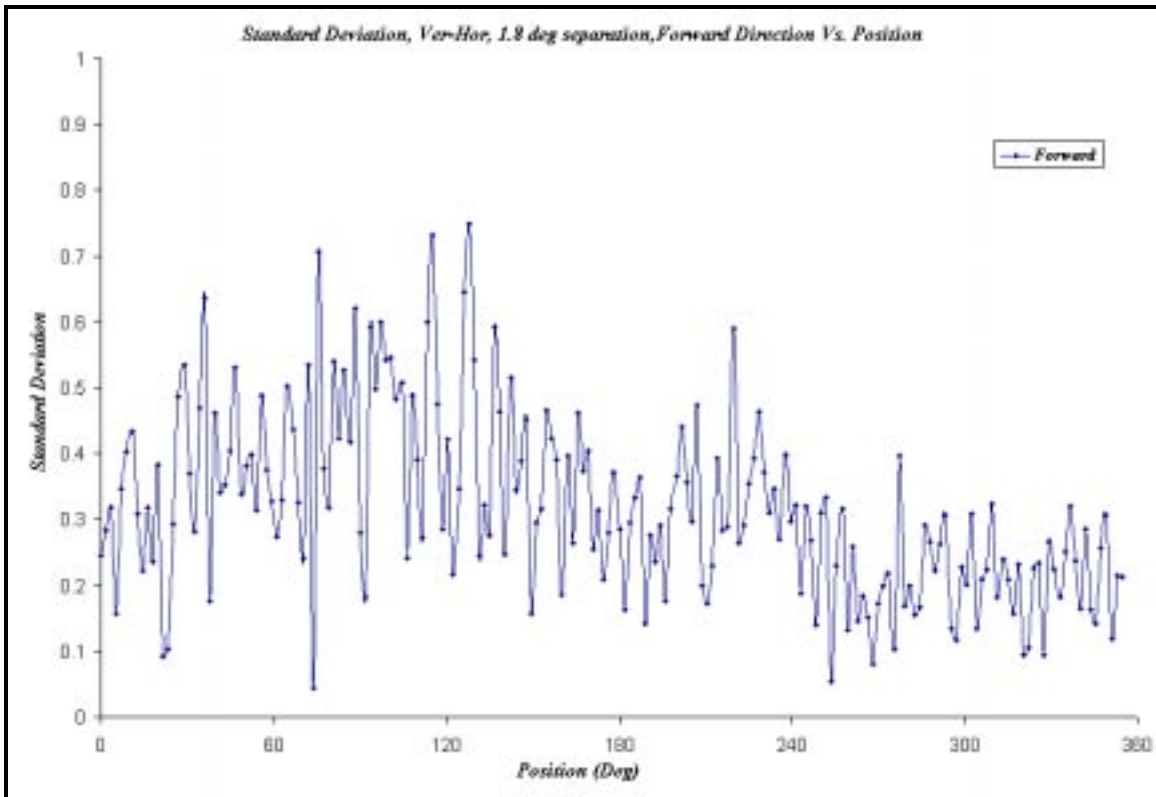
configuration

Figure 5.6 Standard deviation, Ver-Hor, 1.8 deg separation, forward direction

The next two plots Figure 5.7 and Figure 5.8 give the representative patterns when the antennae are in Horizontal - Horizontal orientation.
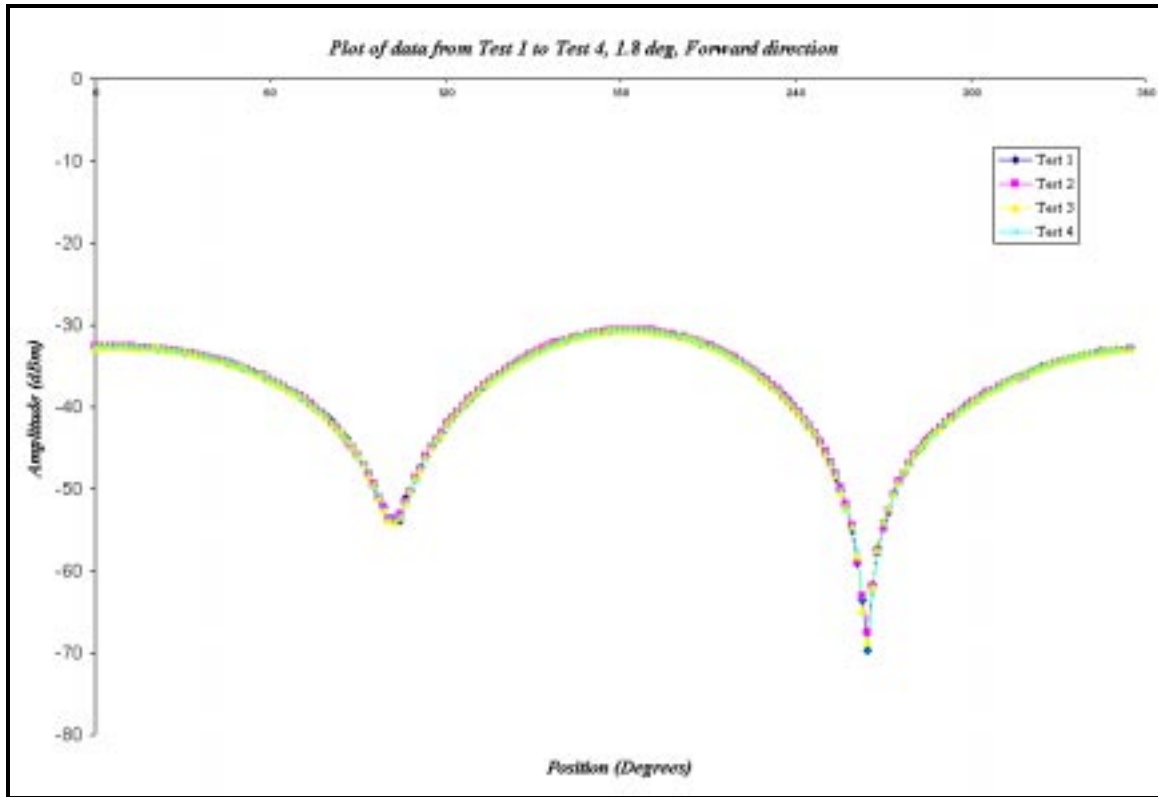
Figure 5.7 Rectangular plot of data from Test 1 to Test 5, forward direction, 1.8 deg separation, Hor-Hor configuration
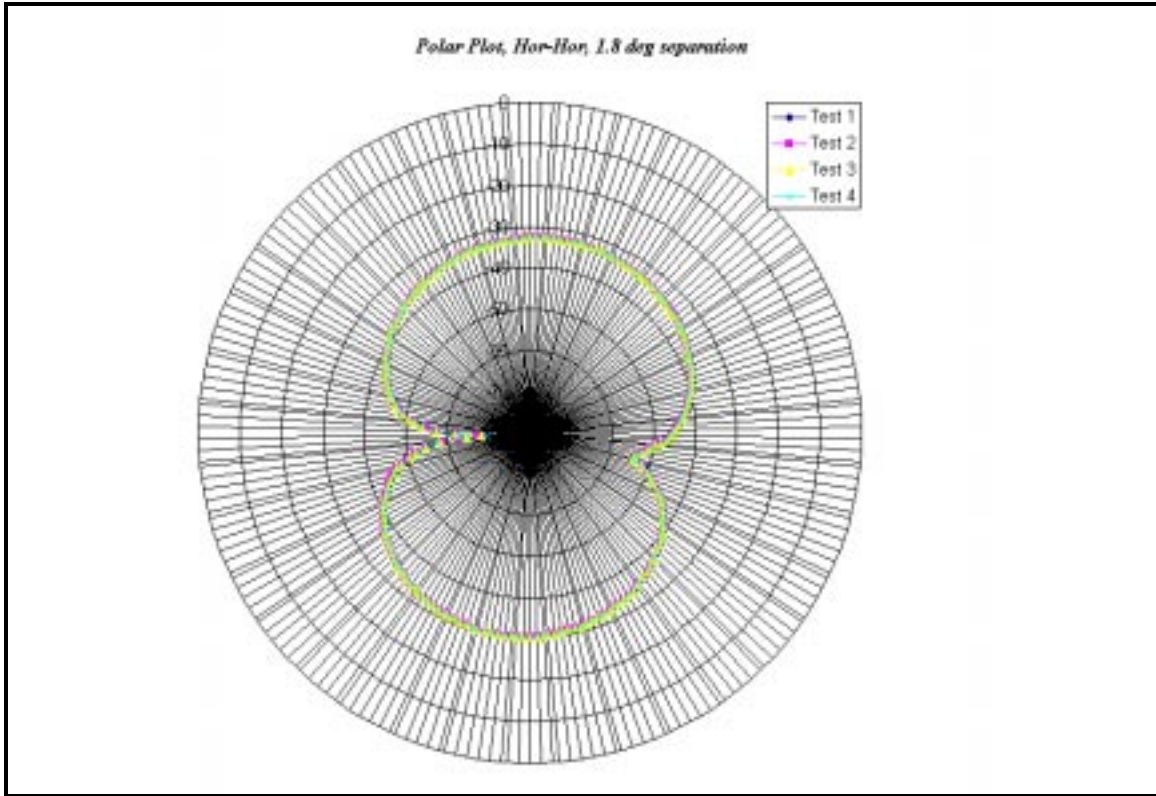
Figure 5.8 Polar plot of data from Test 1 to Test 5, forward direction, 1.8 deg separation, Hor-Hor

configuration

The following Figure 5.9 shows the standard deviation of the amplitude at each data point for the different tests. The standard deviation is marginally higher at the valleys than it is in other positions.
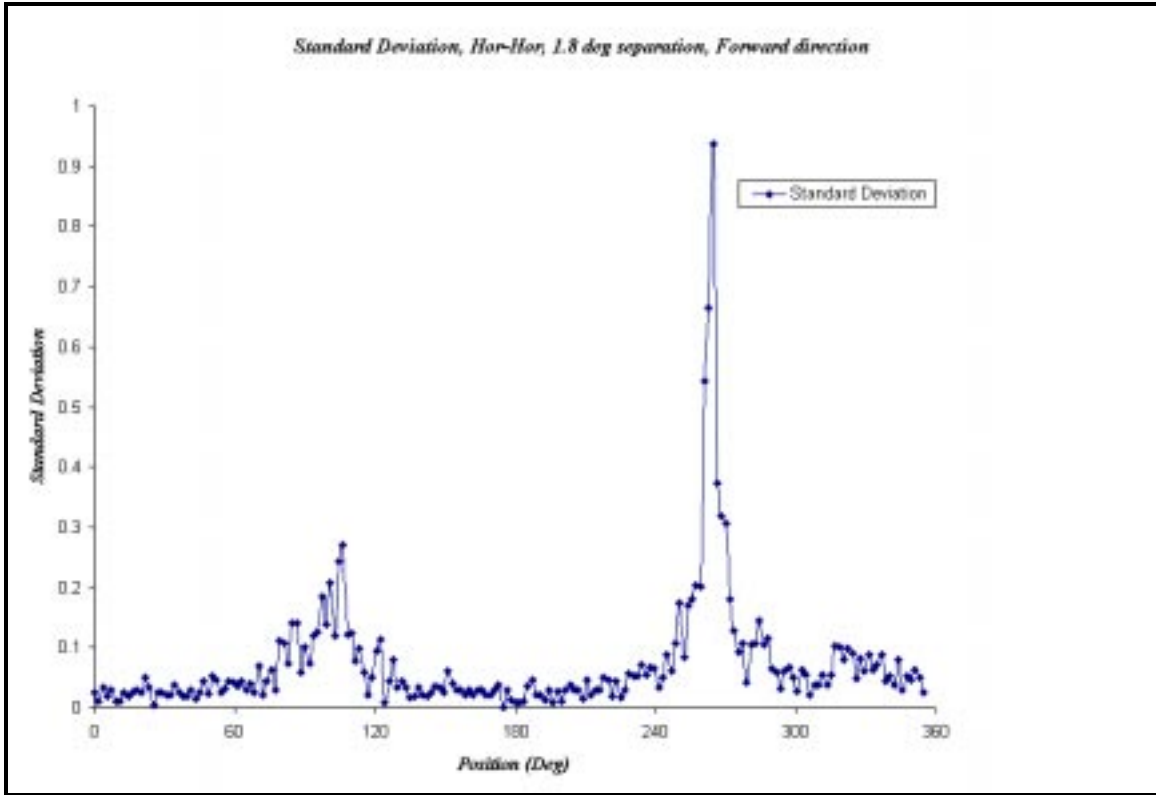
Figure 5.9 Standard deviation, Hor-Hor, 1.8 deg separation, forward direction

