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SHIELDING AND ATTENUATION PROPERTIES OF LARGE BUILDINGS AND STRUCTURES

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Abstract: For various applications, there is a growing need to understand the shielding and/or attenuation properties of large buildings and structures. In this paper, we present experimental data for the coupling of electromagnetic fields into three types of large structures for frequencies ranging from 49-1800 MHz. The data are presented in various ways, including a statistical approach, where the mean and standard deviation of the shielding (or attenuation of the signals) for the various structures are given. We summarize and discuss some of the interesting shielding and attenuation effects observed in these three structures.

I. INTRODUCTION

Understanding the shielding and/or attenuation properties of large buildings and structures is becoming an important issue for two particular applications. First of all, when first responders (emergency workers) enter large structures (such as apartment and office buildings, sports stadiums, stores, malls, warehouses or convention centers), communication using portable radios to individuals on the outside of these large structures can be problematic [1]. This is especially true in large-scale disaster situations (e.g., collapsed buildings). Unreliable communications may occur due to decreased signal strength brought about by losses through structural materials and large variability in the signals. Reports published on the rescue efforts at the World Trade Center Towers [2, 3] highlighted this difficulty.

The second application involves protecting sensitive electronic equipment from harm due to intentional directed electromagnetic energy (e.g., directed electromagnetic weapons). In this application, the shielding properties of large buildings can contribute to the protection of electronic devices. Therefore, understanding the behavior of these large structures gives guidance for the protection of electronic devices.

The National Institute of Standards and Technology (NIST) is investigating the propagation and coupling of radio waves into and out of large structures. We have carried out several experiments in various large structures around the United States to address this issue. In these experiments, we carried portable radios throughout large buildings and structures while recording field strengths with receiving systems outside the structures. The radios were tuned to transmit at frequencies near public safety and cell phone bands (approximately 50 MHz, 160 MHz, 250 MHz, 400 MHz, 900 MHz, and 2 GHz). This paper discusses these experiments and presents shielding and attenuation data for three different structures: a 13 story apartment complex in New Orleans (see Figure 1), the Veterans Stadium in Philadelphia (see Figure 2), and the Convention Center in Washington, DC (see Figure 3). In this paper, we show primary results of the data collected, including propagation statistics, and discuss some of the interesting propagation and attenuation effects we observed.

II. EXPERIMENTAL SET-UP

The experiment, which is referred to as “radio mapping”, involved carrying radio transmitters tuned to various frequencies through the buildings while recording the received signal from a site located outside the building. Figure 4 shows a typical radio that was used.

Figure 1: New Orleans apartment building.

Figure 2: Philadelphia sports stadium.

Figure 3: Washington, DC convention center.

Figure 4: Typical transmitter.

The receiving system is sketched in Figure 5. We assembled four antennas on a 4-meter mast, as illustrated. The radio-frequency output from each antenna was fed through a 4:1 broadband power combiner. This arrangement gave us a single input to the portable spectrum analyzer, which could then scan over all the frequencies of interest without switching antennas. The four antennas were chosen to be optimal (or at least practical) for each of the frequency bands we were measuring. The selected antennas consisted of an end-fed vertical omnidirectional antenna for 50 MHz, a log-periodic-dipole-array (LPDA) used for the 160, 225, and 450 MHz bands, and Yagi-Uda arrays for 900 and 1830 MHz. This assembly could then be mounted on a fixed tripod at one of the listening sites, or it could be inserted into a modified garden cart for portable measurements. The receiving sites contained, in addition to the antenna system, a generator, uninterruptible power supply (UPS), spectrum analyzer, global positioning system (GPS) receiver, computer, and associated cabling.

The measurement system consists of a portable spectrum analyzer, GPS receiver, and a laptop computer (Figures 5 and 6). The data collection process was automated using a graphical programming language. This software was designed to control the analyzer, and to collect, process, and save data at the maximum throughput of the equipment. The software controlled the spectrum analyzer via an IEEE-488 interface bus and the GPS receiver via a serial interface. The GPS information was recorded in order to track the position of the mobile cart during the perimeter measurements around the buildings.

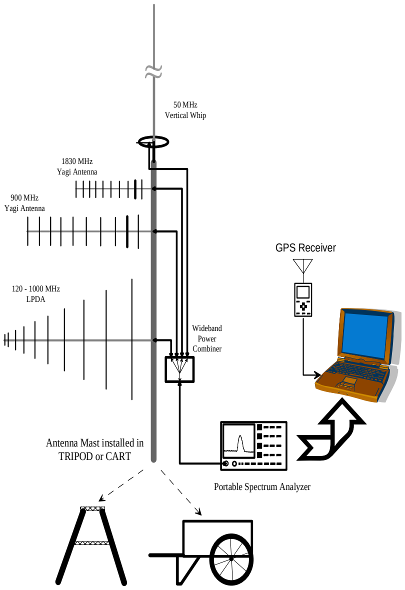

Figure 5: Receiving system.

Figure 6: Measurement instruments on mobile cart.

