

Chapter 4

Measurement Plan

This chapter describes the hardware, methodology and logistics of all propagation measurement campaigns presented in this dissertation. The comprehensive measurement plan, presented in this chapter, is used to serve as guidelines for the actual fieldwork during propagation measurements. The measurement plan specifically documents comprehensive details of the three point-to-point wireless links, chosen for propagation measurement campaigns. In addition, the measurement plan elaborates on the sequence of calibration and propagation measurements performed to record Power Delay Profile (PDP) statistics during different weather events. Steps involved in setting up of channel sounding equipment at different measurement locations are also discussed.

The second half of the chapter elaborates on the rain gauge setup and real-time rainfall recording. Significance of strict time synchronization between propagation measurements and the weather monitoring software is also explained.

4.1 Measurement Site Description

Three cross-campus locations of Virginia Tech are identified for extensive free-space point-to-point Path Loss, and Frequency Diversity propagation measurements in clear-sky and rain conditions. This section of the chapter primarily describes all the measurement locations. Physical location of the transmitter and receiver subsystems, heights of the transmitting and receiving antennas, distance of separation between the transmitting and receiving antennas, and calculated Line of Sight (LOS) propagation link lengths are explicitly presented for all the measurement campaigns. In addition, floor plan maps, aerial view of each measurement location, and relevant pictures of the channel sounding equipment and buildings (that house the channel sounder during propagation measurements), are also included.

The measurement locations and propagation links are chosen to emulate actual downtown pico-cell scenarios with medium and high-rise buildings. For such locations, it is recommended that Local Multipoint Distribution System (LMDS) implementations use high placed and highly directional transmitting and receiving antennas. High placed transmitting and receiving antennas facilitate a clear Line of Sight (LOS) while the use of highly directional antennas ensures minimization of multipath interference from structures close to the LOS.

The aerial view of the first measurement location on the Virginia Tech campus is shown in Figure 4.1. The transmitting antenna and transmitter subsystem of the spread-spectrum channel sounder is placed in the stairwell of Slusher Tower Penthouse. The exact position of the transmitter subsystem in the Penthouse Plan Map is shown in Figure 4.2. The transmitting antenna is positioned close to a glass window, facing the McBryde Hall such that the antenna beam illuminates the receiver antenna and subsystem positioned in McBryde Hall. During the propagation measurements, the receiving antenna and the receiver subsystem are placed in the sixth floor stairwell of the McBryde Hall. Figure 4.3 shows the Plan Map of the sixth floor of McBryde Hall and the position of the channel sounder subsystem.

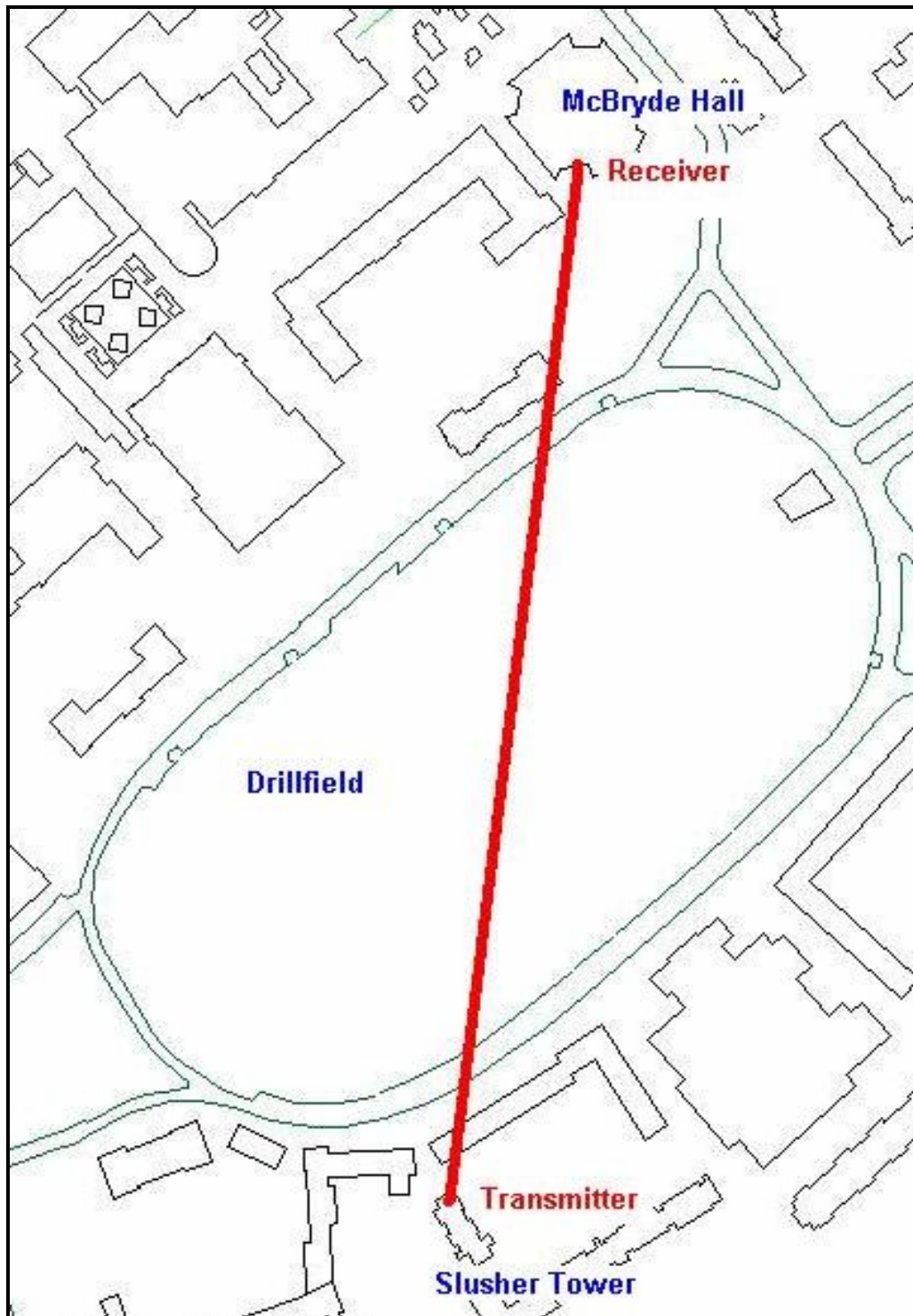


Figure 4.1 Aerial View of Measurement Location 1 on the Virginia Tech Campus. The LOS propagation link length is 531 meters.