The next two plots Figure 5.10 and Figure 5.11 give the representative patterns when the antennae are in Horizontal - Vertical orientation.
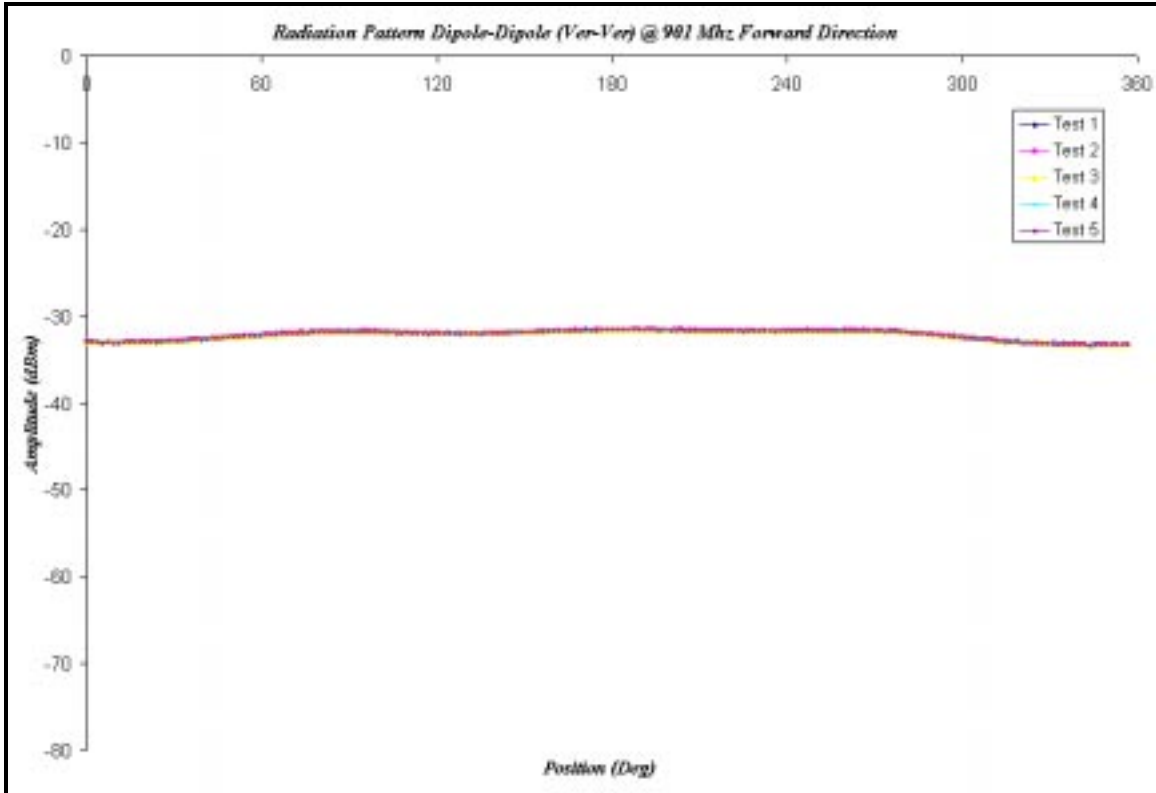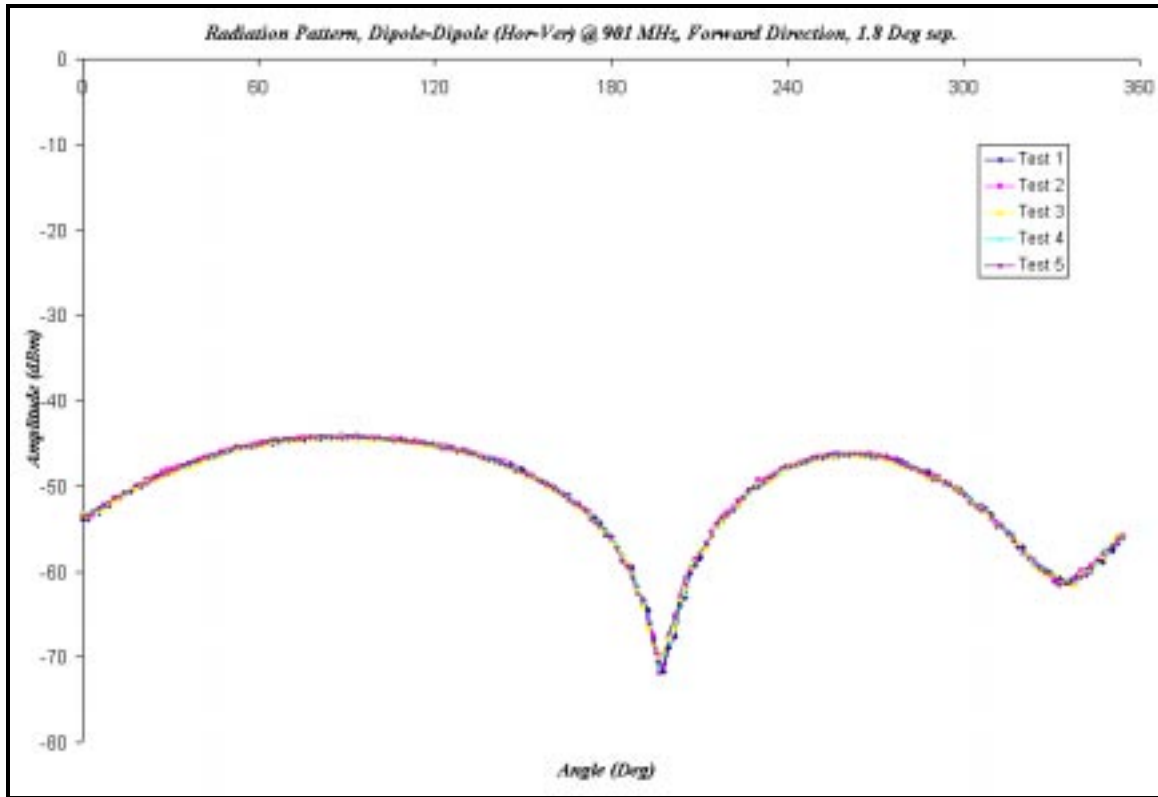

Figure 5.10 Rectangular plot of data from Test 1 to Test 5, forward direction, 1.8 deg separation, Hor-Ver configuration
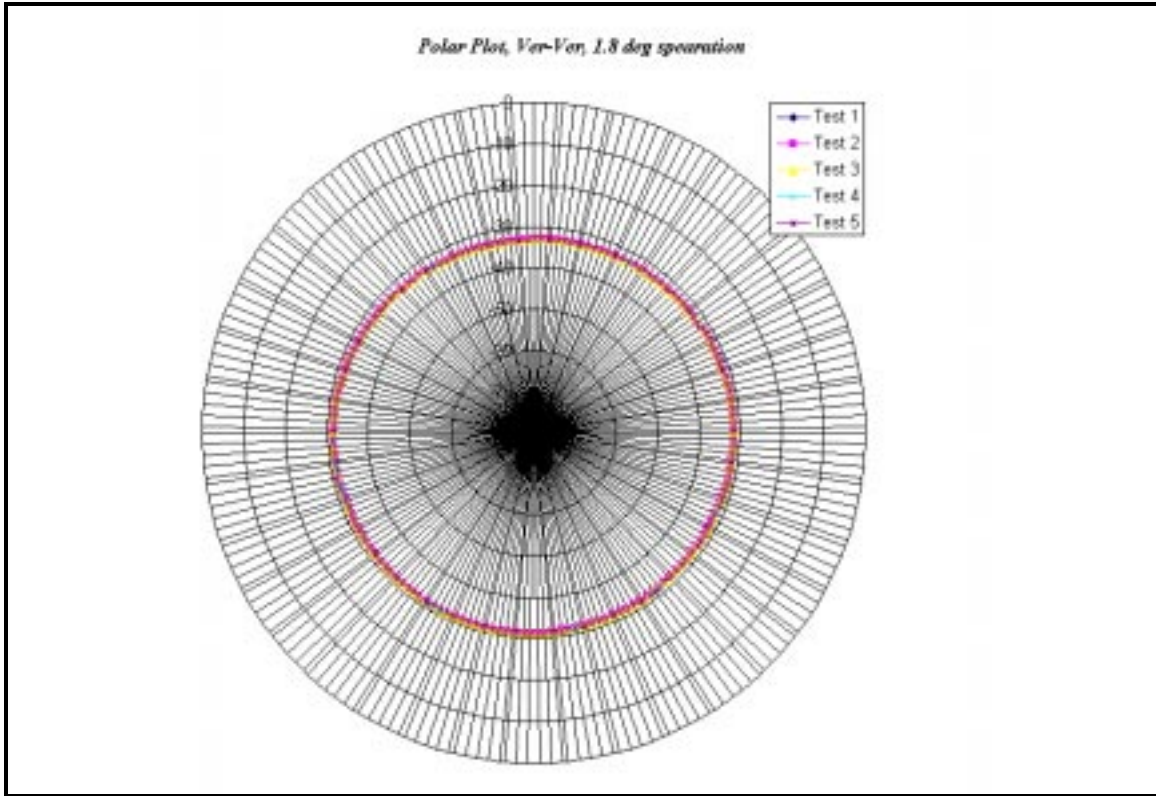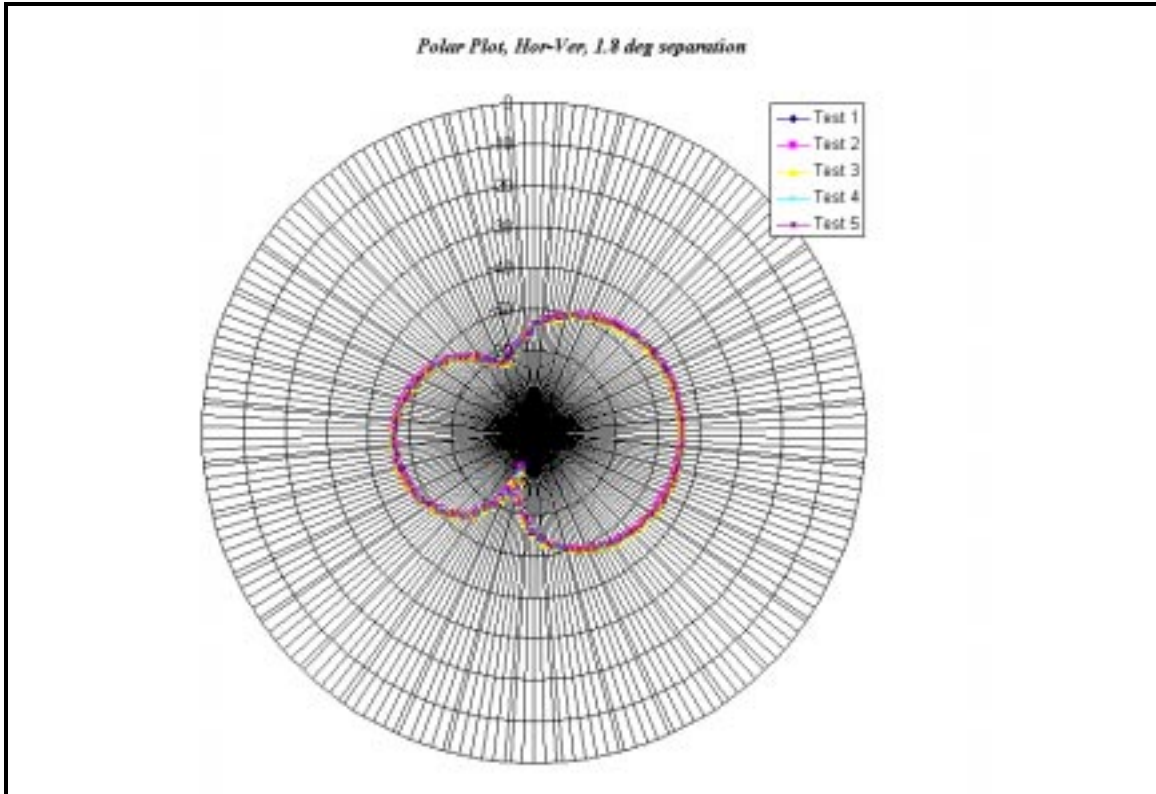
Figure 5.11 Polar plot of data from Test 1 to Test 5, forward direction, 1.8 deg separation, Hor-Ver

configuration

As can be seen in Figure 5.12, the standard deviation of the amplitude is pronounced in the area of the valleys than in the other places and is similar to the deviations obtained for the Hor-Hor configuration.
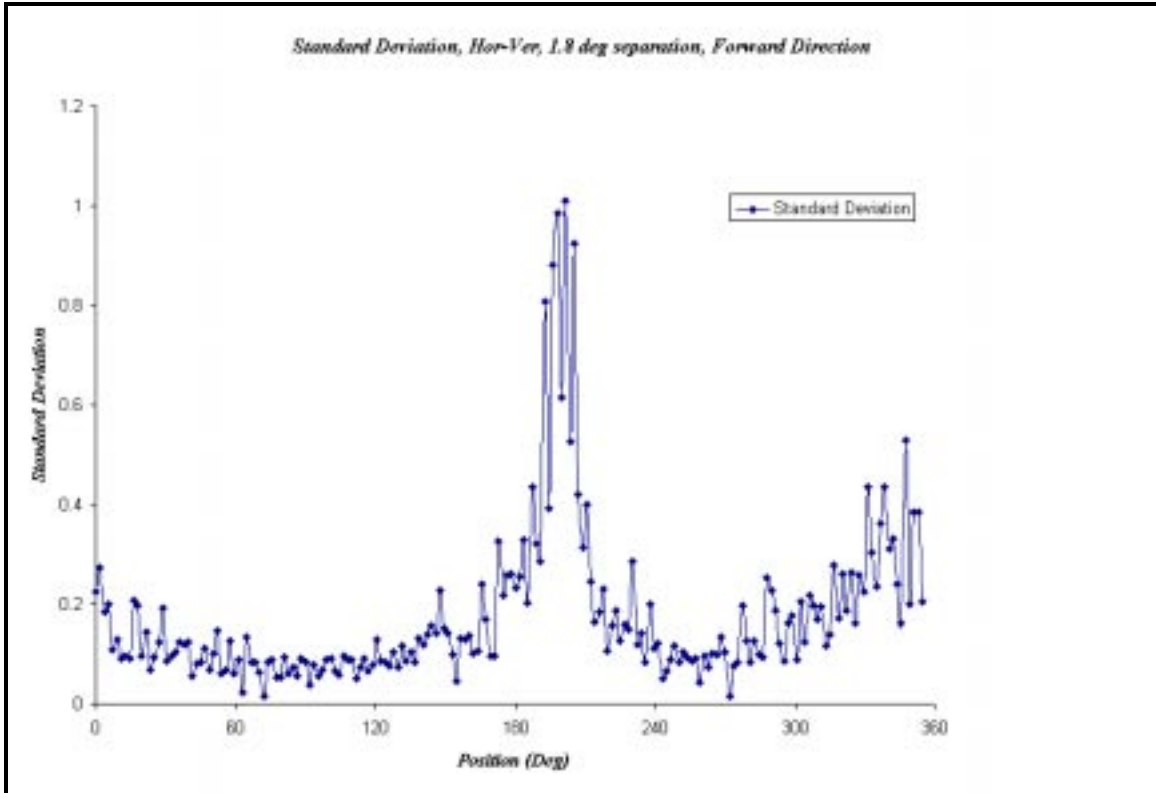
Figure 5.12 Standard deviation, Hor-Ver, 1.8 deg separation, forward direction

5.1.2 CTHA Test Results

Tests were conducted using the CTHA #23 as the receiving antenna and a standard dipole resonating at 901 MHz as the transmitting dipole on 10th April 1999. The CTHA was tuned to resonate at 901 MHz. There are only two possible configurations with the CTHA, namely the Horizontal transmission- Horizontal reception and Vertical transmission- Horizontal reception. Three tests were done for each orientation and the results obtained from the tests are plotted to get the representative patterns as shown in the following figures.

Figure 5.13 and 5.14 are patterns in rectangular and polar coordinates obtained with the antennas in the Ver-Hor configuration.
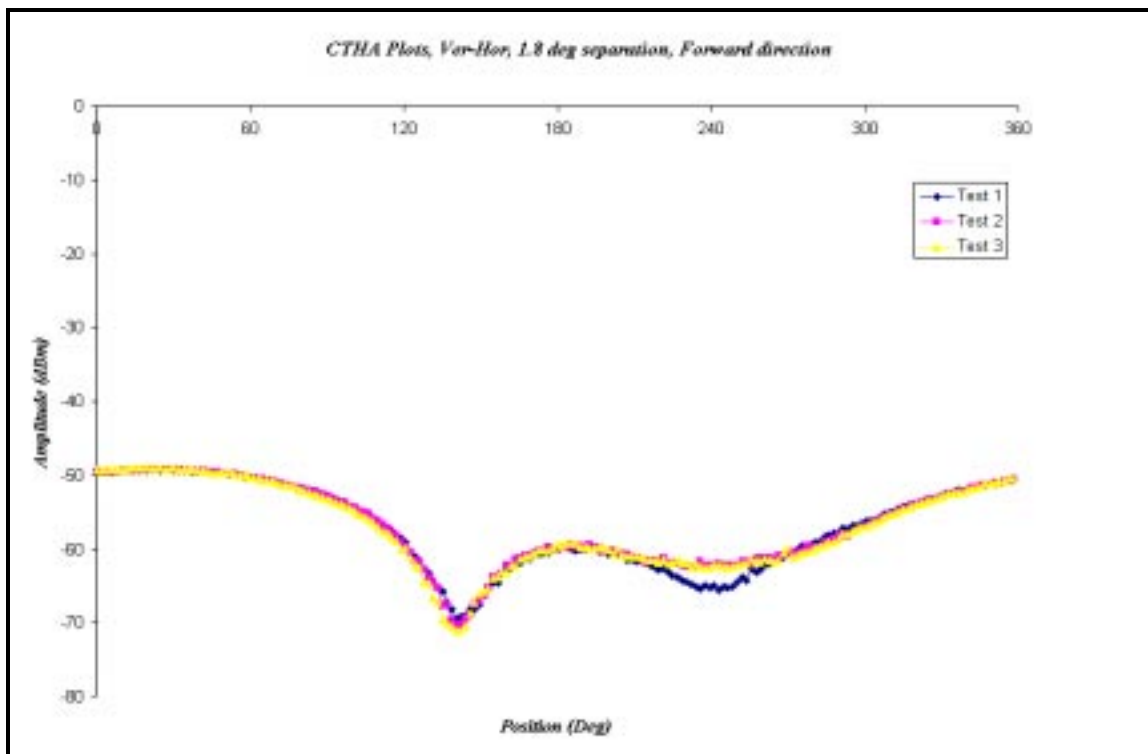
Figure 5.13 CTHA Rectangular Plots, Ver-Hor, 1.8 deg separation, Forward direction
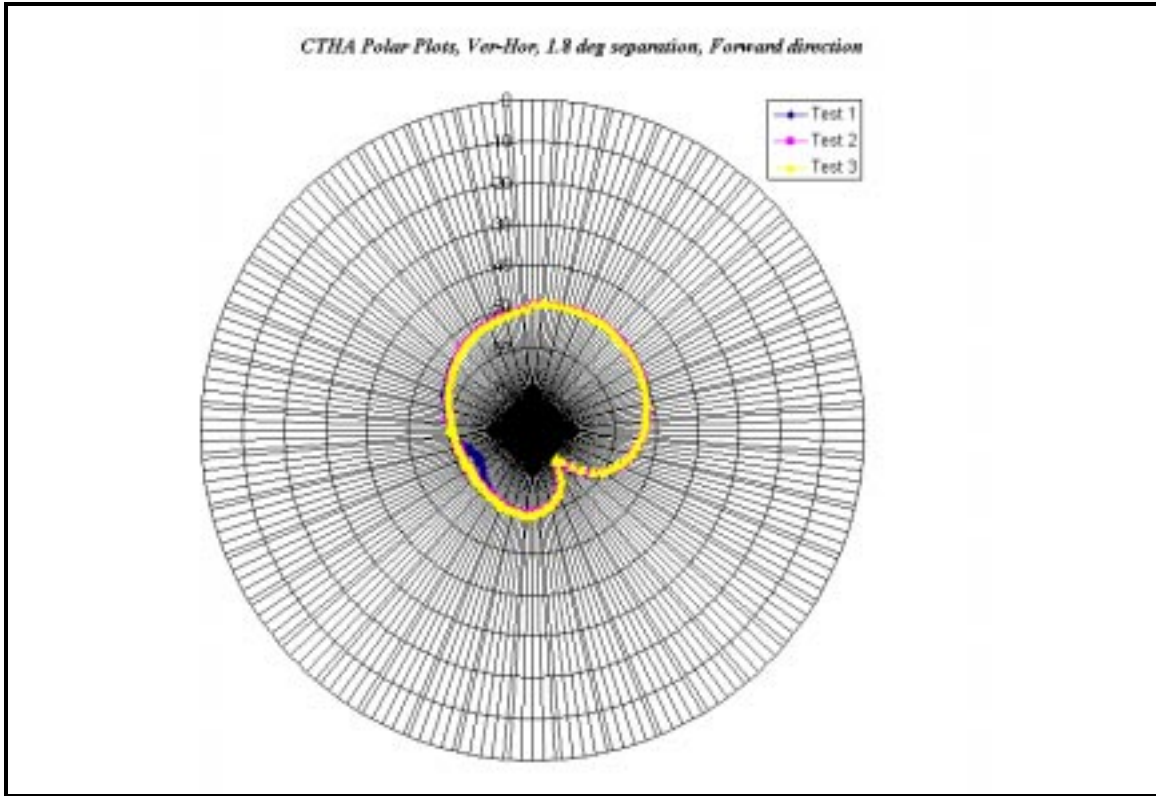
Figure 5.14 CTHA polar plots, Ver-Hor, 1.8 deg separation, forward direction

The standard deviation of the amplitudes at each data point was plotted and is shown in figure 5.15. as in the case of the dipoles, the standard deviation in the amplitude of the sampled field is higher at the valley points than other positions.
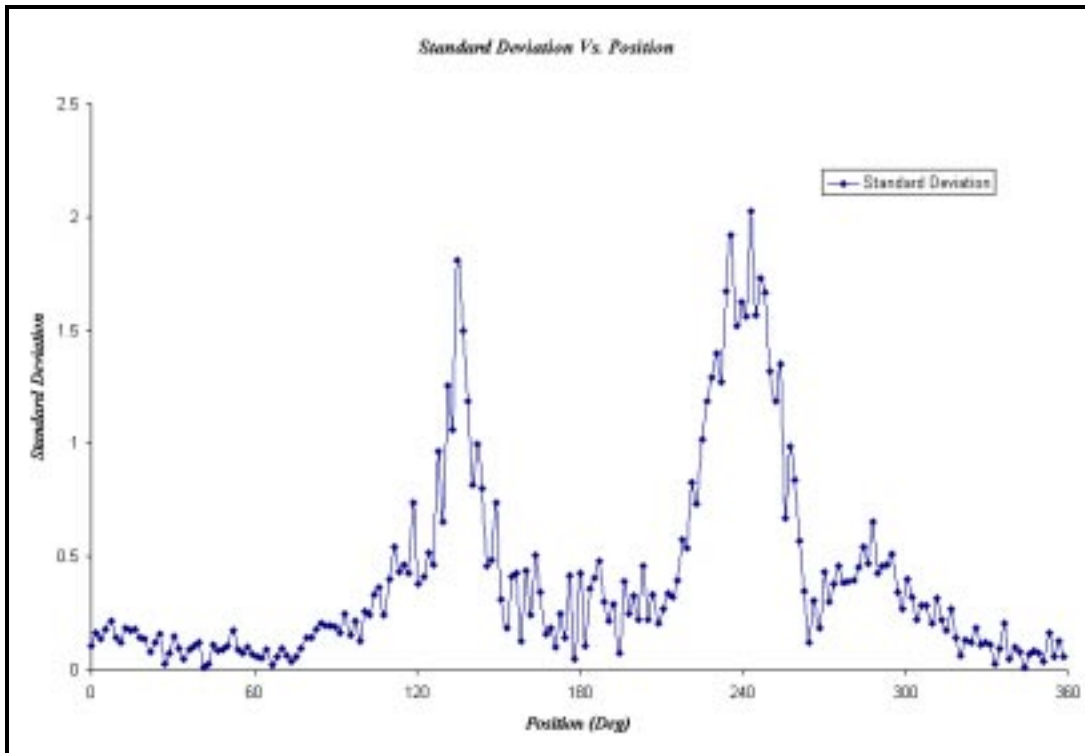
Figure 5.15 Standard deviation, Ver-Hor, 1.8 deg separation, forward direction
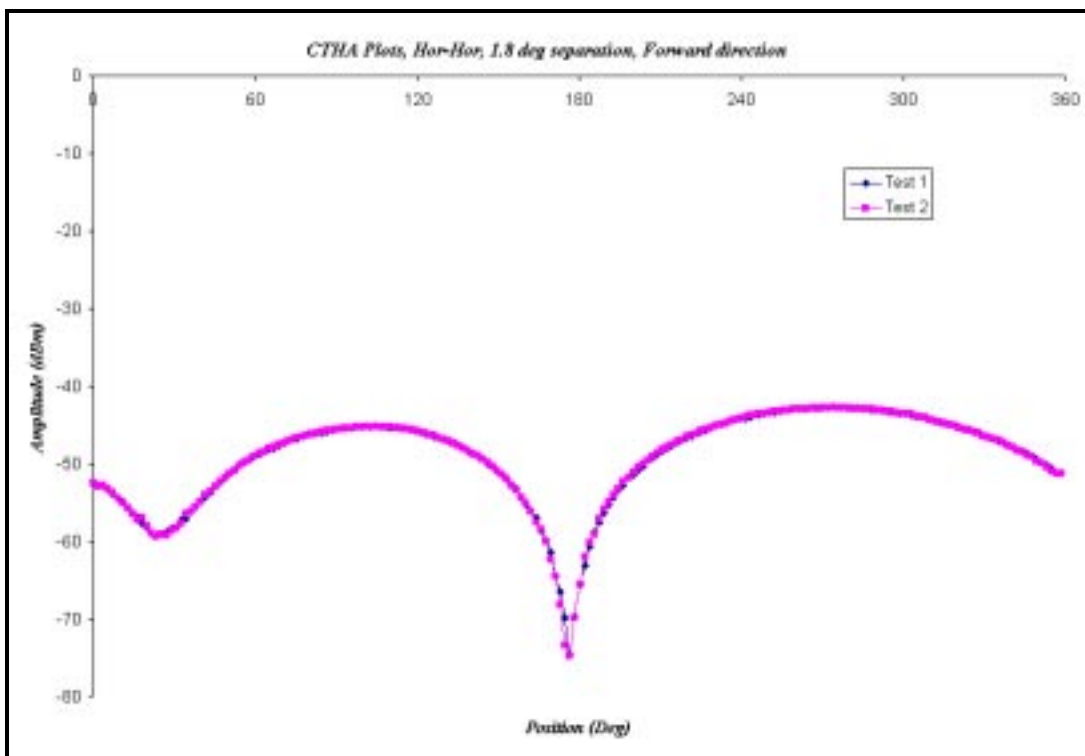
Figure 5.16 CTHA rectangular plots, Hor-Hor, 1.8 deg separation, forward direction
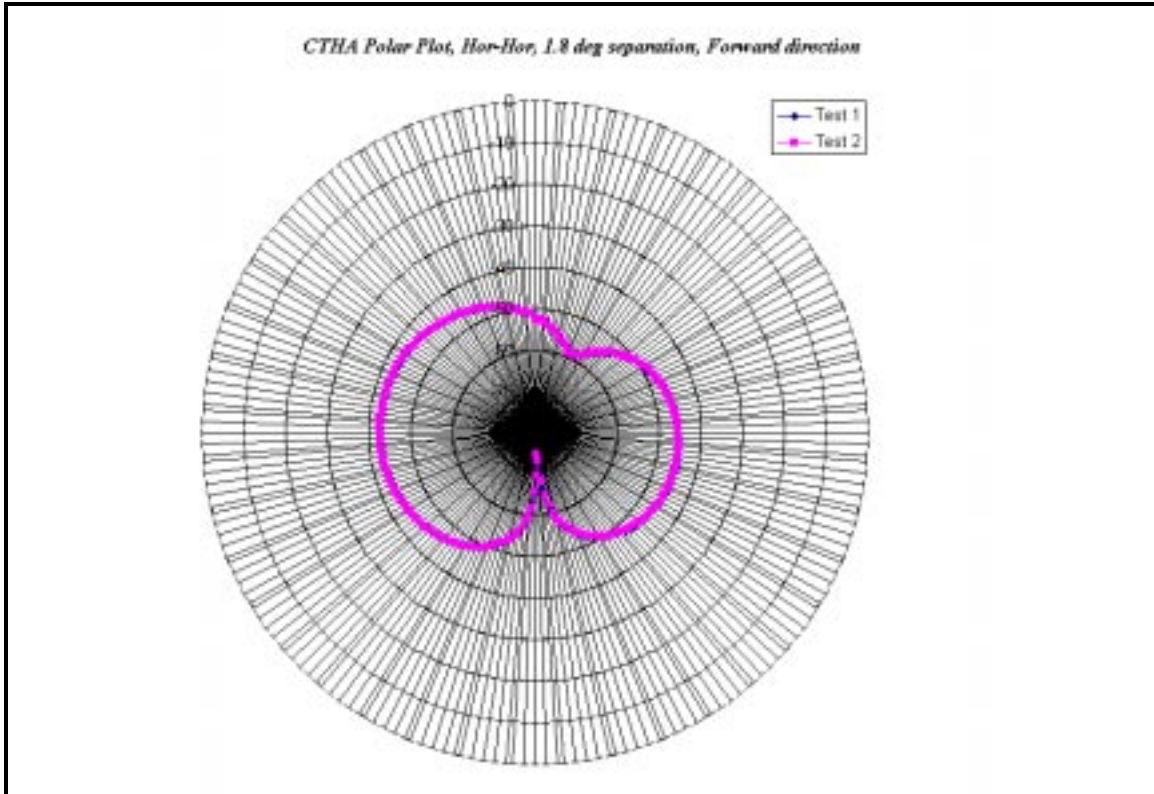
Figure 5.17 CTHA polar plots, Hor-Hor, 1.8 deg separation, forward direction

5.2 Numerical Simulations

The patterns obtained from the dipole experiments conducted in the chamber were compared with numerical results. The dipole radiation patterns and impedance were modeled using a numerical simulation package XFDTD from Remcom Inc.