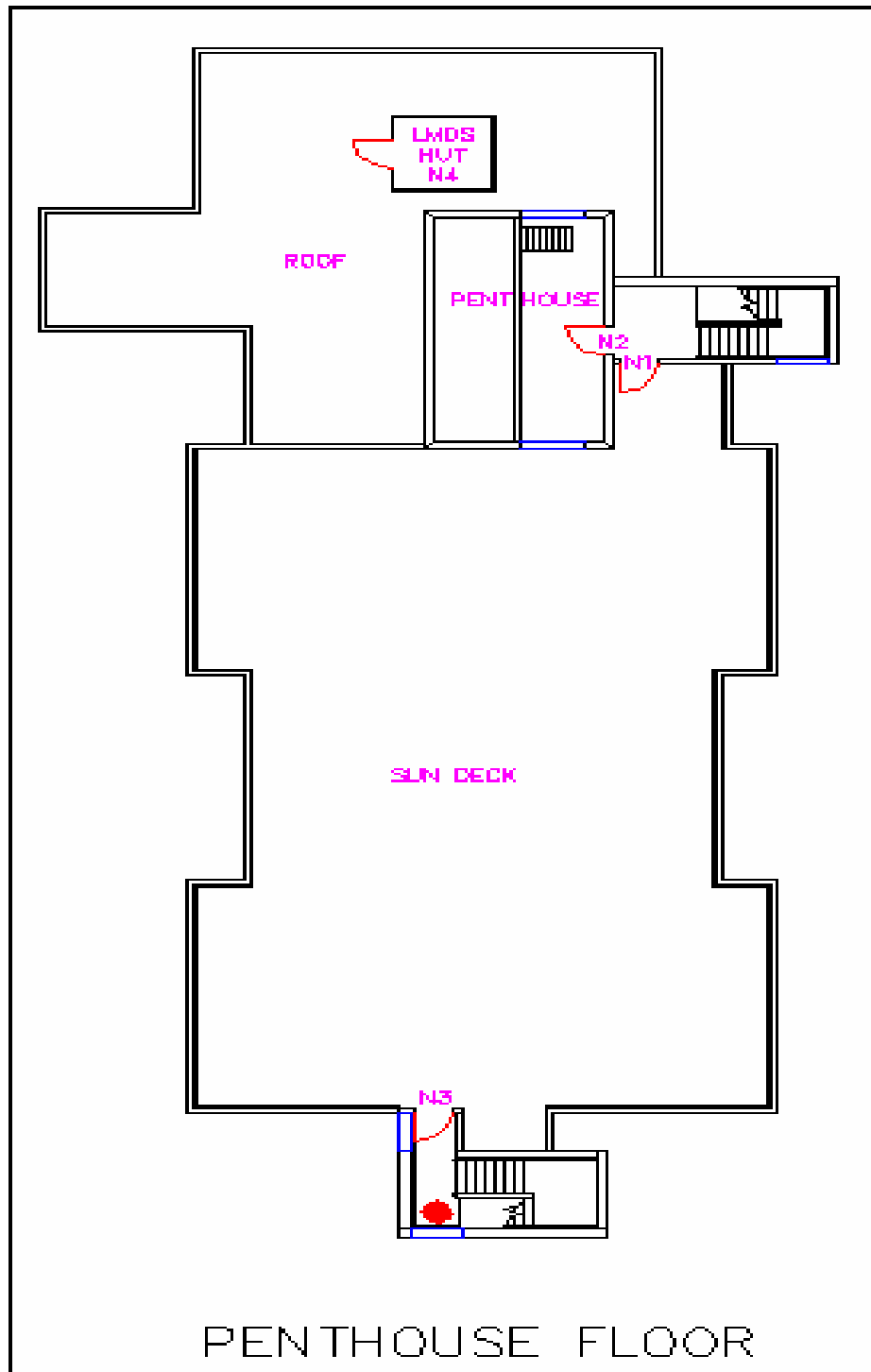


Figure 4.2 The red dot indicates the position of the transmitting antenna and transmitter subsystem in the Plan Map of Slusher Tower Penthouse. The transmitting antenna is facing the McBryde Hall through a glass window which is exactly below the red dot in the Plan Map.

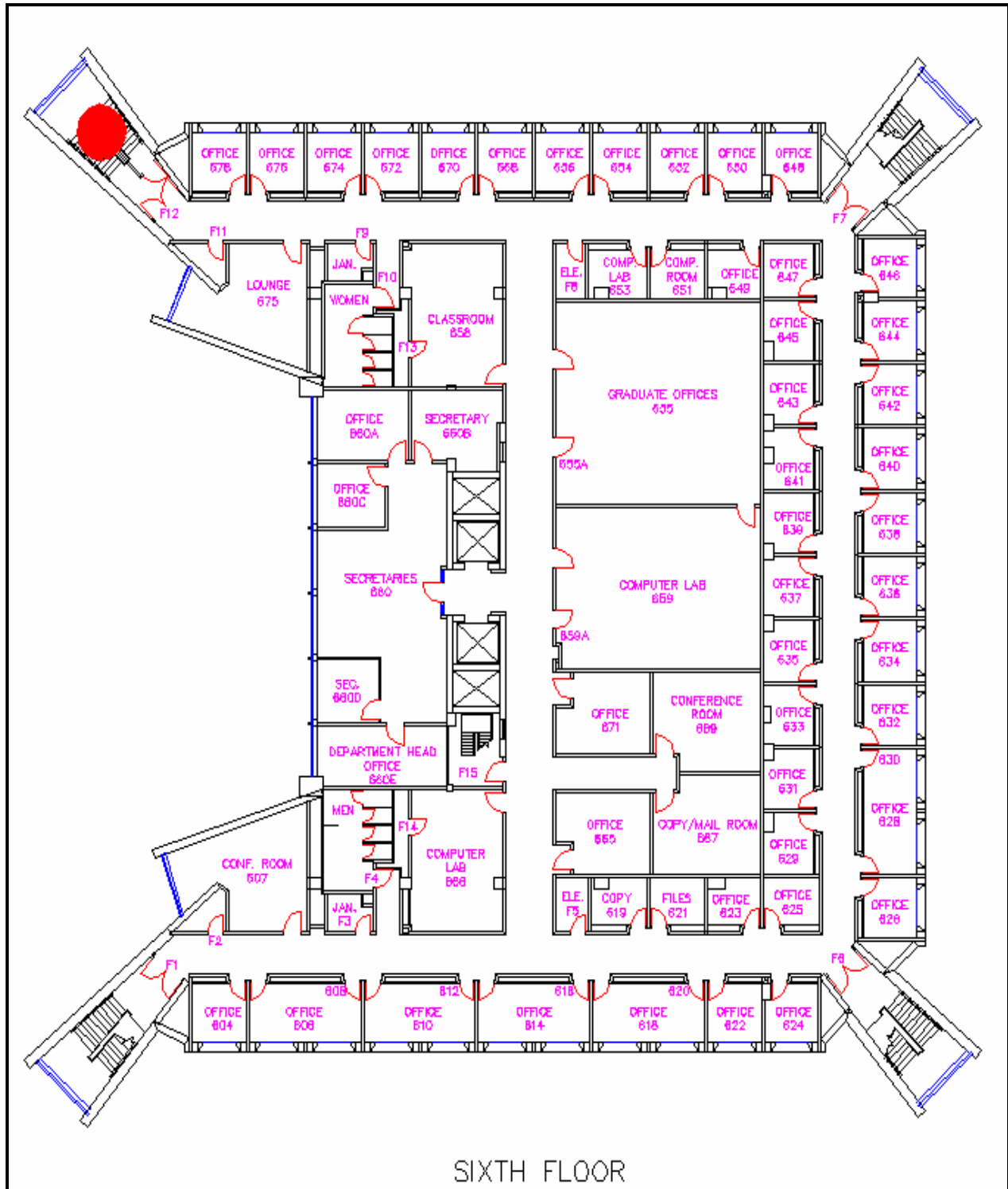


Figure 4.3 The red dot indicates the position of the receiver antenna and the receiver subsystem of the channel sounder in the Plan Map of the sixth floor of McBryde Hall. The receiver antenna is facing the transmitter in the N-W direction relative to the position of red dot in the figure.

Note that the ‘distance of separation’ between on-campus buildings and the ‘elevation’ statistics presented throughout this dissertation have been calculated from corresponding PLAN and ELEVATION Maps available in the University Architects’ Office. The elevation levels of all the building floors specified in respective ELEVATION Maps (and in this dissertation) are relative to a reference ground plane.

During the propagation measurements at Location 1, the height of the transmitting antenna (placed in the Slusher Tower) and receiving antenna (placed in the McBryde Hall) is 53 meters and 44 meters respectively. The corresponding distance of separation between the Slusher Tower and the McBryde Hall is 531 meters. To calculate the Line of Sight (LOS) propagation link length between the transmitting and receiving antennas, let variables H_T and H_R represent the height (relative to the reference plane) of the transmitting and receiving antenna, respectively, and D represent the distance of separation between the two measurement locations. Then the total propagation link length between the antennas can be calculated using Equation 4.1.

$$Link_Length = \sqrt{D^2 + |H_T - H_R|^2} \quad \text{Equation 4.1}$$

Figures 4.4 (a) and (b) respectively show the transmitter and receiver antenna locations during the propagation measurements. The total propagation link length between the two measurement locations depicted in Figure 4.4, calculated using Equation 4.1, is 531.1 meters.

As can be seen from the pictures, the Drillfield separates the transmitter and the receiver locations. Although, there are no obstructing trees or buildings in the Line of Sight (LOS), there are some buildings significantly close to the LOS and may introduce delayed multipath components in the received signal. Also, on a normal school day there are a number of cars parked around the Drillfield, and the human traffic across and around the Drillfield is also significant. These factors can also contribute to multipath components but the use of highly directional horn antennas at the transmitter and receiver subsystems eliminates signal power fluctuations or multipath components.



Figure 4.4.(a) View of Slusher Tower (Tx) from the receiver antenna location in McBryde Hall. The tallest building in the picture is the Slusher Tower.



Figure 4.4.(b) [Left] Close up View of the McBryde Hall. The red cross mark shows the position of the receiving antenna and the receiver subsystem. [Right] View of McBryde Hall from the transmitter antenna location in Slusher Tower.

The second measurement event is performed over a shorter LOS propagation link. During this measurement campaign, the channel sounder transmitter subsystem is maintained in the stairwell of Penthouse of Slusher Tower. However, the position of the transmitting antenna is changed. The transmitting antenna is now setup to face the Newman Library instead of the McBryde Hall. The receiver test equipment along with the receiving antenna is setup in the staff room on the sixth floor of the Newman Library. Figure 4.5 shows the aerial view of Location 2. Figures 4.6 and 4.7, respectively show the positions of the transmitter and receiver subsystems in Plan Maps of the Slusher Tower Penthouse and the sixth floor of the Newman Library

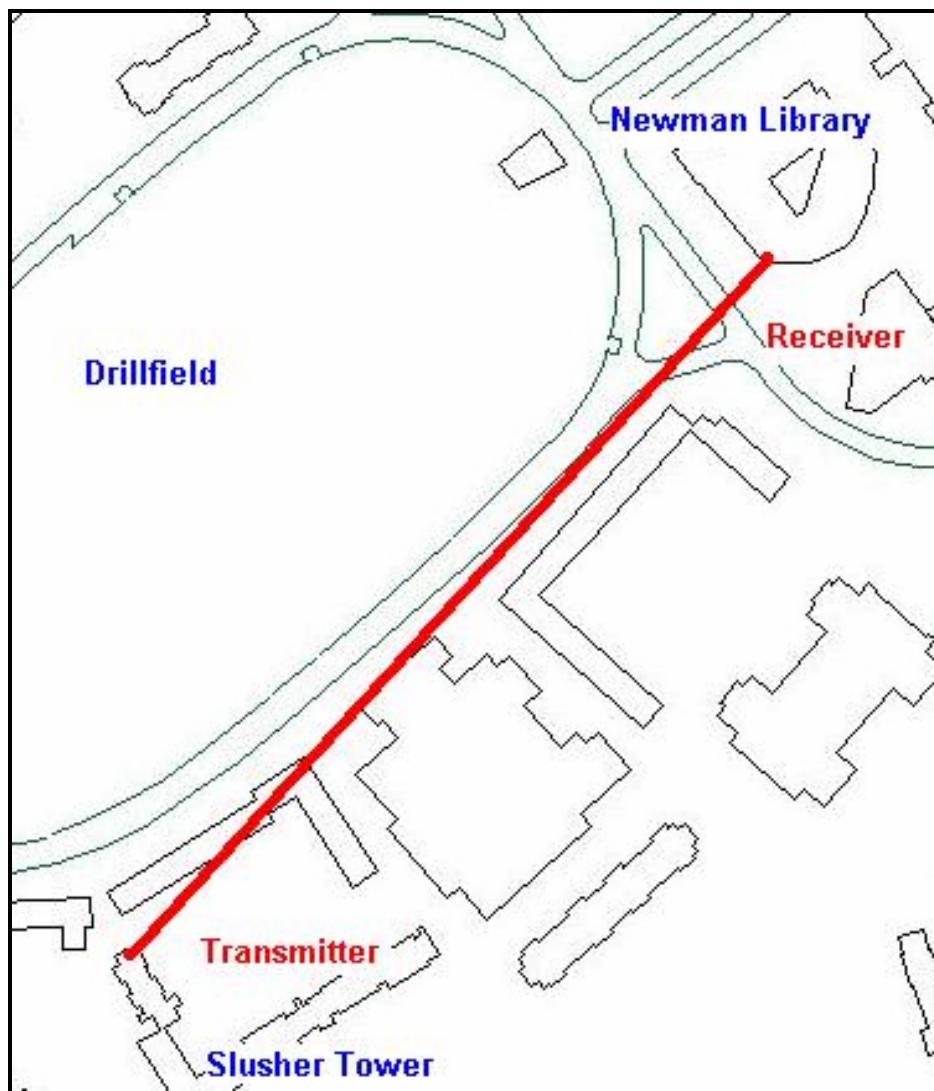


Figure 4.5 Aerial View of Measurement Location 2 (418m long) on the Virginia Tech Campus.

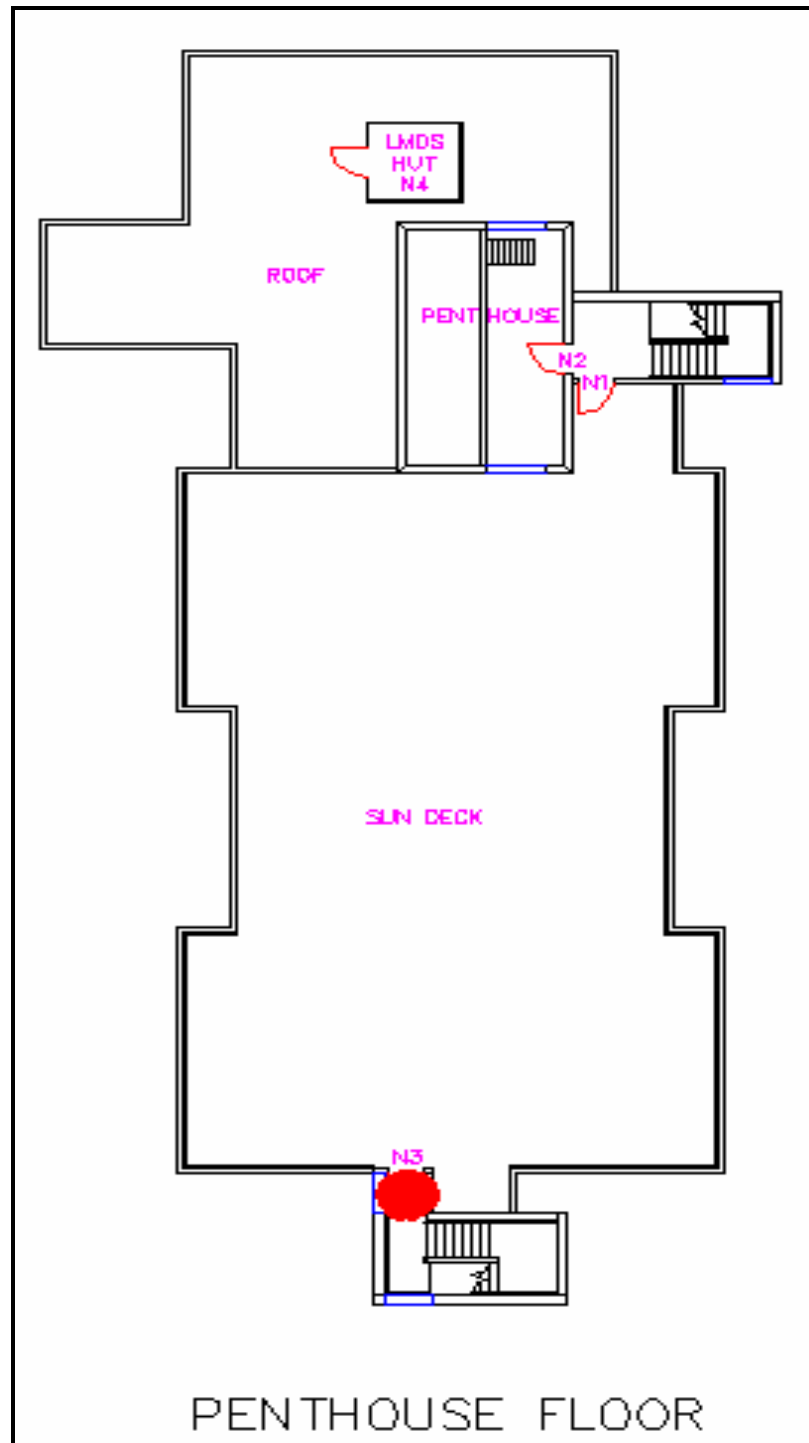


Figure 4.6 The red dot indicates the position of the transmitting antenna and the transmitter subsystem of the channel sounder in the Plan Map of the Slusher Tower Penthouse. The transmitting antenna is facing the receiving antenna placed in the Newman Library through a glass window which is on the exact left side of the red dot in the Plan Map.