The finite difference time domain (FDTD) method for calculation of electromagnetic problems is a transient in time procedure. In this, the time is divided into small discrete steps and the calculations are made on the geometry of the radiator built on a fine mesh. More information on the method used in this software could be found in the user's manual for XFDTD [14].

When using the XFDTD software, the geometry of the radiator is constructed by means of small discrete cells. The dimensions of each cell are the same and are such that the cell edges are at least 0.1 times the wavelength of the input signal. The geometry is modeled so that there are at least 6 to 10 cells around the geometry as free space. This is needed so that it absorbs the radiated and the scattered fields and gives a far field pattern.

In this project, various models for the dipole were tried before settling on the model that closest resembles the actual dipole. The calculations that are involved in modeling the dipole are given as follows.

The frequency at which the dipole is designed to resonate is $\nu = 901$ MHz. This gives the wavelength of the radiation to be $\lambda = 0.33296$ meters. Maintaining the requirement that the cell edges should be at least 0.1λ, the maximum cell edge dimension is 0.033296 meters. The radiator is a half wave dipole and so, the dimension of the geometry of the dipole is $\lambda/2 = 0.16648$ meters. The cell edges have to be defined that a whole number of cells could be used to define the geometry of the dipole. Various combinations of the cell size, free space around the radiator and the geometry of the radiator itself were tried out before settling on a particular combination that resembles the actual dipole close enough for comparisons. The dipole is modeled in such a way that the feed point is at its center and spans one cell in width. The input signal is fed to the dipole through the feed point. While calculating the grid size, the relative dimensions are maintained in such a way that $\Delta y = \Delta z = 2\Delta x$. This means that the mesh is finer along the x-direction than it is along the y and z - directions. An important result of this is that the number of cells in the y and z directions is half the number of the cells in the x direction,

which reduces the total number of cells in the grid. As a result, the time for computation is considerably reduced.

Various combinations of the geometry were examined and the results of the simulations are given in the following paragraphs with details of the geometry modeled and the reasons behind the modeling. Even though different models were tried, there were a few parameters that were consistent throughout the modeling. Real space is the actual space in physical dimensions that the whole grid is supposed to represent and the numerical space is the space the cells in the grid represent. The models are designed in such a way that the real space is maintained a constant while the numerical space is varied.

Of the models simulated, model #8 was found to be the closest to the experimental results. The results obtained with model #8 are summarized here.

Model #8

The feed configuration for this model is along the + X-axis. There are 5 cells on the arm of the dipole.

Number of cells on the grid = 181×121×121 cells.

Cell size = 2.774×5.549×5.549 mm

Number of cells on the dipole = 60

Number of cells on each arm = 5

Number of cells at feed point = 1

Time step = 7.555 Pico seconds

Feed point characteristics:

Feed point coordinates: 91, 56, and 61 on the grid.

Direction: + X direction.

Amplitude: 10 volts.

Nature: Gaussian input signal.

Pulse width = 32 time steps.

Total time of simulation = 1025 time steps.
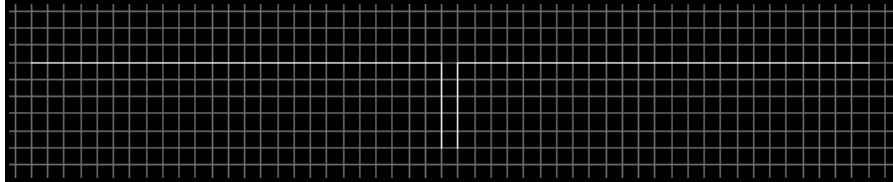
Figure 5.18 Model #8 of dipole
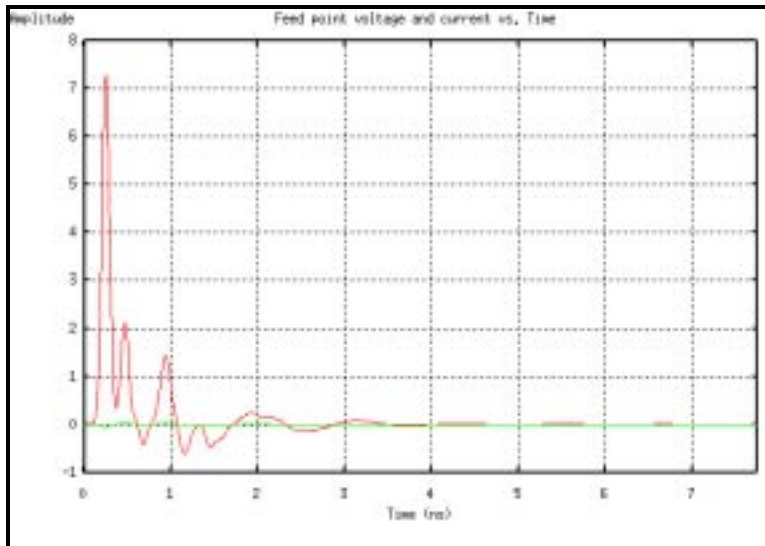
Figure 5.19 Feed point voltage and current vs. time.

The feed point voltage and current die down to almost zero in a few nano seconds. Figure 5.10 shows the input impedance as a function of the frequency. The raw data would be a better indicator of the resonance frequency.
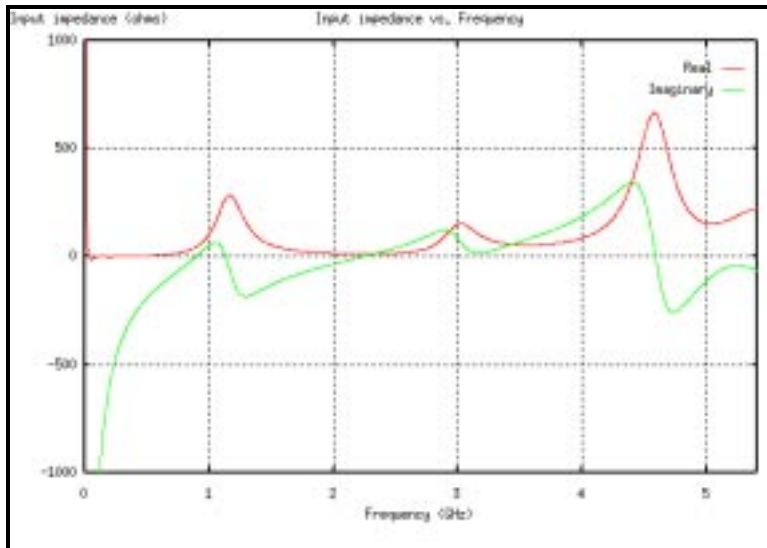
Figure 5.20 Input impedance vs. frequency
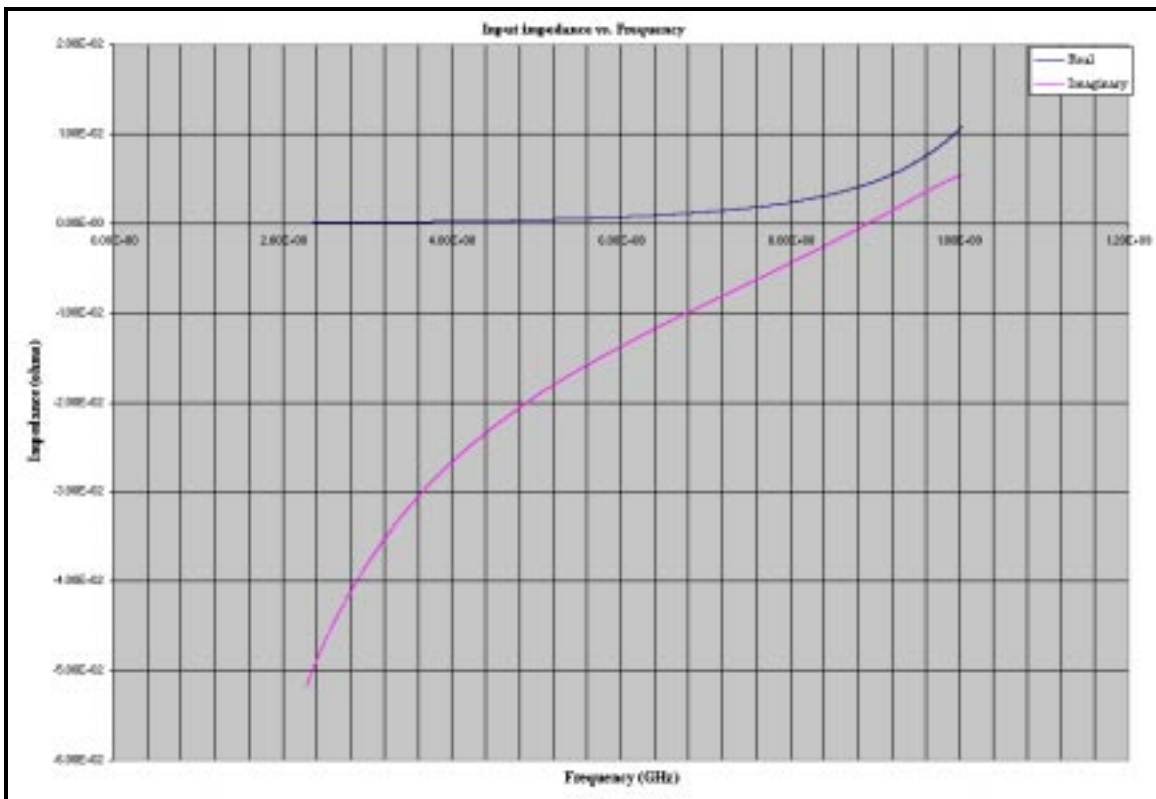
Figure 5.21 Excel plot of data from XFDTD simulations for Model #8

Plotting the raw data obtained from the simulations of the model in XFDTD gives

a better idea of the effectiveness of the model. The resonance frequency is 893 MHz. Of

all the models, this gives a resonance frequency closest to the designed frequency. A deviation of 8 MHz from the designed frequency is acceptable, as it is less than 1% of the designed frequency. So, this model is used as the reference model in the steady state simulations.

Chapter 6 - Conclusions

The objective of the project was to design and implement an instrumentation and data acquisition module for the testing and analysis of physically small antennas. Antennas such as small dipoles and more specifically CTHA could be classified as physically small antennas as they have a small profile. These were to be tested in an anechoic chamber located at WVU and maintained by the Center for Industrial and Research Applications (CIRA). The following figure gives us an idea of what is meant by physically small antennas. The dipole and the CTHA are placed along a 6" ruler.
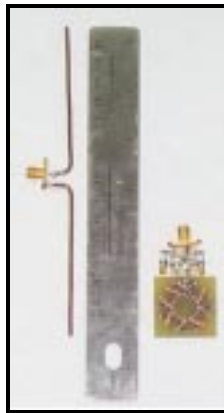
Figure 6.1 Dipole and CTHA tested in the anechoic chamber

A mechanical arm was built with fiberglass for this purpose and placed inside the CTHA anechoic chamber. An interface program was written is Visual Basic and run on a desktop personal computer to coordinate the working of the positioner, spectrum analyzer, and the signal generator.

The whole system was tested for repeatability of measurements in the chamber. The results obtained from the chamber for tests on different dates over a period of four

months were found to be consistent, thus confirming that the system was capable of producing repeatable results over a period of time.

The present system is capable of sampling the field of the antenna only in one plane ($\theta = 90°$ and $\phi = 0°$ to $\approx 360°$). The system could be improved by extending its capability to sample an almost spherical region around the antenna under test by tilting the table and changing the azimuth angle (θ). The capability to do so already exists and the system only needs to be tested for repeatability and the resulting data put in a presentable form.

Chapter 7 - References

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Appendix A - Antenna Range Design

A.1 Antenna Test Ranges

For the purpose of mapping the radiation patterns of antennas, test ranges are designed. The choice of the test ranges is such that the influence of the operating environment on the pattern of the antenna under test is minimal. In addition to the near free space environment, the radiation from the transmitting antenna should be a plane wave over the effective aperture of the antenna under test.

A plane wave is defined as a wave whose magnitude and phase of the fields are uniform and in particular, with respect to the antenna, uniform over the effective area plane of the test antenna. As the electromagnetic radiation propagates spherically from its source it resembles a plane wave only at large distances from the source [2]. Since it is not possible to achieve large distances in a confined test space like an anechoic chamber, the separation between the two antennas is maintained such that at least an approximation of a plane wave is possible over the aperture of the antenna under test. This generates a nearly error free plane wave that illuminates the test aperture.

A nearly error free plane wave is one in which the amplitude and phase, from center to edge of the illuminating field over the test aperture, do not deviate by more than 1 decibel and 30° respectively. Usually the antenna under test is in the receiving mode with the transmitting antenna used to just illuminate this antenna with electromagnetic radiation at the frequency for which the receiving antenna is designed.

Tests are conducted on outdoor ranges or indoors, in anechoic chambers depending on their nature. In the case of mapping the far field patterns, the tests are conducted on outdoor test ranges that satisfy a few qualifying factors. For an outdoor test range to qualify, it is desired that the terrain of the test range be essentially flat and have uniform surface conditions. Also, it is desired that the range does not have any interfering electromagnetic fields or even if there are some radiators in the vicinity their effect on the antenna under test is minimal. Based on these requirements, the outdoor test ranges are classified into two categories as free space and reflection ranges. The free space ranges are designed in such a manner that all the effects of the environment are suppressed to acceptable level [3]. On the other hand, reflection ranges are those that are designed in such a way that the interference pattern created by the reflections off the ground plane and the direct wave result in an approximate plane wave at the test antenna.

Of the two categories, the reflection ranges could be further subdivided as elevated test range, slant ranges, compact range and most anechoic chambers. Of the above listed test ranges, the elevated test range and the ground reflection range are the most basic types ranges. The test range selection also depends on the type of test. For recording the radiation patterns, the range should consist all the area illuminated by the test antenna especially the area around and behind the antenna under test.

In designing either of the basic test ranges, factors listed below should be taken into consideration.

A.1.1 Coupling Between Source Antenna and Test Antenna

The total field of an antenna is a resultant of two parts, the radiation part and the reactive part. For most antennas, the radiation field decays at a rate proportional to the reciprocal of the square of the distance from the antenna and the reactive field decays at least the reciprocal of the square of the distance from the antenna. This cannot be generalized for all the antennas as different antennas behave differently under various conditions. Usually, the transmitting antenna and the antenna under test are placed apart in such a way that their reactive fields do not interact with each other, but in many practical situations, that might not be possible. This creates an interaction between the two fields, resulting in errors in measurements of the amplitude. The effect of this coupling on the field of the antenna under test would become negligible if the spacing between the two antennas were more than 10 times the wavelength of the operating frequency. In addition to the interaction between the reactive fields of the two antennas, there is also an interaction between the radiation fields. This causes a reradiative coupling or mutual coupling between the two antennas wherein a part of the energy received by the antenna under test is reradiated towards the transmitting antenna and similarly, a part of the energy received by the transmitting antenna is reradiated towards the antenna under test. Although the energy that is reradiated is not high, it could cause an error in measurement of the signal amplitude.

A.1.2 Transverse and Longitudinal Amplitude Taper of the Illuminating Wave Front

Tapering of the amplitude of the transmitted signal in both the transverse and the longitudinal directions could result in erroneous patterns recorded by the receivers. In order to have an acceptable degree of accuracy in the pattern measurements, the excitation field should be consistent in amplitude along the range axis and also the plane normal to the range axis. As a result, it becomes important that the range is designed to handle such aberrations.

A.1.3 Phase Curvature of Illuminating Wave Front

The phase of the illuminating field over the aperture of the antenna is not exactly constant and is also subjected to variations. For all practical purposes, the variation is a function between the transmitting antenna and the antenna under test. This is more significant in the case of near field measurements where the separation between the test antenna and the transmitting antenna is considerably less than $2d^2/\lambda$, where "d" is the diameter of the source antenna. The most common approach to this problem is to maintain the separation between the test antenna and the source, R, such that $R \geq D^2/\lambda$, where D is the separation between the antennas. The phase variation over the length of the range for this separation is given by the relationship $\Delta\phi \cong \pi D^2 / 4\lambda R$. This separation would in effect reduce the phase variation to less than $\pi/8$ radians, which can be considered to be negligible.

A.1.4 Spatial Variations in the Illuminating Wave Front Due to Reflections

The ground plane plays a major part in influencing the pattern of the antenna under test. The radiation from the transmitting antenna reaches the antenna under test in two different paths. One, it takes the direct path to the test antenna through air and the other path is one where the radiation is reflected from the ground plane. If the ground plane is flat and uniform, then it essentially acts as a mirror for the incident radiation, reflecting the incident radiation onto the test antenna. Even though there might be some energy absorbed by the ground plane, the reflection produces a phase change of 180° in the illuminating radiation. As a result, the resultant illumination on the antenna under test is a vector sum of the electromagnetic radiation arriving from the two directions, the direct path and the reflected path. If the reflection off the ground plane is assumed as a perfect mirror reflection, and the transmitting antenna is isotropic, then the resultant field would be a sum of different waves interfering with different phase relationships. At some points, the waves might arrive with a phase difference of 180° and at some other points; they might arrive in phase with each other. If the amplitudes of the waves are assumed to be to be nearly equal, then the resultant would be a standing waveform.

As in the outdoor test range, reflections occur in the anechoic chambers too. As mentioned, anechoic chambers are classified into two categories as rectangular and tapered anechoic chambers. In the case of rectangular anechoic chambers, even though all the walls of the chamber are covered by a high quality radiation absorbing foam, specular reflections occur from these surfaces, particularly if the angle of incidence of the radiated energy on the foam is large. One of the ways to avoid this problem would be to make

sure that the angle of incidence is small enough that the reflected energy from the foam is low enough not to influence the measurements. Usually, for high quality foam, this angle of incidence is in the range 0° to 70° as measured from the normal to the wall. If the anechoic chamber is rectangular, then this leads to a restriction on the width or height of the chamber so that

$$W \geq R/2.75,$$

where R is the separation between the transmitting antenna and the antenna under test and W is the width or height of the rectangular anechoic chamber.

On the other hand, consider the design of a tapered anechoic chamber. This is designed in the shape of a pyramidal horn that tapers from the small transmitting end to a larger rectangular test region. The tapered anechoic chamber has two modes of operation in the band of frequencies it is designed to operate. At the lower end, it is possible to place the transmitting antenna at almost the apex of the taper, so that the reflections that occur from the walls are utilized constructively to direct the field to the receiving antenna at the other end of the taper. For properly placed antennas, there is little phase difference between the direct path radiation and the reflected path radiation that reaches the antenna under test. These two waves interfere constructively to produce a slowly varying spatial pattern and as a result an incident radiation that has a relatively smooth amplitude variation in the test region. The location for positioning the antenna is best determined experimentally, although the following expression

$$h_t < \lambda R/4h_r$$

where h_t is the height of the transmitting antenna from the chamber wall, λ is the wavelength of operation, R is the distance of the transmitting antenna from the antenna under test and h_r is the perpendicular distance from the antenna under test and the chamber wall. If the antenna is positioned differently, then the interference patterns might not be what is desired, with highly significant amplitude variations. One drawback of the tapered anechoic chamber is that the field does not spread like a spherical wave and so, tests based on the Friis transmission formula cannot be used.

A.1.5 Interference by Spurious Radiating Sources

Ideally the field over the aperture of the test antenna is assumed to be pure and due to only the transmitting antenna. Practically this is not possible, as the incident energy would be reflected off various structures around the test antenna as well as of the terrain of the test range as discussed in the previous sections. In addition to these, the test antenna is also subjected to stray radiation from nearby radiators. Thus, the energizing radiation on the test antenna originates from two sources; the near axis incident field and the wide axis incident field. There are different methods of measuring and quantifying these fields.

More details of the influence of these factors on the testing of the antennas on outdoor ranges could be found in the IEEE Standard Test Procedures for Antennas [17].

A.2 Antenna Range Instrumentation

In general, the instrumentation required for an antenna test range can be divided into five different categories as

- Transmitting antenna system.

- Receiving system.

- Positioning system.

- Recording system.

- Data Processing system.

The type of instrumentation required and its complexity depends on the application and the requirements imposed by it. A block diagram of the basic instrumentation system for the antenna test range is as shown.
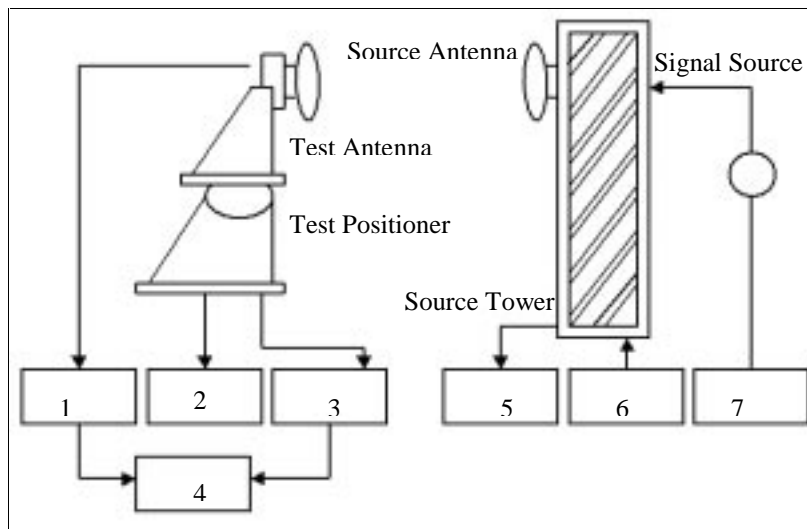
Figure A.1 Instrumentation for antenna test ranges

1 – Receiver
2 – Positioner Control
3 – Test Positioner Indicators
4 – Pattern Recorder
5 – Source Tower Indicators
6 – Source Tower Control
7 – Source Control

The test range is usually designed to operate over a wide band of frequencies and so, is fully equipped with transmitting antennas that cover the range of operation and have the requisite polarization properties for the tests.

The test range has a signal source system to excite the transmitting antenna and is chosen so that it satisfies the following performance requirements. It should have a means of tuning the frequency of the signal source to the desired frequency. Since the antennas and their related circuitry is highly frequency sensitive, the source should be capable of holding the frequency steady within range 0.01 to 0.1 percent of the set frequency for the duration of the test and also, the transmitted radiation at the set frequency should be spectrally pure. The power output required depend on the type of tests that are being conducted, the source and test antenna gains, the receiver sensitivity, the transmission loss between the two antennas and the dynamic range of operation. The signal source should be capable of delivering power with variation within ± 0.05 dB and also be capable of modulating the transmitted signal, as this might be required in some applications.

The next category in the Antenna range instrumentation would be the receiving systems. Initially, during the early times, bolometers were used in antenna amplitude measurement systems and great care had to be taken to ensure that proper measurements

were made. But in this project, a Hewlett Packard spectrum analyzer is used, that is relatively easy to maintain and take measurements.

The third category of instrumentation is the positioner, which is very important, as a proper positioning system is required to map the field exactly. There are two kinds of antenna positioners, namely the fixed line of sight and the movable line of sight positioners. For either of the two positioners, two orthogonal axes are required if true θ and ϕ cuts are to be made. These axes are designated as the θ rotational axis and the ϕ rotational axis and is as shown. The ϕ axis permits cuts in ϕ direction with θ as the parameter and vice versa. Spherical coordinates are used in these positioners. There are two kinds of antenna positioners that are described by the IEEE Standard Test procedures for Antennas that could be used in the case of fixed line of sight systems. They are the azimuth over elevation and the elevation over azimuth positioners.

As with any mechanical system, there are errors associated with the positioners too. The errors that are introduced in the patterns mapping are angle errors or pointing errors. These can be outlined as follows.

A.2.1 Errors Due to Geometry

Geometric errors can be divided into four categories as coordinate – axis alignment error and orthogonality error and the collimation error. The coordinate axis alignment error results when there is an improper alignment of the coordinate system of the test antenna and that of the positioner. The orthogonality error occurs when the θ and ϕ axes are not perpendicular to each other. The third type of geometric error is the collimation error, which occurs due the non-orthogonality of the θ axis with the line from the origin of the positioner coordinate system to the source antenna. The last of this classification is the axis runout and axis wobble error [3].

A.2.2 Shaft Position Error

The next category of errors associated with the positioners is the shaft position error. This is a typical error associated with any mechanical system that involves transmission of power through long shafts. When power is transmitted through such a system, the angular displacement at the bottom of the shaft is not the same as the displacement at the top of the shaft, which is lesser than that at the bottom of the shaft. The extent of the difference depends on the nature of the material of the shaft and its stiffness modulus. The higher the modulus of rigidity, the lower is the difference in angular displacement.

The motion of the stepper motors used can have a significant effect on the positioning of the rotator. As the motor rotates, it acquires momentum and as a result of the inertia developed, it cannot come to a stop at the exact position that is required. The

momentum will carry it a little further than required and introduces an error in the positioning of the rotator. If the momentum were high, then the error introduced would be correspondingly high. This could be reduced in two ways, one by reducing the weight of the entire setup and two by reducing the acceleration the rotator is subjected to.

A.2.3 Deflection Errors

These errors occur when there are structural changes in the positioner due to changes in the environment, which cause thermal expansion or contraction and changes in the forces applied to the positioner. Some of the various factors that cause deflection error are solar heating and changes in forces applied on the positioner. The effect of solar heating could be reduced by using solar reflectors, insulating shields, reflecting paints, barriers or by placing the positioner in an environment that is not exposed to sunlight, such as an anechoic chamber. The effect of the changes in forces that are applied on the positioner is reflected more when the forces are bending moments applied at the antenna mounting surfaces. Adding counter balance weights in the design in such a way that the changes due to the bending moments are minimized could reduce the effects of such moments.

The next in the antenna range instrumentation is the antenna pattern recorder. This provides a graphical representation of the antenna pattern, with the amplitude as a function of the angular position of the antenna. Typically, antenna pattern recorders were electromechanical devices, but in recent, graphing software is used to plot the amplitude variations of the pattern with angular position. Antenna patterns maybe recorded in either polar or rectangular coordinates. Polar coordinates are used in the case where the antenna

under test is not highly directional and particularly for visualizing the power distribution in space. On the other hand, rectangular coordinates are used with the amplitude variations on the *y-* axis and the angular position on the *x-* axis for antennas that are highly directional and in cases where crowding of data points needs to be avoided in regions of relatively low gain [3]. Another method of representing the amplitude patterns is by means of contour plots. These plots are obtained by connecting points of equal signal strengths with lines to form isolevel contours.