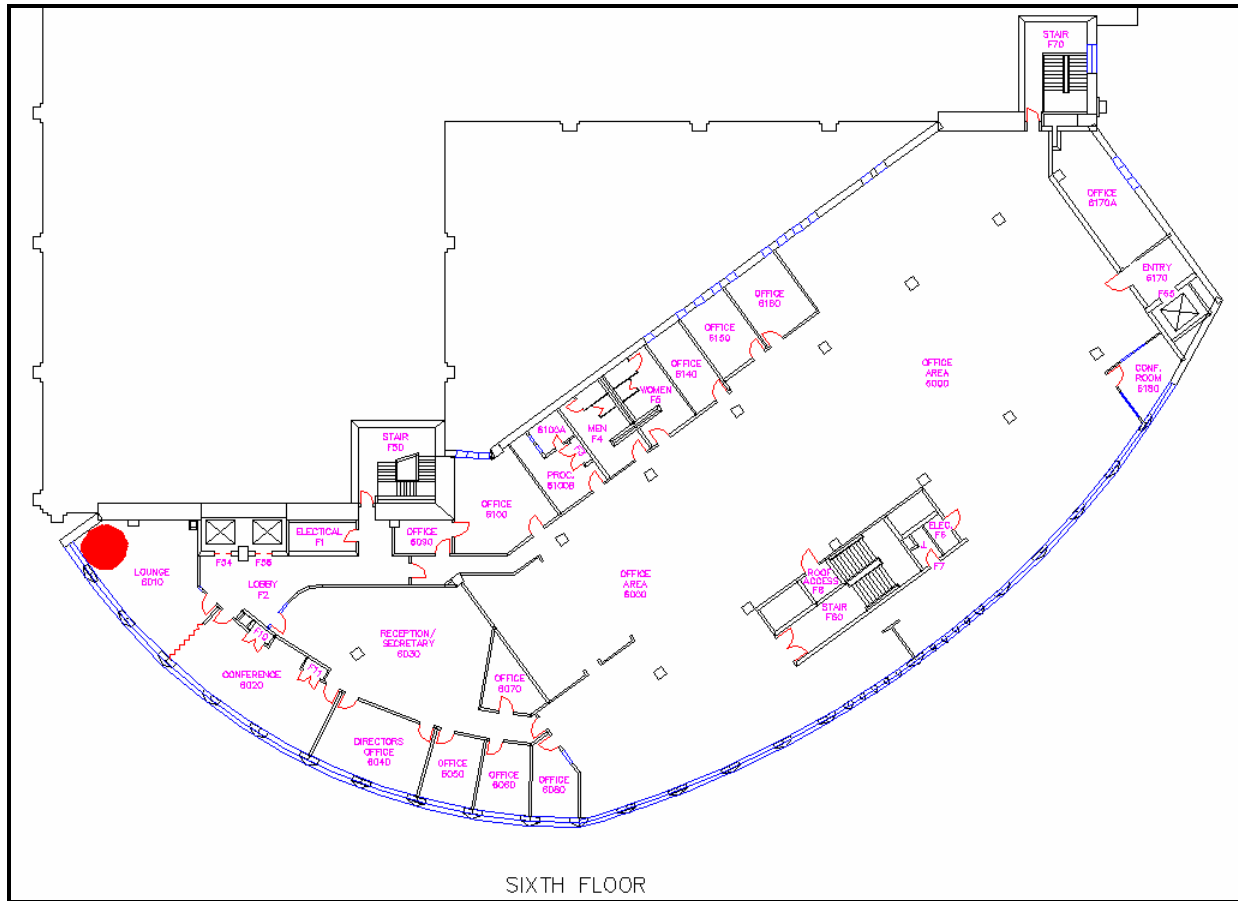


Figure 4.7 The red dot in the figure indicates the position of the receiving antenna and the receiver subsystem in the Plan Map of the sixth floor of Newman Library. The receiving antenna is facing the transmitting antenna in the Slusher Tower through a glass window. In the Plan Map, the glass window is right next to the red dot in S-W direction.

In this measurement configuration, the height of the transmitting antenna, placed in the Slusher Tower, is 53 meters and that of the receiving antenna, placed in the Newman Library, is 37.5 meters, respectively. The distance of separation between the Slusher Tower and the Newman Library is 418 meters. According to Equation 4.1, the calculated LOS propagation link length for the current measurement configuration is 418.3 meters. Figures 4.8 (a) and 4.8.(b), respectively show the transmitter and receiver antenna locations. The picture depicted in Figure 4.8.(a) was taken during clear sky conditions immediately after a moderate snow fall. The accumulations from the snowfall can be seen in the picture.

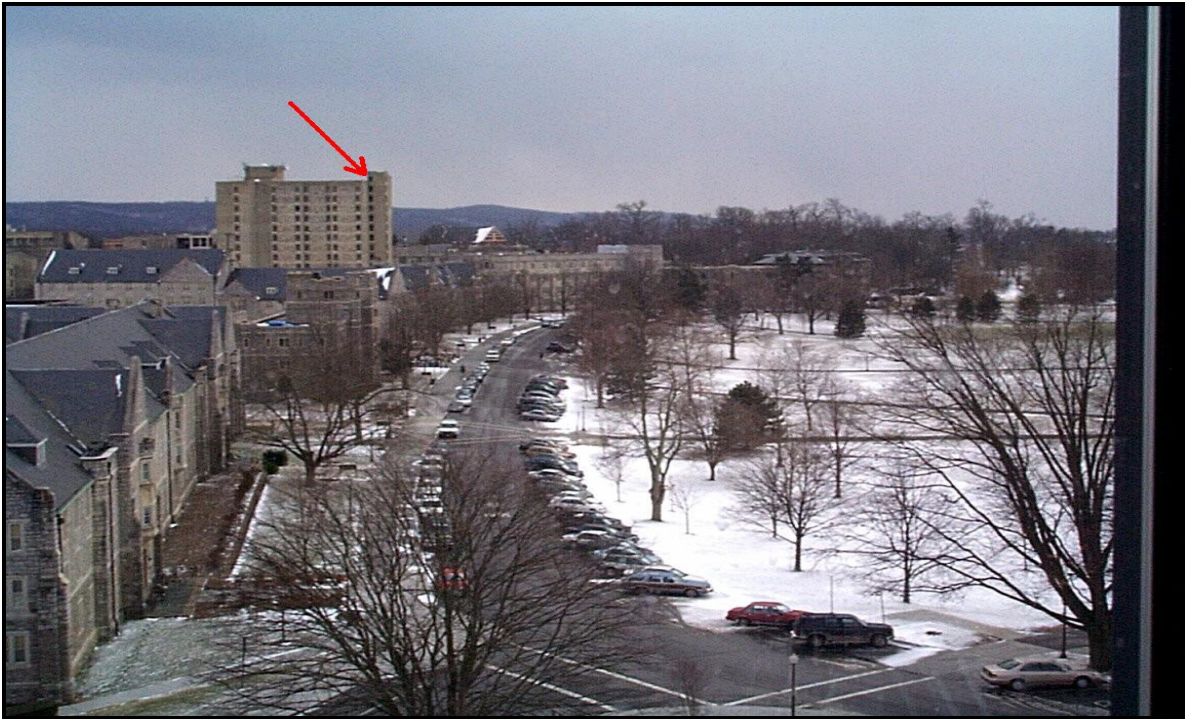


Figure 4.8.(a) View of Slusher Tower from receiver antenna location in the Newman Library. The position of the transmitting antenna in the Slusher Tower is marked.

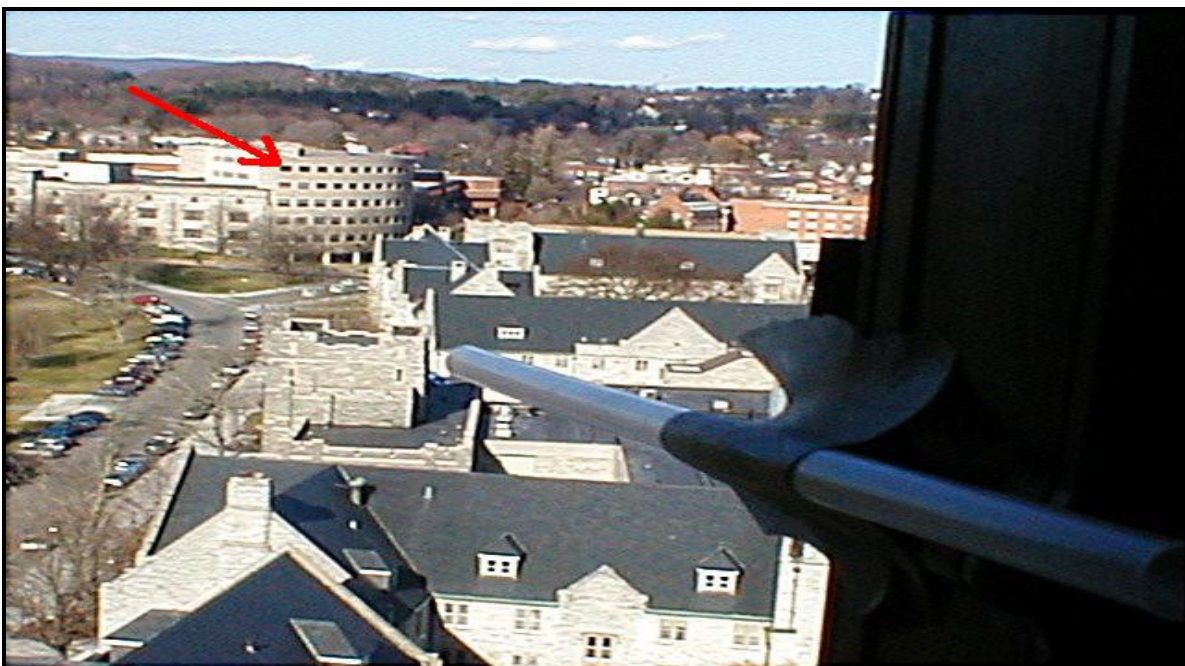


Figure 4.8.(b) View of the Newman Library from Slusher Tower. The location of the receiving antenna is marked in the figure.