Appendix B - Program Code

B.1 Form 1

```
Option Explicit
        Dim s As Long, step_number As String, switchstat As Integer
        Dim st, Dim l As Integer

Private Sub cmdAbout_Click ()
'Show the About form.
   Form10.Show
End Sub

Private Sub cmdMarker_Click ()
'Display the form to set the marker.
   Form5.Show
End Sub

Private Sub cmdModulation_Click ()
'Display the form to set Modulation.
   Form2.Show
End Sub

Private Sub cmdRFpower_Click ()
'Display the form to set RF power.
   Form4.Show
End Sub

Private Sub cmdMotorOption_Click ()
'Display the appropriate form for the motor.
   Form7.Show
End Sub

Private Sub cmdPolarplot_Click ()
'Load the polar plot form.
   Form9.Show
End Sub

Private Sub cmdRTD_Click ()
'Launch the Real Time Data window.
   Form11.Show
End Sub

Private Sub cmdSetRFpower_Click ()
```

```
’ Display the appropriate form to set the signal generator stuff.
    Form4.Show
End Sub

Private Sub cmdSigGenerator_Click ()

    ’ Check for the status of the handle ud1. If ud1 is 0 then initialize the
    ’ Board, else continue with other things...
    If ud1 = 0 Then
       Screen.MousePointer = vbHourglass
       ibfind "gpib0", ud1
       ibsic ud1
       ibrsc ud1, 1
       ibsre ud1, 1
       ibdev 0, 19, 0, 13, 1, 0, ud3
       Screen.MousePointer = vbDefault
          If ud3 = -1 Then
             Msg = "Error In Initializing"
             Style = vbOKOnly
             Title = "Signal Generator"
             Response = MsgBox (Msg, Style, Title)
          Else
             Msg = "Signal Generator Initialized"
             Style = vbOKOnly
             Title = "Signal Generator"
             Response = MsgBox (Msg, Style, Title)
          End If
       Else
       ibdev 0, 19, 0, 13, 1, 0, ud3
       ibwrt ud3, "*TST?"
          If ud3 = -1 Then
             Msg = "Error In Initializing"
             Style = vbOKOnly
             Title = "Signal Generator"
             Response = MsgBox (Msg, Style, Title)
          Else
             Msg = "Signal Generator Initialized"
             Style = vbOKOnly
             Title = "Signal Generator"
             Response = MsgBox (Msg, Style, Title)
          End If
       End If
End Sub

Private Sub cmdSpecAnalyzer_Click ()
    ’ Check for the status of ud1. If ud1 is 0 then initialize the
```

```
    ' Board, else continue with other things...
    If ud1 = 0 Then
       Screen.MousePointer = vbHourglass
       ibfind "gpib0", ud1
       ibsic ud1
       ibrsc ud1, 1
       ibsre ud1, 1
       ibdev 0, 18, 0, 13, 1, 0, ud2
       Screen.MousePointer = vbDefault
       ibwrt ud2, "ip"
          If ud2 = -1 Then
             Msg = "Error in Initializing Device"
             Style = vbOKOnly
             Title = "Error"
             Response = MsgBox(Msg, Style, Title)
          Else
             Msg = "Spectrum Analyzer Initialized"
             Style = vbOKOnly
             Title = "Spectrum Analyzer"
             Response = MsgBox(Msg, Style, Title)
          End If
    Else
       ibdev 0, 18, 0, 13, 1, 0, ud2
          If ud2 = -1 Then
             Msg = "Error in Initializing Device"
             Style = vbOKOnly
             Title = "Error"
             Response = MsgBox(Msg, Style, Title)
          Else
             Msg = "Spectrum Analyzer Initialized"
             Style = vbOKOnly
             Title = "Spectrum Analyzer"
             Response = MsgBox(Msg, Style, Title)
          End If

    End If
    markerstatus = 0
End Sub

Private Sub cmdStart_Click ()
' Reload the RPM on the motors. The new value of the rpm
' is set along with the angular separation between data points.
' For a separation of 0.9 degrees, the speed is 10 rpm.
' For a separation of 1.8 and 4.5 degrees, the speed is 20 rpm.
   status = load_rpm(1, 3, rpm)
' Set the Mousepointer to Hourglass.
```

```
       Screen.MousePointer = vbHourglass
' Disable the Write Option.
    Command2.Enabled = False
' Check if the marker is set.
    If markerstatus = 0 Then
        Msg = "Marker NOT Set!"
        Style = vbOKOnly
        Title = "Error"
        Response = MsgBox(Msg, Style, Title)
        Screen.MousePointer = vbDefault
    Else
        ' Set the Units to measure the Amplitude.
            ibwrt ud2, "tdf p;aunits dbm"
        ' Initialize the counter variable.
            i = 0
            id_number = i
        ' Take measurements at the Home position.
            ibwrt ud2, "mka?"
ibrd ud2, pos (i, 1)
            data_value = pos(id_number, 1)
        ' Load the real time data form.
            Form11.Show
        ' Initialize the position counter.
            Position = ref_home_pos
        ' Now start the motion in the forward direction.
            status = find_home(1, 3, 0)
        ' Start the loop to check the limit switch status.
            Do
                ' Check the status of the limit switches.
                    status = read_lim_stat(1, switchstat)
                ' If the forward position is reached, then stop motion.
                    If switchstat = 8 Then
                        status = stop_motion(1, 3)
                        i = i + 1
                        id_number = i
                        ibwrt ud2, "mka?"
                        ibrd ud2, pos(i, 1)
                        data_value = pos(id_number, 1)
                        status = read_pos(1, 3, ref_for_pos)
                        Exit Do
                    Else
                        ' Check the position counter.
                            status = read_pos(1, 3, Nposition)
                        ' Check for the positioning.
                            If Nposition = Position + m * increment Then
                                i = i + 1
```

```
                id_number = i
                ibwrt ud2, "mka?"
                ibrd ud2, pos(i, 1)
                data_value = pos(id_number, 1)
                Position = Nposition
            Else
            End If
        End If
    Loop
' Set the counter variable in the reverse direction.
        i_rev = 0
        id_number = i_rev
        ibwrt ud2, "mka?"
        ibrd ud2, revpos(i_rev, 1)
        data_value = pos(id_number, 1)
        ""Position = Nposition""
' Set the rotator to go in the opposite direction.
        status = find_home(1, 3, -1)
      Do
      'Take measurements in the opposite directions too.
      ' Check the Status of the Limit Switches.
        status = read_lim_stat(1, switchstat)
      ' If the Home position is reached, then stop motion.
        If switchstat = 512 Then
            status = stop_motion(1, 3)
            ibwrt ud2, "mka?"
            i_rev = i_rev + 1
            id_number = i_rev
            ibrd ud2, revpos(i_rev, 1)
            data_value = pos(id_number, 1)
            status = read_pos(1, 3, ref_home_pos)
            Exit Do
        Else
        ' Check the position counter.
            status = read_pos(1, 3, Nposition)
        'Check for positioning.
          If Nposition = Position - m * increment Then
            i_rev = i_rev + 1
            id_number = i_rev
            ibwrt ud2, "mka?"
            ibrd ud2, revpos(i_rev, 1)
            data_value = pos(id_number, 1)
            Position = Nposition
          Else
          End If
        End If
```

```
        Loop
    j = i
    j_rev = i_rev
    If Check1.value = 1 Then k = k + 1: Form6.Show
    Screen.MousePointer = vbDefault
    Command2.Enabled = True
    End If
End Sub

Private Sub Command1_Click()
'Switch on the Signal Generator RF signal.
    ibwrt ud3, "OUTP:STAT ON"
    Command3.Visible = True
    Command3.Enabled = True
    Command1.Enabled = False
    Command1.Visible = False

End Sub

'Write the data to the Disk.
Private Sub Command2_Click()

        'Time and Date.
            Dim mytime, mydate
            mytime = Time
            mydate = Date
        'Set Progressbar Stuff.
            ProgressBar1.Visible = True
        'Set the name and other details.
            UserName = Text3.Text
            description = Text4.Text
        'Open the file for Writing the Data.
            Header4 = Space$(100)
            Header4 = FileName.Text
            Open Header4 For Output As #1
            ProgressBar1.Min = 0
            ProgressBar1.Max = j
            Print #1, "Date :"; mydate
            Print #1, "Time :"; mytime
            Print #1, "Name of User:"; UserName
            Print #1, "Description of the Test:"; description
            Print #1, Header1
            Print #1, Header2
            Print #1, Header3
            Print #1,
            Print #1, "Measurements in the Forward Direction"
```

```
      Print #1,
      Print #1, "Angle(deg)"; ","; "Amplitude(dBm)"
      Print #1,
      For i = 0 To j
         ProgressBar1.value = i
         Print #1, i * rotator_angle; ","; Val(pos(i, 1))
      Next i
      Print #1,
      Print #1, "Measurements in the Backward Direction"
      Print #1, "Angle(deg)"; ","; "Amplitude(dBm)"
      Print #1,
      ProgressBar1.Visible = True
      ProgressBar1.Min = 0
      ProgressBar1.Max = j_rev
      For i = 0 To j_rev
         ProgressBar1.value = i
         Print #1, i * rotator_angle; ","; Val(revpos(j_rev - i, 1))
      Next i
      ProgressBar1.Visible = False
    ' Close the File after Writing.
      Close #1


End Sub

Private Sub Command3_Click()
ibwrt ud3, "OUTP:STAT OFF"
Command3.Enabled = False
Command3.Visible = False
Command1.Enabled = True
Command1.Visible = True

End Sub

Private Sub Command4_Click()
' Set the upper limit of motion as 72 degrees for the table.


End Sub

Private Sub Form_Load ()
   Command3.Visible = False
   Command1.Visible = False
   Label1.Visible = False
   Text1.Text = 0
   ' Initialize the memory for storing data...
```

```
      For i = 0 To 400
         For j = 0 To 20
            pos(i, j) = Space$(100)
            revpos(i, j) = Space$(100)
         Next j
      Next i


End Sub

Private Sub mnu2Dplot_Click()
'Display the appropriate form.
   Form6.Show
End Sub

Private Sub mnuExit_Click ()
   If ud2 And ud3 > 0 Then
      'Set the Instruments to their original state.
      ibwrt ud2, "MKOFF ALL"
      ibwrt ud3, "AM:STAT OFF"
      ibwrt ud3, "FM:STAT OFF"
      ibwrt ud3, "PM:STAT OFF"
      ibwrt ud3, "OUTP:STAT OFF"
      ibwrt ud3, "POW:REF:STAT OFF"
      'Set the instrument to its Local state.
      ibloc ud2
      ibloc ud3
   ElseIf ud2 > 0 Then
      ibwrt ud2, "MKOFF ALL"
      ibloc ud2
   ElseIf ud3 > 0 Then
      ibwrt ud3, "AM:STAT OFF"
      ibwrt ud3, "FM:STAT OFF"
      ibwrt ud3, "PM:STAT OFF"
      ibwrt ud3, "OUTP:STAT OFF"
      ibwrt ud3, "POW:REF:STAT OFF"
      ibloc ud3
   End If
   'End the session by closing the program.
      End
End Sub

Private Sub mnuMotors_Click ()
' PLEASE  NOTE:  THE  INITIALIZING  COMMANDS  FOR  THE  TABLE
(MOTOR #4) ARE COMMENTED!

'Initialize the motors...
```

```
         ' Set Position Mode.
            'Set the motion in the Absolute mode of operation.
               status = set_pos_mode(1, 3, 0)
                'status = set_pos_mode(1, 4, 0)
         ' Set Stop Mode
            ' A value of 2 is for setting the stop mode
            ' in the halt mode...
            Mode = 2
            status = set_stop_mode(1, 3, Mode)
            'status = set_stop_mode(1, 4, Mode)
         ' Set the limit switches polarity.
            ' Set the entire limit & home switches in the non-inverting mode.
            status = set_lim_pol(1, 4095)
         ' Enable limits.
            ' Enable all limit & home switches.
            status = enable_limits(1, 4095)
         ' Initialization steps that have to be executed
         ' before operating the motors.

         ' Load Steps/Rev
            steps = 800
            status = store_steps_rev(1, 3, steps)
            'status = store_steps_rev(1, 4, steps)
         ' Load acceleration.
            status = load_accel(1, 3, 1)
            'status = load_accel(1, 4, 1)
         ' Load RPM.
            'rpm = 20
            status = load_rpm(1, 3, 30)
            'status = load_rpm(1, 4, rpm)
         ' Load the MotorInit form to find home.
            Load Form8

End Sub

Private Sub mnuSFreq_Click ()
   Form3.Show
End Sub



Private Sub Tiltdown_Click ()
' Enable the tilt increase button.
   Tiltup.Enabled = True

' This can be used to decrease the tilt of the table from any position to
```

```
’ go to the desired position.
   newtilt_dec = Val(Text1.Text) - 1.8
’ Check for the limits of movement. The limit is set to -72 degrees from the
horizontal
’ position of the table.
   If newtilt_dec < -72 Then
      Msg = "Limit of Tilt reached!"
      Title = "Warning!"
      Response = MsgBox(Msg, vbOKOnly, Title)
      Tiltdown.Enabled = False
      newtilt_dec = -72
   Else
   End If
’ Display the tilt position.
Text1.Text = CStr (newtilt_dec)

End Sub

Private Sub Tiltup_Click ()
’ Enable the Tiltdown button.
   Tiltdown.Enabled = True
’ This can be used to increase the inclination of the table from the
’ horizontal home position to the desired tilt position.
   newtilt_inc = Val(Text1.Text) + 1.8
’ Check for limits of movement. The limit is set at +72 degrees from the
’ horizontal position of the table.
   If newtilt_inc > 72 Then
      Msg = "Limit of Tilt reached"
      Title = "Warning!"
      Response = MsgBox(Msg, vbOKOnly, Title)
      Tiltup.Enabled = False
      newtilt_inc = 72
   Else
   End If
’ Display the tilt position.
   Text1.Text = CStr(newtilt_inc)
End Sub

Private Sub Timer1_Timer()
’ This is to display the date and time on the User Interface window.
   Label8.Caption = Now
End Sub
```