It can be seen from the figures that there exists a clear LOS between the transmitting and receiving antennas. There are a number of buildings below the LOS but since all of them have slanting roofs, none of them contributes any multipath component in the received signal. Also, the reflections from ground, human traffic, and car traffic are discounted since the receiver antennas are highly directional. The received signal therefore consists of only a single multipath component - the Line of Sight (LOS) signal.

The third measurement location identified for propagation measurements is identical to previous measurement locations except for the fact that the propagation distance separating the transmitting and receiving antennas is smaller. In this measurement configuration, the transmitting antenna and the test equipment is placed in one of the offices on the sixth floor of the McBryde Hall. The transmitting antenna is mounted on a tripod and placed next to a glass window, such that the antenna beam illuminates the rear side of the New Engineering Building (NEB). In this dissertation, the NEB is referred by its new name – The Durham Hall. The receiving antenna is placed in the MPRG propagation laboratory on the fourth floor of the Durham Hall overlooking the transmitter. The aerial view of the third measurement location is shown in Figure 4.9.

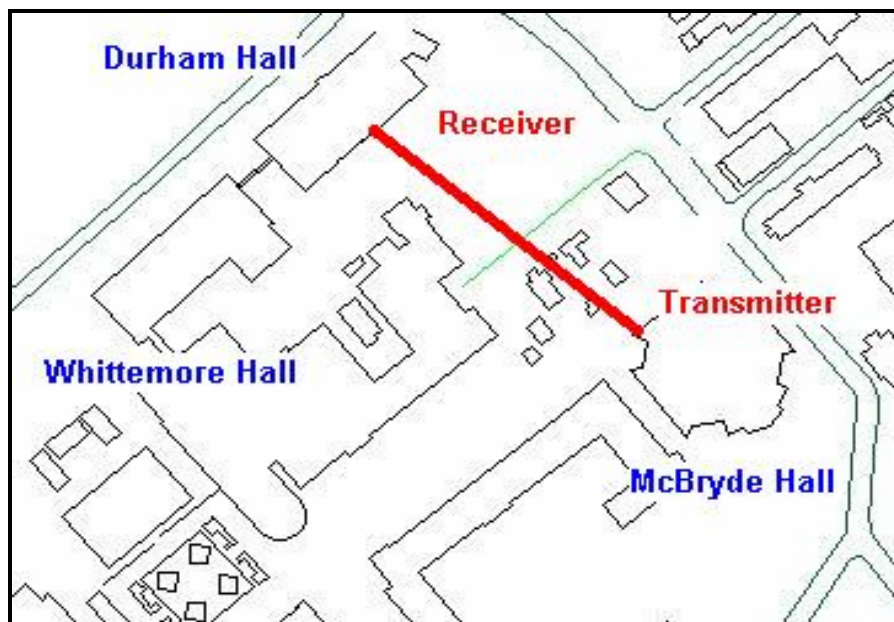


Figure 4.9 Aerial view of the Measurement Location 3 (161m) on the Virginia Tech campus.

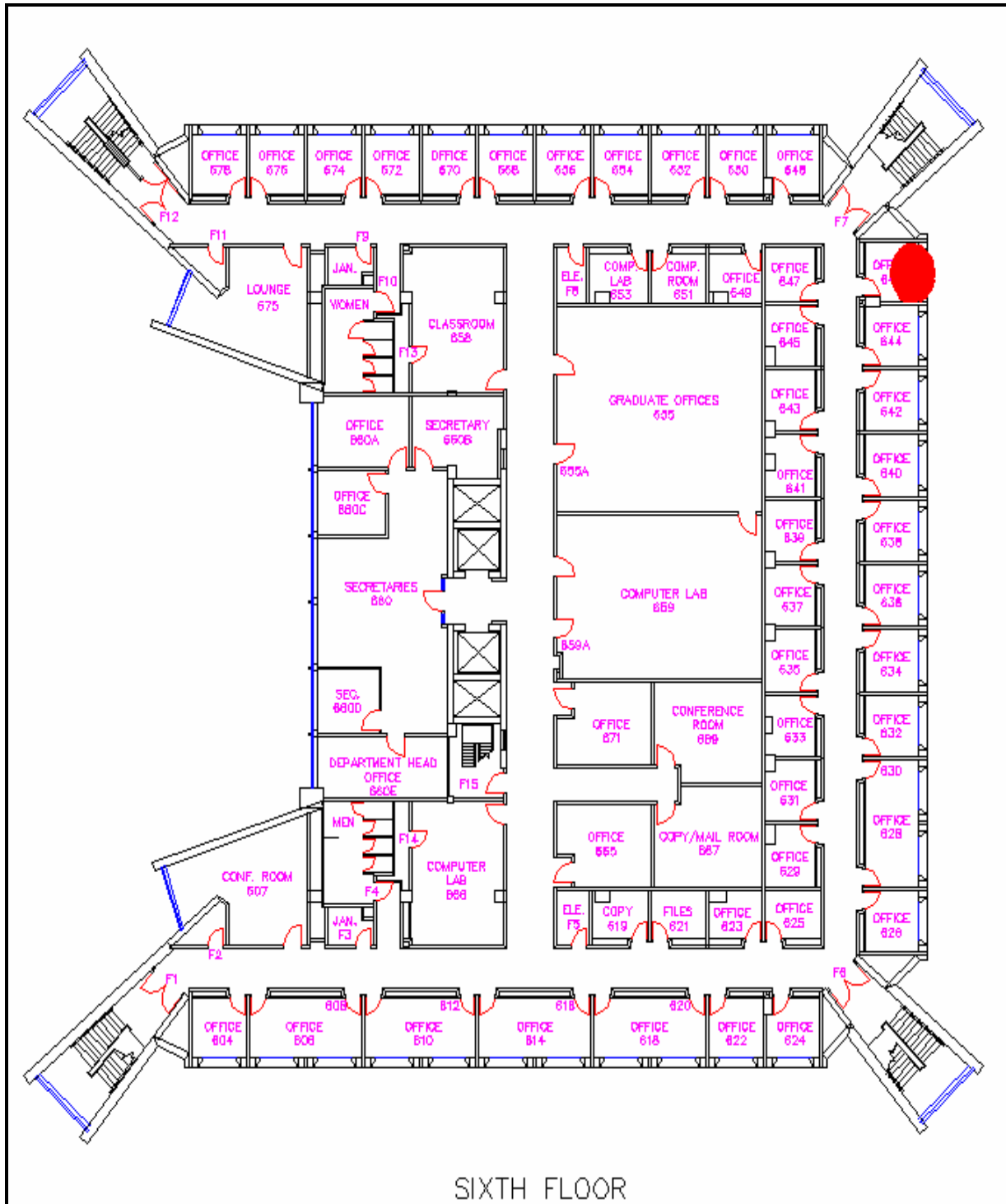


Figure 4.10.(a) The red dot indicates the position of the transmitter subsystem in the Plan Map of sixth floor of McBryde Hall. The transmitter is facing the receiver antenna in Durham Hall through a glass window. The glass window is on the immediate right of the red dot in Plan Map.



Figure 4.10.(b) The red dot indicates the position of the receiver subsystem in the Plan Map of fourth floor of Durham Hall. The receiver is facing the transmitting antenna in McBryde Hall. The window is on the immediate left of the red dot.

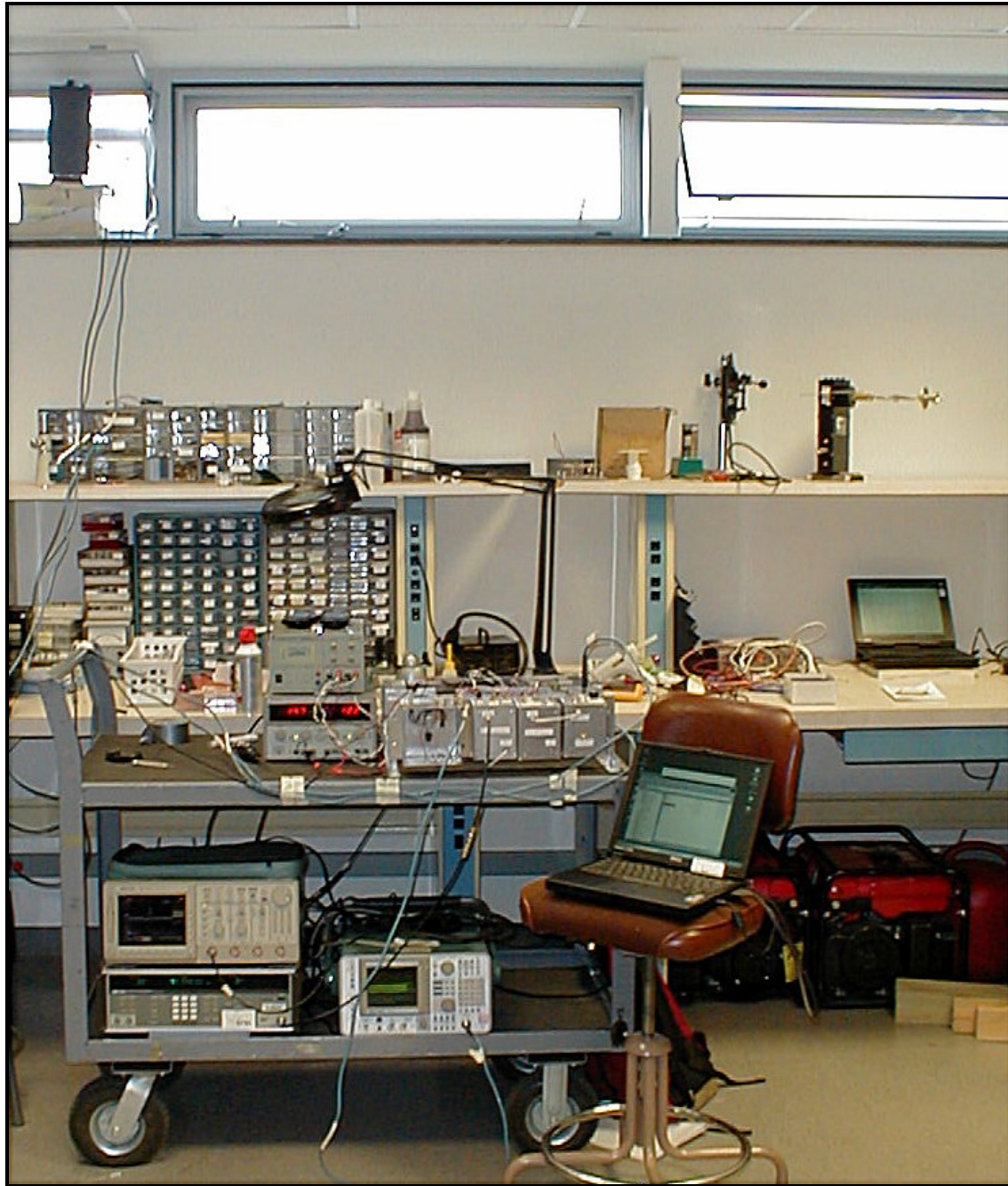


Figure 4.11 The Receiver subsystem setup in the MPRG Propagation Laboratory on the fourth floor of Durham Hall. The receiving antenna, facing the transmitting antenna in the McBryde Hall, can be seen in top left of the picture. The measurement laptop computer used to record the propagation measurements real-time can be seen placed on a chair next to the receiver subsystem. The picture also shows other components and test equipment of the channel sounder receiver subsystem. The laptop computer on the extreme right is a part of the rain gauge setup and is used to record rainfall statistics.



Figure 4.12.(a) View of McBryde Hall from receiver antenna location in Durham Hall. The location of the transmitting antenna is marked using a red arrow.



Figure 4.12.(b) View of Durham Hall from transmitter antenna location in McBryde Hall. The receiver antenna location is marked using a red arrow.

For this configuration, the total propagation link length is 161 meters. As can be seen from figures above, there is a clear LOS between the transmitting and receiving antennas. However, there is a tall tree significantly close to the LOS near the transmitting antenna. During the propagation measurements at location 3, there were no leaves on the tree and hence it did not contribute to any multipath components.

4.2. Test Equipment Setup and Measurement Sequences

This section of the chapter outlines the sequence of free-space calibration, path loss and frequency diversity measurements performed over a period of four months. All relevant equipment setup and propagation measurement details from the measurement campaigns are also presented. In addition, the setup procedure and functionality of the rain gauge, used to record rain rates, is included. As mentioned in Sections 2.3, 3.2 and 3.3, the proposed propagation measurement campaigns involve recording of Path Loss statistics (during clear-sky and rain) and Frequency Diversity statistics during clear sky conditions.

Table 4.1 lists all the propagation measurements performed during the months of February, March, April and May of the Year 2001. The first measurement campaign in Table 4.1 comprise of free-space calibration measurements followed by frequency diversity propagation measurements over a 531 meter free-space radio link. These sanity check measurements are performed to functionally evaluate the performance of the spread-spectrum sliding correlator channel sounder. The free-space calibration measurements are performed at 12 carrier frequencies [Table 3.1], separated by 100MHz in the 38GHz frequency band. The transmitting and receiving antennas are placed in the front porch of the Whittemore Hall and the propagation measurements are recorded over a free-space link length of 15 meters. All the steps outlined in Sections 3.3.2.1 and 3.3.2.2 are followed to map the spectrum analyzer voltage values to respective external attenuation values so as to facilitate calculation of path loss statistics. The voltage-attenuation mapping process and its significance for the propagation campaigns are explained in detail in Sections 3.3.2.3 and 3.3.2.4. The significance of free-space calibration at each of 12 carrier frequencies is also explained in Section 3.3.2.2.

Table 4.1 List of Propagation Measurement Campaigns

	Measurement Details	Date (Year 01')	Location
1	Free-space Calibration Measurements (performed at 12 carrier frequencies in the 38GHz band, separated by 100MHz [Table 3.1] for frequency diversity propagation measurements)	Feb 16	Test Location: Front porch of the Whittemore Hall
2	Frequency Diversity Propagation Measurements (performed at 12 carrier frequencies in the 38GHz band, separated by 100MHz [Table 3.1] with different RF bandwidths)	Feb 17	Location 1 (531m link): Slusher - McBryde Link
3	Free-space Calibration Measurements (performed at 12 carrier frequencies in the 38GHz and 60GHz bands each)	Mar 05	Calibration Location: Fourth floor NEB in front of elevators
4	Frequency Diversity Propagation Measurements (performed at 38GHz and 60GHz for 12 carrier frequencies each during clear sky conditions)	Mar 07	Location 2 (418m link): Slusher - Newman Link
6	Path Loss Measurements (performed at 38GHz and 60GHz during clear sky conditions. Both horizontal and vertical polarization statistics were measured at 38GHz.)	Mar 09	Location 2 (418m link): Slusher - Newman Link
7	Frequency Diversity Propagation Measurements (performed at 38GHz and 60GHz for 12 carrier frequencies each during clear sky conditions)	Mar 10	Location 1 (531m link): Slusher - McBryde Link
8	Path Loss Measurements (performed at 38GHz and 60GHz during clear sky conditions. Both horizontal and vertical polarization statistics were measured at 38GHz.)	Mar 11	Location 1 (531m link): Slusher - McBryde Link
9	Free-space Calibration Measurements (performed at 12 carrier frequencies in the 38GHz and 60GHz bands each.)	Mar 30	Calibration Location: Fourth floor NEB in front of elevators
10	Path Loss Measurements at 38GHz (horizontal and vertical polarization) and 60GHz (vertical polarization) during clear-sky and rain events.	Apr 01 to May 14	Location 3 (161m link): McBryde - NEB Link

4.2.1 Guidelines for setting up Channel Sounder Transmitter Subsystem

This section presents a step-by-step procedure for setting up the Channel Sounder Transmitter Subsystem at any predefined measurement location. The steps listed below are same for all measurement campaigns and hence site-specific details are omitted.