B.2 Form 2

```
Option Explicit


Private Sub AMOption1_Click()
   'Make the options visible.
      Frame4.Visible = True
      Frame5.Visible = False
      Frame6.Visible = False

End Sub

Private Sub AMOption2_Click()
   'Make the options visible.
      Frame4.Visible = False
      Frame5.Visible = True
      Frame6.Visible = False


End Sub

Private Sub AMOption3_Click()
   'Make the options visible.
      Frame4.Visible = False
      Frame5.Visible = False
      Frame6.Visible = True

End Sub

Private Sub cmdAMcancel_Click ()
   'Unload the form
      Unload Me
End Sub

Private Sub cmdAMset_Click ()
'Set the other options off.
   ibwrt ud3, "FM:STAT OFF"
   ibwrt ud3, "PM:STAT OFF"
'Turn on Amplitude Modulation.
   ibwrt ud3, "AM:STAT ON"
'Set the parameters.

   If AMOption1.value = True And AMinternal1.value = True Then
      AMchoice = 1
   ElseIf AMOption1.value = True And AMinternal2.value = True Then
```

```
          AMchoice = 2
       ElseIf AMOption2.value = True And AMexternal1.value = True Then
          AMchoice = 3
       ElseIf AMOption2.value = True And AMexternal2.value = True Then
          AMchoice = 4
       Else
          AMchoice = 5
       End If
' Set the combination of parameters to get appropriate
' Modulation.
    Select Case AMchoice
       Case 1
          ibwrt ud3, "AM:INT:FREQ 1 kHz"
       Case 2
          ibwrt ud3, "AM:INT:FREQ 400 Hz"
       Case 3
          ibwrt ud3, "AM:EXT:COUP DC"
       Case 4
          ibwrt ud3, "AM:EXT:COUP AC"
       Case 5
          Msg = "Choose Modulating Freq. "
          Style = vbOKOnly
          Title = "Error !"
          Response = MsgBox(Msg, Style, Title)
       End Select
    Unload Me
End Sub


Private Sub cmdFMcancel_Click ()
    ' Unload the form.
       Unload Me
End Sub


Private Sub cmdFMset_Click ()
' Set the other modulation options off.
    ibwrt ud3, "AM:STAT OFF"
    ibwrt ud3, "PM:STAT OFF"
' Turn on Frequency Modulation.
    ibwrt ud3, "FM:STAT ON"
' Set the parameters.
    If FMOption1.value = True And FMinternal1.value = True Then
       FMchoice = 1
    ElseIf FMOption1.value = True And Fminternal2.value = True Then
       FMchoice = 2
    ElseIf FMOption2.value = True And FMexternal1.value = True Then
       FMchoice = 3
```

```
        ElseIf FMOption2.value = True And FMexternal2.value = True Then
           FMchoice = 4
        Else
           FMchoice = 5
        End If
        Select Case FMchoice
           Case 1
              ibwrt ud3, "FM:INT:FREQ 1 kHz"
           Case 2
              ibwrt ud3, "FM:INT:FREQ 400 Hz"
           Case 3
              ibwrt ud3, "FM:EXT:COUP DC"
           Case 4
              ibwrt ud3, "FM:EXT:COUP AC"
           Case 5
              Msg = "Choose Modulating Freq. "
              Style = vbOKOnly
              Title = "Error !"
              Response = MsgBox(Msg, Style, Title)
        End Select
     Unload Me
End Sub


Private Sub cmdPMcancel_Click ()
   ' Unload the form.
      Unload Me
End Sub


Private Sub cmdPMset_Click ()
' Set the other Modulation options off.
   ibwrt ud3, "AM:STAT OFF"
   ibwrt ud3, "FM:STAT OFF"
' Turn on Phase Modulation.
   ibwrt ud3, "PM:STAT ON"
' Set the parameters.
   If PMOption1.value = True And PMinternal1.value = True Then
      PMchoice = 1
   ElseIf PMOption1.value = True And PMinternal2.value = True Then
      PMchoice = 2
   ElseIf PMOption1.value = True And PMinternal1.value = True Then
      PMchoice = 3
   ElseIf PMOption1.value = True And PMOption2.value = True Then
      PMchoice = 4
   Else
      PMchoice = 5
   End If
```

```vb
' Set the combination of parameters to get appropriate
' Modulation.
   Select Case PMchoice
      Case 1
         ibwrt ud3, "PM:INT:FREQ 1 kHz"
      Case 2
         ibwrt ud3, "PM:INT:FREQ 400Hz"
      Case 3
         ibwrt ud3, "PM:EXT:COUP DC"
      Case 4
         ibwrt ud3, "PM:EXT:COUP AC"
      Case 5
         Msg = "Choose Modulating Freq. "
         Style = vbOKOnly
         Title = "Error !"
         Response = MsgBox(Msg, Style, Title)
      End Select
   Unload Me
End Sub

Private Sub FMOption1_Click()
   ' Set the other frame invisible.
      Frame10.Visible = True
      Frame11.Visible = False
      Frame12.Visible = False
End Sub
Private Sub FMOption2_Click()
   ' Set the other frames invisible.
      Frame10.Visible = False
      Frame11.Visible = True
      Frame12.Visible = False
End Sub
Private Sub FMOption3_Click()
   ' Set other frames invisible
      Frame10.Visible = False
      Frame11.Visible = False
      Frame12.Visible = True
End Sub



Private Sub Mod1_Click()
   ' Set the other frame invisible.
      Frame1.Visible = True
      Frame2.Visible = False
      Frame3.Visible = False
```

```vb
End Sub
Private Sub Mod2_Click()
    ' Set the other frame invisible.
        Frame1.Visible = False
        Frame2.Visible = True
        Frame3.Visible = False
End Sub
Private Sub Mod3_Click()
    ' Set the other frames invisible.
    Frame1.Visible = False
    Frame2.Visible = False
    Frame3.Visible = True
End Sub
Private Sub PMOption1_Click()
    ' Make the options visible.
        Frame7.Visible = True
        Frame8.Visible = False
        Frame9.Visible = False
End Sub

Private Sub PMOption2_Click()
    ' Make options visible.
        Frame7.Visible = False
        Frame8.Visible = True
        Frame9.Visible = False
End Sub
Private Sub PMOption3_Click()
    ' Make options visible.
        Frame7.Visible = False
        Frame8.Visible = False
        Frame9.Visible = True
End Sub
```

B.3 Form 3

```
Option Explicit

Private Sub Cancel_Click ()
Unload Me
End Sub

Private Sub CenterFreq_Click ()
   Frame1.Visible = True
   CenterFreqSet.Visible = True
   Frame2.Visible = True
   Frame3.Visible = False
   Frame4.Visible = False
   StartStopFreqSet.Visible = False
   identifier = 1
End Sub

Private Sub CenterFreqSet_Click ()
   Center_Frequency = Text1.Text
   Span_Frequency = Text2.Text

   If CFOption1.value = True Then
      freq = "CF" + " " + Text1.Text + "MHz"
      Header1 = "The Center Frequency is" + Text1.Text + "  MHz"
      H1 = Text1.Text + "  MHz"
   ElseIf CFOption2.value = True Then
      freq = "CF" + " " + Text1.Text + "kHz"
      Header1 = "The Center Frequency is" + Text1.Text + "  kHz"
      H1 = Text1.Text + "  kHz"
   Else
      freq = "CF" + " " + Text1.Text + "Hz"
      Header1 = "The Center Frequency is" + Text1.Text + "  Hz"
      H1 = Text1.Text + "  Hz"
   End If

   If SPOption1.value = True Then
      Span = "SP" + " " + Text2.Text + "MHz"
      Header2 = "The Frequency Span is" + Text2.Text + "  MHz"
      S1 = Text2.Text + "  MHz"
   ElseIf SPOption2.value = True Then
      Span = "SP" + " " + Text2.Text + "kHz"
      Header2 = "The Frequency Span is" + Text2.Text + "  kHz"
      S1 = Text2.Text + "  kHz"
   Else
```

```vb
      Span = "SP" + " " + Text2.Text + "Hz"
      Header2 = "The Frequency Span  is" + Text2.Text + "  Hz"
      S1 = Text2.Text + "  Hz"
   End If

   ibwrt ud2, freq
   ibwrt ud2, Span
   Form1.Flabel.Caption = "Center Frequency"
   Form1.Slabel.Caption = "Span"
   Form1.Label9.Caption = H1
   Form1.Label10.Caption = S1
   Unload Me
End Sub




Private Sub StartStopFreq_Click ()
   Frame1.Visible = False
   Frame2.Visible = False
   CenterFreqSet.Visible = False
   Frame3.Visible = True
   Frame4.Visible = True
   StartStopFreqSet.Visible = True
   identifier = 2
End Sub

Private Sub StartStopFreqSet_Click ()
If STAOption1.value = True Then
   start_freq = "FA" + " " + Text3.Text + "MHz"
   Header1 = "The Start Frequency is " + Text3.Text + "  MHz"
   H2 = Text3.Text + "  MHz"
   ElseIf STAOption2.value = True Then
   start_freq = "FA" + " " + Text3.Text + "kHz"
   Header1 = "The Start Frequency is " + Text3.Text + "  kHz"
   H2 = Text3.Text + "  kHz"
   Else
   start_freq = "FA" + " " + Text3.Text + "Hz"
   Header1 = "The Start Frequency is " + Text3.Text + "  Hz"
   H2 = Text3.Text + "  Hz"
End If
If STOOption1.value = True Then
   stop_freq = "FB" + " " + Text4.Text + "MHz"
   Header2 = "The Stop Frequency is " + Text4.Text + "  MHz"
   S2 = Text4.Text + "  MHz"
   ElseIf STOOption2.value = True Then
   stop_freq = "FB" + " " + Text4.Text + "kHz"
```

```
        Header2 = "The Stop Frequency is " + Text4.Text + "  kHz"
        S2 = Text4.Text + "  kHz"
        Else
        stop_freq = "FB" + " " + Text4.Text + "Hz"
        Header2 = "The Stop Frequency is " + Text4.Text + "  Hz"
        S2 = Text4.Text + "  Hz"
        End If

ibwrt ud2, start_freq
ibwrt ud2, stop_freq
Form1.Flabel.Caption = "Start Frequency"
Form1.Slabel.Caption = "Stop Frequency"
Form1.Label9.Caption = H2
Form1.Label10.Caption = S2
Unload Me
End Sub
```

B.4 Form 4

```
Option Explicit

Private Sub cmdReference_Click ()
  ' Set the Reference Power level.
     ibwrt ud3, "pow:ref:stat on"
     ibwrt ud3, "pow:ref" + " " + Text3.Text + "dBm"

End Sub




Private Sub PLOption1_Click()
  Frame3.Visible = False
End Sub

Private Sub PLOption2_Click()
  Frame3.Visible = True
End Sub

Private Sub RefCancel_Click ()
  Unload Me
End Sub

Private Sub SGcmd1_Click()
  If Option1.value = True Then
     SGfrequency = "FREQ:CW" + " " + Text1.Text + "MHz"
     SGlabel = Text1.Text + "MHz"
     ElseIf Option2.value = True Then
     SGfrequency = "FREQ:CW" + " " + Text1.Text + "kHz"
     SGlabel = Text1.Text + "kHz"
     Else
     SGfrequency = "FREQ:CW" + " " + Text1.Text + "Hz"
     SGlabel = Text1.Text + "Hz"
  End If
  SGpower = "POW:AMPL" + " " + Text2.Text + "dBm"
  ibwrt ud3, SGfrequency
  ibwrt ud3, SGpower
  Form1.Command1.Visible = True
  Form1.Label1.Visible = True
  Form1.Label7.Caption = SGlabel
  Unload Me
End Sub
```

```
Private Sub SGcmd2_Click()
    Unload Me
End Sub
```

B.5 Form 5

```
Option Explicit

Private Sub Command1_Click()
   Unload Me
   markerstatus = 0
End Sub

Private Sub Form_Load ()
If identifier = 1 Then
MaCfreq.Caption = H1
maspan.Caption = S1
ElseIf identifier = 2 Then
Label1.Caption = "Start Frequency"
Label2.Caption = "Stop Frequency"
MaCfreq.Caption = H2
maspan.Caption = S2
End If
End Sub
Private Sub SAstuff_Click ()
'Check if the Spectrum Analyzer is Initialized.
   If ud2 = 0 Then
      Msg = "Error! Spectrum Analyzer not Initialized."
      Style = vbOKOnly
      Title = "Error!"
      Response = MsgBox(Msg, Style, Title)
   Else
      'Set the Marker frequencies.
        If Marker1.value = True Then
           Markerfreq = "mkn" + " " + Text1.Text + "MHz"
           Header3 = "The Marker frequency is " + Text1.Text + "MHz"
           mark = Text1.Text + "MHz"
        ElseIf Marker2.value = True Then
           Markerfreq = "mkn" + " " + Text1.Text + "kHz"
           Header3 = "The Marker frequency is " + Text1.Text + "kHz"
           mark = Text1.Text + "kHz"
        Else
           Markerfreq = "mkn" + " " + Text1.Text + "Hz"
           Header3 = "The Marker frequency is " + Text1.Text + "Hz"
           mark = Text1.Text + "Hz"
        End If
      'Write it to the Spectrum Analyzer.
        ibwrt ud2, Markerfreq
```

```
            markerstatus = 1
            Form1.Label11.Caption = mark
            Unload Me
    End If
End Sub
```