1. After performing free-space calibration measurements at all the frequencies of interest, the transmitter subsystem is powered down and carefully disassembled. As explained before, free-space calibration data is used to perform mapping of recorded PDPs statistics to respective path loss values. It is therefore necessary that the state of the system during propagation measurements is exactly the same as that during free-space calibration measurements. In order to preserve the state of the system, all cable connections are labeled and test equipment settings are stored before demounting the antenna from the tripod and disassembling the system.
2. Next, the transmitter subsystem is carefully moved to the predefined measurement location. The tripod antenna stand is appropriately positioned, setup and leveled using a spirit level meter. The transmitting antenna is mounted on the tripod and aligned such that the main beam of the antenna illuminates the receiver antenna location.
3. All cable connections between channel sounder components namely Rubidium Oscillator, Signal Generators, PN Sequence Generator and the Horn Antenna Unit, are restored. Equipment settings for the Frequency and Signal Generators are also restored. All the system connections and settings are diligently verified to be correct before powering up the system. The final configuration is shown in Figure 3.1.

Note that before any measurement or calibration, described in this dissertation, all of the transmitter and receiver equipment is powered on and operated for a period of at least 30 minutes. The losses, gains, and noise figures for many of the system components depend on operating temperature and hence this warm-up period allows the equipment to reach a steady-state operating temperature and eliminate erroneous results that change with time.

4.2.2 Guidelines for setting up Channel Sounder Receiver Subsystem

This section presents a step-by-step procedure for setting up the Channel Sounder Receiver Subsystem at any predefined measurement location. The steps listed below are same for all measurement campaigns and hence site-specific details are omitted.

1. The channel sounder receiver subsystem is powered down and disassembled after free-space calibrations in a similar fashion as described above. All the cables are neatly labeled and equipment settings for the Frequency Generator, External Attenuators, Oscilloscope and Spectrum Analyzer are stored. The GPIB cable connecting the Oscilloscope to the laptop computer is also disconnected after powering down the Oscilloscope and the laptop computer.
2. The receiver subsystem is moved to the predefined measurement location and all the cable connections between test equipment and other components of the channel sounder are restored. The final receiver subsystem configuration is shown in Figure 3.1. After verifying all the system connections, the External Attenuator (EA) is set at maximum and the system is powered on. This is done to limit the total power fed to the Spectrum Analyzer (SA). According to SA specifications, the maximum input power can be 30dBm.
3. Next, the PN sequence generator is reset and the receiver attenuation (EA) is reduced in steps of 10dB until the signal is sufficiently above the noise floor as seen in the SA. The receiving and transmitting antennas are now accurately aligned manually such that the received signal power in the SA is maximized.
4. The system is allowed to warm up for about 30 minutes and then a computer controlled PDP measurement is initiated. Power Delay Profiles as visible on the oscilloscope screen are recorded into the laptop computer via a GPIB interface. These sanity check measurements verify the overall system functionality. Data recording process, data file formats and post processing software are explained in detail in Appendix A of this dissertation.

4.2.3 Rain Gauge Setup and Data Recording [Dav97]

This section of the chapter explains the setup procedure for the rain gauge - The Weather Monitor II Station. The functionality of each component of the Weather Monitor II Station is explained. All the steps involved in configuration of the WeatherLink® software to facilitate automatic, uninterrupted recording of rainfall data are also outlined. Rain rate data recording conventions and a sample data file is also included.

4.2.3.1 Weather Monitor II Station

The Weather Monitor II is a precision equipment, designed to give extremely accurate rain rate statistics. In addition to recording real-time rain rates, with appropriate accessories, the station can also record atmospheric temperature, wind direction, wind velocity, humidity and atmospheric pressure. The station setup, during the measurement campaigns, for real-time recording of rain rates primarily consists of a Weather Computer with LCD and keypad, a Junction Box and a Rain Collector system.

The Weather Computer is a stand-alone computer that can display and record real-time weather statistics (temperature, pressure, rain rates, humidity etc). The keypad of the unit facilitates site-specific or weather event-specific configuration of the monitoring station and the LCD displays the desired set of real-time weather statistics. All the data recording accessories (Rain Collector, Anemometer, temperature and humidity sensors etc) are connected to the Weather Computer via the Junction Box using special cables. Elaborate connection details and sanity check system test details are documented in [Dav97]. Depending upon the site-specific configuration of the Weather Monitoring Station, the computer initiates simultaneous data acquisition from various accessories at regular intervals of time and records relevant statistics.

The Rain Collector II unit is a self-emptying collector that measures rainfall in 0.01-inch increments. It is a tipping bucket rain gauge as shown in Figure 4.13. The unit consists of two specially designed buckets that tip when the weight of 0.01 inches of rain falls into them. As can

be see in the figure, when one bucket tips, the other bucket quickly moves into place to accumulate the rain. Each time a bucket tips, an electronic signal is sent to a recorder and in order to calculate the rainfall for a certain time period, one can simply multiply the number of marks on the recorder by .01 inches. Also, if the recorder is equipped with a clock, one can determine how much rain fell during a certain time without actually being present at the station.

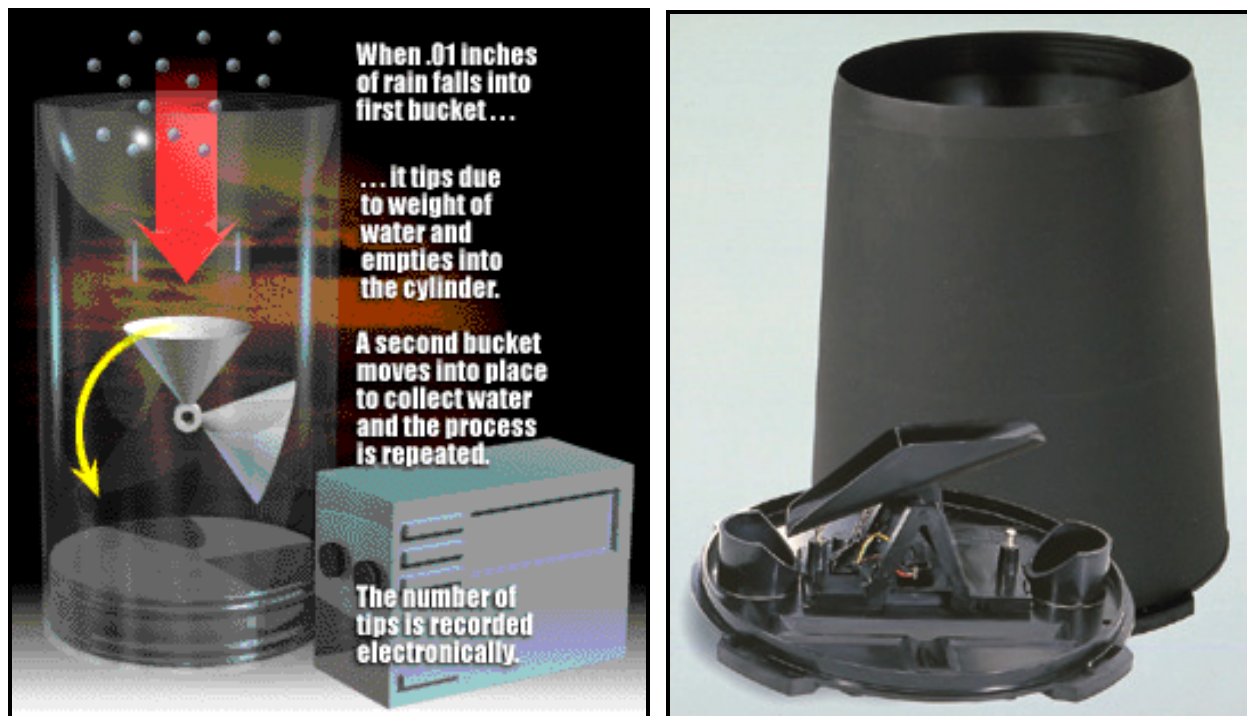


Figure 4.13 [Right] The Rain Collector Assembly used with the Weather Monitoring Station. [Left] Pictorial representation of functioning of the Rain Collector Assembly.

The Weather Monitor II Station can be connected to a personal computer to facilitate ease of configuration and automatic data recording for extended periods of time. The WeatherLink® Data Logger software allows the user to access Weather Monitor Station via personal computers directly or remotely (via Modem). The software also facilitates storing, viewing, plotting, analyzing, exporting and printing of recorded weather statistics.