B.6 Form 6

```
Option Explicit

Private Sub cmdClose_Click ()
' Unload the form.
    Unload Me
End Sub

Private Sub Form_Load ()
' Check the data for the Minimum and Maximum values.
        minimum = Val(pos(i, 1))
        maximum = Val(pos(i, 1))
        For counter = 1 To j - 1
           If Val(pos(counter, 1)) >= maximum Then
              maximum = Val(pos(counter, 1))
           Else
           End If
        Next counter
        For counter = 1 To j - 1
           If Val(pos(counter, 1)) <= minimum Then
              minimum = Val(pos(counter, 1))
           Else
           End If
        Next counter
     Text1.Text = maximum
     Text2.Text = minimum
     Chart.ChartGroups(1).Data.NumSeries = 1
     Chart.ChartGroups(1).Data.NumPoints(1) = i
' Set the stuff on the plot.
     Chart.ChartGroups(1).ChartType = oc2dTypePlot
     Chart.AllowUserChanges = False
     Chart.ChartArea.Axes("X").Max.value = i + 5
     Chart.ChartArea.Axes("Y").Max.value = 0 'maximum + 2.5
     Chart.ChartArea.Axes("Y").Min.value = -80 'minimum - 2.5
     Chart.ChartArea.Axes("Y").Origin.value = 0 'maximum + 2.5
     'Chart.ChartGroups(1).Styles(1).line.Color = RGB(128, 0, 0)
     Chart.ChartGroups(1).Styles(1).line.Width = 1
     Chart.ChartGroups(1).Styles(1).Symbol.Shape = oc2dShapeDot
     Chart.ChartGroups(1).Styles(1).Symbol.Size = 3
     Chart.ChartGroups(1).Styles(1).Symbol.Color = RGB(128, 0, 0)

For i = 1 To j - 1
     Chart.ChartGroups(1).Data.x(1, i) = i
     Chart.ChartGroups(1).Data.y(1, i) = Val(pos(i, 1))
```

```
Next i
Chart.IsBatched = False
End Sub
Private Sub mnucopy_Click()
' Copy to the clipboard.
   Chart.CopyToClipboard (oc2dFormatBitmap)
End Sub
```

Form 7

```
Option Explicit
Private Sub cmdCancel_Click()
   ' Unload the form...
      Unload Me
End Sub
Private Sub cmdDone_Click()
   Form1.Label12.Caption = Text1.Text + "  Deg"
   Form1.Label13.Caption = CStr(0) + "  Deg"
' Finish the procedures and Unload it.
   Unload Me
End Sub
Private Sub Combo1_Click()
'Display the Selected Angular separation.
   Text1.Text = Combo1.Text
'Set the angular separation to a variable.
   rotator_angle = Val(Text1.Text)
End Sub
Private Sub Combo2_Click()
'Display the Selected Angular separation.
   Text2.Text = Combo2.Text
'Set the angular separation to a variable.
   table_angle = Val(Text2.Text)
End Sub

Private Sub Command4_Click()
' Unload the form.
   Unload Me
End Sub

Private Sub Rotset_Click()

   ' Set the steps for the rotator.
     If rotator_angle = 0.9 Then
        increment = 30
        rpm = 10
     ElseIf rotator_angle = 1.8 Then
```

```
          increment = 60
          rpm = 20
      ElseIf rotator_angle = 4.5 Then
          increment = 150
          rpm = 20
      Else
          Title = "Warning!"
          Msg = "Angular Separation Set to default, 0.9 degrees!"
          Response = MsgBox(Msg, vbOKOnly, Title)
          increment = 30
      End If
   ' Set Mouse pointer to default.
      Screen.MousePointer = vbDefault

End Sub

Private Sub Tabset_Click()
' Set the Parameters for the Table.
   'set the table increment.
      Tableincrement = 60
   ' Set Mouse pointer to default.
      Screen.MousePointer = vbDefault
End Sub
```

B.7 Form 7

```
Option Explicit
Private Sub cmdCancel_Click()
  ' Unload the form...
     Unload Me
End Sub
Private Sub cmdDone_Click()
  Form1.Label12.Caption = Text1.Text + "  Deg"
  Form1.Label13.Caption = CStr(0) + "  Deg"
' Finish the procedures and Unload it.
  Unload Me
End Sub
Private Sub Combo1_Click()
'Display the Selected Angular separation.
  Text1.Text = Combo1.Text
'Set the angular separation to a variable.
  rotator_angle = Val(Text1.Text)
End Sub
Private Sub Combo2_Click()
'Display the Selected Angular separation.
  Text2.Text = Combo2.Text
'Set the angular separation to a variable.
  table_angle = Val(Text2.Text)
End Sub

Private Sub Command4_Click()
' Unload the form.
  Unload Me
End Sub

Private Sub Rotset_Click()

  ' Set the steps for the rotator.
    If rotator_angle = 0.9 Then
      increment = 30
      rpm = 10
    ElseIf rotator_angle = 1.8 Then
      increment = 60
      rpm = 20
    ElseIf rotator_angle = 4.5 Then
      increment = 150
      rpm = 20
    Else
      Title = "Warning!"
```

```
        Msg = "Angular Separation Set to default, 0.9 degrees!"
        Response = MsgBox(Msg, vbOKOnly, Title)
        increment = 30
      End If
   ' Set Mouse pointer to default.
      Screen.MousePointer = vbDefault

End Sub

Private Sub Tabset_Click()
' Set the Parameters for the Table.
   'set the table increment.
      Tableincrement = 60
   ' Set Mouse pointer to default.
      Screen.MousePointer = vbDefault
End Sub
```

B.8 Form 8

```
Option Explicit

Private Sub Form_Load ()
    Screen.MousePointer = vbHourglass
    'Display a messagebox.
        'Msg = "Motors Initializing...Please Wait"
        'Response = MsgBox(Msg, vbOKOnly)
    'In this form set both the motors to find their respective
    'Home and final Positions and record the positions.

    'Set the Rotator to find home.
        status = find_home(1, 3, 0)
    Do
        'Read the Limit switch status.
        status = read_lim_stat(1, switchstat)
        'Check if the forward limit switch is tripped or not.
        If switchstat = 8 Then 'Forward limit switch is tripped.
            'Stop motion for just a moment
            status = stop_motion(1, 3)
            'Read the position counter.
            status = read_pos(1, 3, ref_for_pos)
            Exit Do
        Else
        End If
    Loop
    'Start the motion in the reverse direction to find home position.
        status = find_home(1, 3, -1)
    Do
        'Read the Limit switch status.
        status = read_lim_stat(1, switchstat)
        'Check if the forward limit switch is tripped or not.
        If switchstat = 512 Then 'Motion is automatically stopped as home is found.
            'Read the position counter.
            status = read_pos(1, 3, ref_home_pos)
            Exit Do
        Else
        End If
    Loop
'Do the calculations for the number of steps per degree.
    'Have an intermediate step.
    temp = Abs(ref_home_pos - ref_for_pos)
    'Steps per degree is given as
```

```
steps_per_degree = Int (temp / 360)
Screen.MousePointer = vbDefault
   If ref_for_pos > ref_home_pos Then
      m = 1
   Else
      m = -1
   End If
End Sub
```

B.9 Form 9

```
Option Explicit

Private Sub Command1_Click()
Unload Me
End Sub

Private Sub Form_Load ()
Dim pos(400, 1)
Dim mystr, mystr1
Dim i As Integer
Dim PauseTime, Start, Finish, TotalTime
Chart.ChartGroups(1).Data.NumSeries = 1
Chart.ChartGroups(1).Data.NumPoints(1) = 360
minimum = Val(pos(i, 1))
    maximum = Val(pos(i, 1))
    For counter = 1 To j - 1
       If Val(pos(counter, 1)) >= maximum Then
          maximum = Val(pos(counter, 1))
       Else
       End If
    Next counter
    For counter = 1 To j - 1
       If Val(pos(counter, 1)) <= minimum Then
          minimum = Val(pos(counter, 1))
       Else
       End If
    Next counter
  Text1.Text = maximum
  Text2.Text = minimum
'Set the stuff on the plot.
  Chart.ChartGroups(1).ChartType = oc2dTypePolar
  Chart.AllowUserChanges = False
  Chart.ChartGroups(1).Styles(1).line.Width = 1
  Chart.ChartGroups(1).Styles(1).Symbol.Shape = oc2dShapeDot
  Chart.ChartGroups(1).Styles(1).Symbol.Size = 3
  Chart.ChartGroups(1).Styles(1).Symbol.Color = RGB(128, 0, 0)
  Chart.ChartArea.Axes("Y").Min = -90
  Chart.ChartArea.Axes("Y").Max = 0


Chart.ChartArea.AngleUnit = oc2dAngleUnitDegrees
  For i = 1 To 200
```

```
        Chart.ChartGroups(1).Data.x(1, i * 1.8) = i * 1.8
        Chart.ChartGroups(1).Data.y(1, i * 1.8) = Val(pos(i, 1))
    Next i
End Sub

Private Sub mnucopy_Click()
Chart.CopyToClipboard (oc2dFormatBitmap)
End Sub

Private Sub Text1_Click()
Chart.Header.Text = Text1.Text
End Sub
```

B.10 Form 11

```
Private Sub Form_Load ()
'Load the appropriate values of the displayed variables.
  Label3.Caption = CStr(id_number * rotator_angle)
  Label4.Caption = CStr(pos(id_number, 1))

End Sub
```

Appendix C - Sample Data Set from Anechoic Chamber Tests

A sample data set is given here from the various tests conducted in the anechoic chamber. The data given here is for the dipole tests conducted on the 15 December 1998, with the dipoles in the Vertical transmission - Vertical reception configuration (Ver-Ver). The plots corresponding to this data set are Figures 5.1, 5.2 and 5.3, shown in chapter 5.

Date: 12/15/98
Time: 12:21:05 PM
Name of User: Srikanth
Description of the Test: Dipole-Dipole (Ver-Ver)
The Center Frequency is 901 MHz
The Frequency Span is 10 MHz
The Marker frequency is 901 MHz

Measurements in the Forward Direction

Angle (deg)   Amplitude (dBm)

Angle	Amplitude	Angle	Amplitude	Angle	Amplitude	Angle	Amplitude
0	-32.98	91.8	-31.74	181.8	-31.48	271.8	-31.65
1.8	-33.01	93.6	-31.72	183.6	-31.44	273.6	-31.67
3.6	-33.01	95.4	-31.74	185.4	-31.48	275.4	-31.72
5.4	-33.09	97.2	-31.69	187.2	-31.48	277.2	-31.72
7.2	-33.03	99	-31.72	189	-31.44	279	-31.74
9	-33.01	100.8	-31.77	190.8	-31.48	280.8	-31.82
10.8	-32.98	102.6	-31.87	192.6	-31.51	282.6	-31.89
12.6	-32.96	104.4	-31.82	194.4	-31.51	284.4	-31.94
14.4	-32.98	106.2	-31.87	196.2	-31.53	286.2	-31.91
16.2	-32.98	108	-31.87	198	-31.51	288	-31.98
18	-32.91	109.8	-31.89	199.8	-31.53	289.8	-32.08
19.8	-32.98	111.6	-31.89	201.6	-31.53	291.6	-32.08
21.6	-32.91	113.4	-31.94	203.4	-31.55	293.4	-32.21
23.4	-32.89	115.2	-31.91	205.2	-31.58	295.2	-32.24
25.2	-32.84	117	-31.94	207	-31.53	297	-32.26
27	-32.82	118.8	-31.89	208.8	-31.53	298.8	-32.35
28.8	-32.77	120.6	-31.91	210.6	-31.58	300.6	-32.45
30.6	-32.77	122.4	-31.98	212.4	-31.6	302.4	-32.49

32.4	-32.75	124.2	-31.96	214.2	-31.6	304.2	-32.47
34.2	-32.77	126	-31.96	216	-31.65	306	-32.56
36	-32.7	127.8	-31.94	217.8	-31.67	307.8	-32.63
37.8	-32.68	129.6	-31.96	219.6	-31.62	309.6	-32.66
39.6	-32.63	131.4	-31.98	221.4	-31.67	311.4	-32.7
41.4	-32.56	133.2	-31.96	223.2	-31.67	313.2	-32.82
43.2	-32.52	135	-31.91	225	-31.67	315	-32.91
45	-32.52	136.8	-31.94	226.8	-31.69	316.8	-32.91
46.8	-32.49	138.6	-31.91	228.6	-31.72	318.6	-32.87
48.6	-32.42	140.4	-31.89	230.4	-31.65	320.4	-32.94
50.4	-32.38	142.2	-31.89	232.2	-31.67	322.2	-33.01
52.2	-32.35	144	-31.84	234	-31.65	324	-33.01
54	-32.24	145.8	-31.89	235.8	-31.62	325.8	-33.04
55.8	-32.24	147.6	-31.8	237.6	-31.65	327.6	-33.11
57.6	-32.24	149.4	-31.84	239.4	-31.65	329.4	-33.16
59.4	-32.08	151.2	-31.82	241.2	-31.58	331.2	-33.18
61.2	-32.08	153	-31.8	243	-31.6	333	-33.18
63	-32.08	154.8	-31.72	244.8	-31.58	334.8	-33.14
64.8	-32.01	156.6	-31.65	246.6	-31.55	336.6	-33.23
66.6	-32.01	158.4	-31.67	248.4	-31.62	338.4	-33.16
68.4	-31.89	160.2	-31.65	250.2	-31.62	340.2	-33.23
70.2	-31.96	162	-31.67	252	-31.6	342	-33.23
72	-31.96	163.8	-31.65	253.8	-31.58	343.8	-33.25
73.8	-31.84	165.6	-31.62	255.6	-31.6	345.6	-33.28
75.6	-31.82	167.4	-31.55	257.4	-31.58	347.4	-33.25
77.4	-31.77	169.2	-31.6	259.2	-31.53	349.2	-33.28
79.2	-31.82	171	-31.51	261	-31.55	351	-33.25
81	-31.8	172.8	-31.53	262.8	-31.55	352.8	-33.3
82.8	-31.8	174.6	-31.51	264.6	-31.62	354.6	-33.23
84.6	-31.74	176.4	-31.51	266.4	-31.55	356.4	-33.23
86.4	-31.69	178.2	-31.46	268.2	-31.6		
88.2	-31.74	180	-31.51	270	-31.58		
90	-31.72						