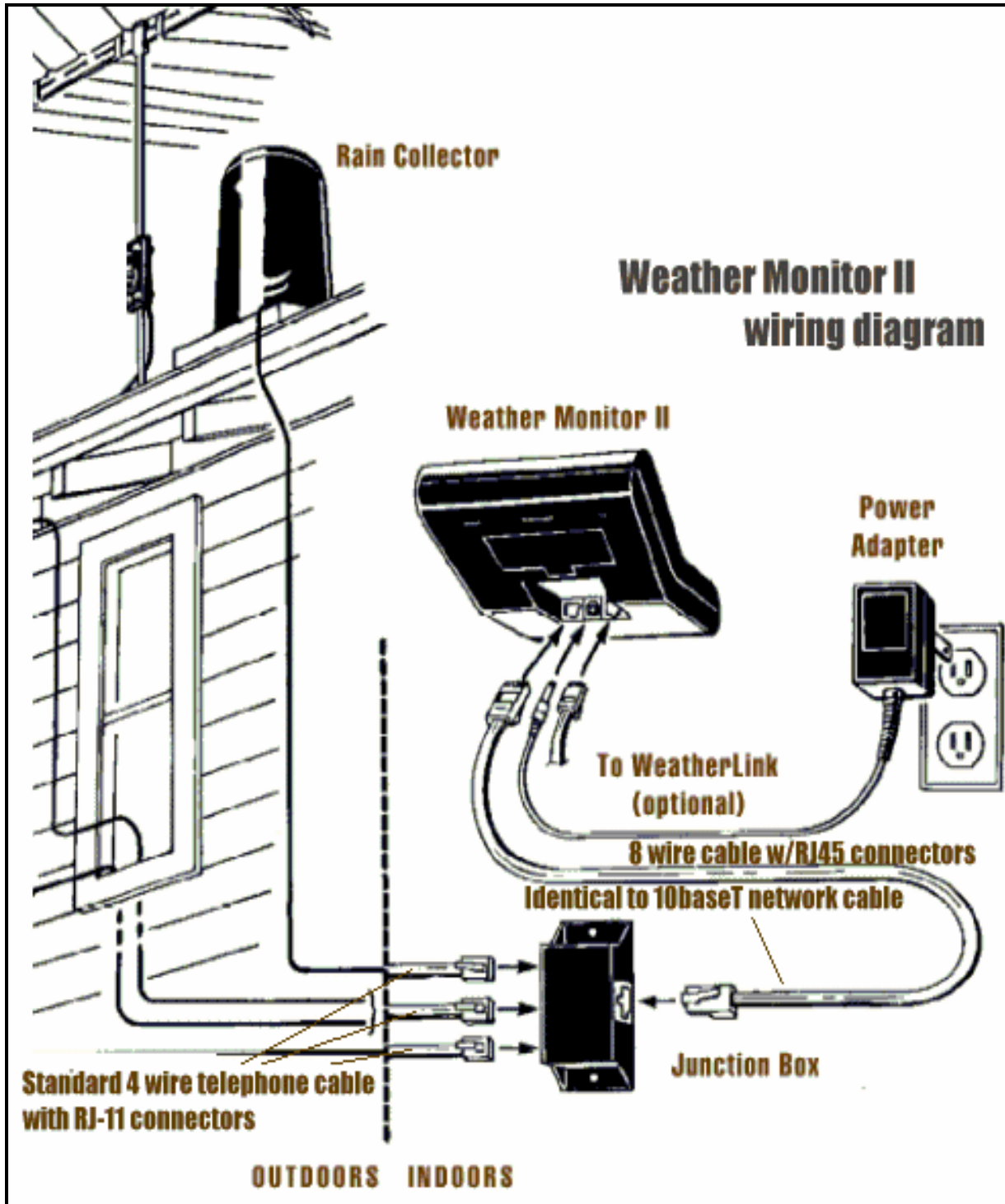


Figure 4.14 Typical Weather Monitor Station Setup for rain data acquisition and recording.

During the measurement campaigns, the Weather Monitor Station was connected directly to a laptop computer via a 9-pin serial port adapter and cable. The final system configuration is shown in Figure 4.14. For connection details between the Weather Monitor and the personal computer, please refer to [Wea97].

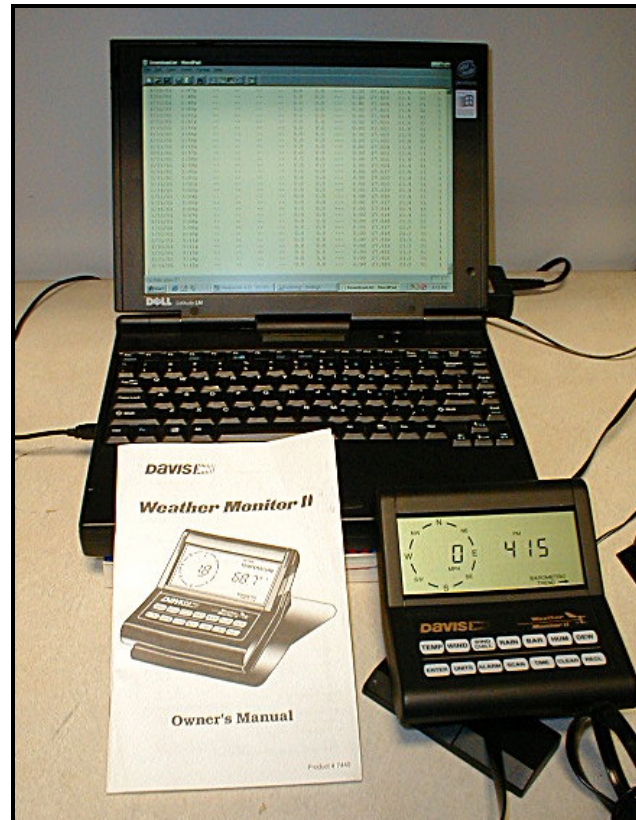


Figure 4.15 Rain Data recording laptop computer and the WeatherLink console

4.2.3.2 WeatherLink® Software Setup

The WeatherLink® Software is installed on the laptop computer after all the connections and the functionality of the Weather Monitor Station is verified in accordance with the guidelines documented in [Dav97]. In order to interact with the Weather Monitor Station, the first step is to add a monitoring station, which entails naming the station, configuring the WeatherLink® software to work with the defined station and the computer hardware, and setting station values

such as time, total rainfall and calibration numbers. The steps followed to configure automatic rainfall data acquisition and data recording are outlined below.

1. Adding a Station: A new monitoring station, for managing data acquisition and data recording was created - 'Location3'.
2. Serial Port Verification: For direct connections with the personal computers, the software contains a procedure for locating the serial port to which the monitoring station is connected and whether the serial port is working correctly. The option thus facilitates verification of connectivity between the computer and the weather monitoring station. In addition, it also allows user to specify baud rate for data transfer. For direct connections with personal computers, the baud rate setting is maintained at 2400.
3. Station Configuration: The Station Configuration window allows selection of weather monitor model from the drop-down list box. Next, specify the increment in which the rain collector measures rainfall. The software is also capable of automatically creating a text file that contains all downloaded records for the last two days after each download. This feature is enabled by selecting the appropriate check box. Weather Monitor Model II and Rain Collector II (rainfall measured in increments of 0.01-inches) are used during the measurement campaigns.
4. Station Time: The weather statistics and the Power Delay Profile (PDP) measurements are simultaneously recorded into two different laptop computers. The weather monitoring station records rainfall statistics against time. Similarly, each of the recorded Power Delay Profile (PDP) data files are accurately time stamped by the internal computer clock. In order to relate the recorded PDP statistics with the corresponding weather events, it is vital to synchronize the two measurement laptop computers. The software allows setting of time and date on the station console from the computer. Since the time and date on the weather monitor station and the laptop computer should be the same to prevent any ambiguity during data recording and downloading, the software facilitates resetting of PC time and date to that of the weather monitoring station. Throughout the measurement campaigns, both laptop computers were strictly time synchronized.

5. **Archive Interval:** The archive interval is the duration between successive automated data acquisitions and recording by the laptop computer. The archive intervals supported by the software are 1, 5, 10, 15, 30, 60, and 120 minutes. The archive interval is indicative of the amount of data stored in the archive memory before periodic downloads. The total time taken for acquisition and recording of 25 PDP snapshots is about two minutes. Therefore, throughout the measurement campaigns, the archive interval is set at 1 minute to facilitate recording of rain rates with least ambiguity.
6. **Rain Calibration:** Based on the type and model of Rain Collector specified in the Station Configuration window, the software automatically changes the station console's rainfall calibration number to the correct setting.
7. **Total Rain:** The software also allows specifying a total rainfall amount to reflect any rainfall that occurred before the data acquisition software is activated.
8. **Auto Download:** The software can be setup to automatically download data at specified times each day. For a predefined station, the software allows user to specify hour(s) at which automatic download should be initiated. To force the software to automatically download a specific number of minutes after the selected hour(s), the number of minutes can be specified in the 'Offset Time' box. Throughout the measurement campaigns, the data was downloaded every hour to prevent loss of data due to unforeseen malfunctioning of the unit.