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III. EXPERIMENTAL DATA

Figures 7 and 8 show typical sets of data collected during the radio-mapping experiments (moving transmitter, fixed receivers) for the apartment building. We see that propagation through the building can reduce the radio signal by as much as 50 dB, depending on the location of the transmitter. The horizontal axis is labeled location. These numbers are actually locators in the data files. These reference locator numbers correspond to different locations within (or on the outside) of the building structure. Lab books recorded the number assigned to each location.

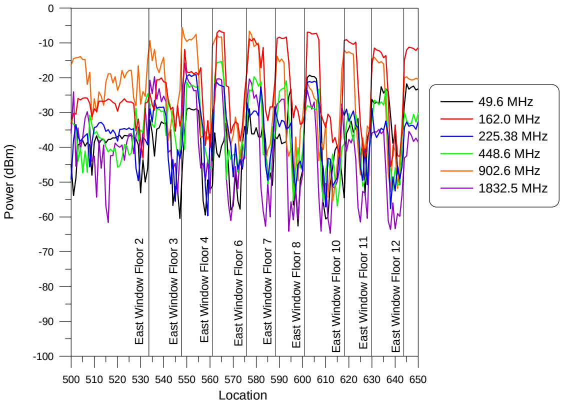

Figure 7: Radio-mapping result for apartment building.

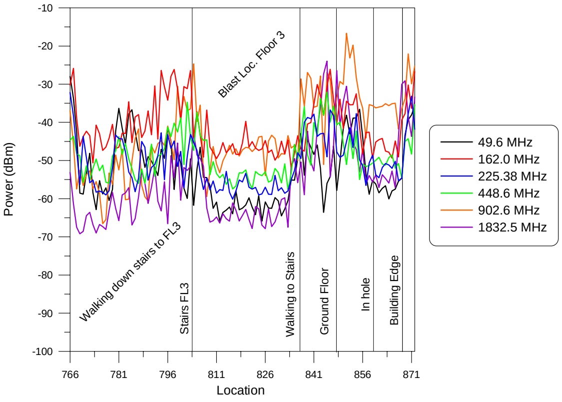

Figure 8: Radio-mapping result for apartment building.

Figures 9 and 10 show typical sets of data collected during the radio-mapping experiments (moving transmitter, fixed receivers) for the sports stadium. We see that propagation through the building can reduce the radio signal by as much as 60 dB, depending on the location of the transmitter.

Figures 11 and 12 show typical sets of data collected during the radio-mapping experiments (moving transmitter, fixed receivers) for the convention center. We see that propagation through the building can reduce the radio signal by as much as 70 dB, depending on the location of the transmitter.

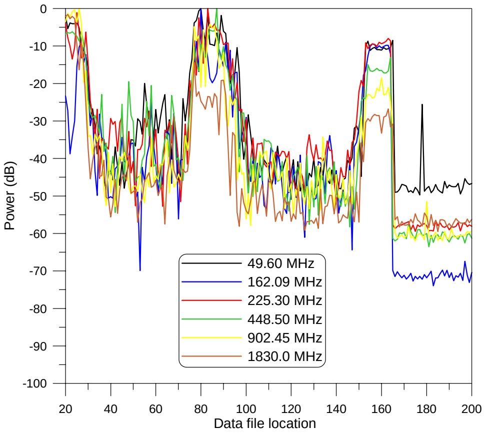

Figure 9: Radio-mapping result for the sports stadium (seating and walk areas).

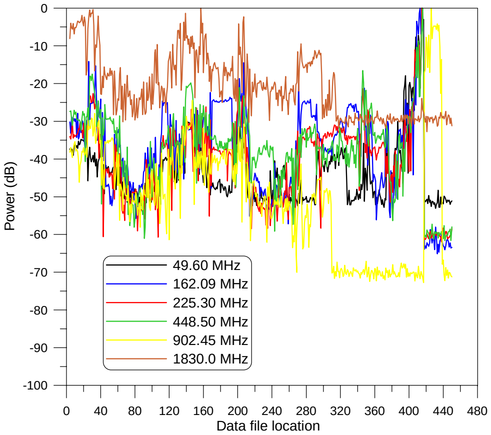

Figure 10: Radio-mapping result for the sports stadium (playing field and locker rooms).

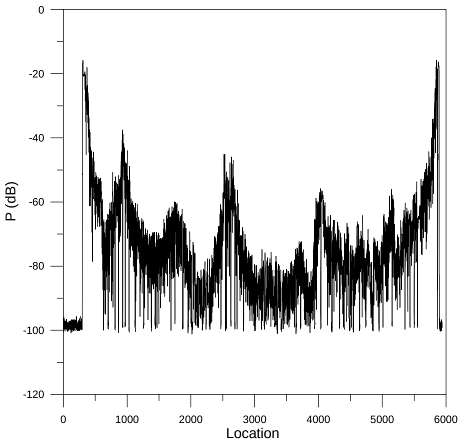

Figure 11: Radio-mapping result for the convention center at 226.40 MHz.

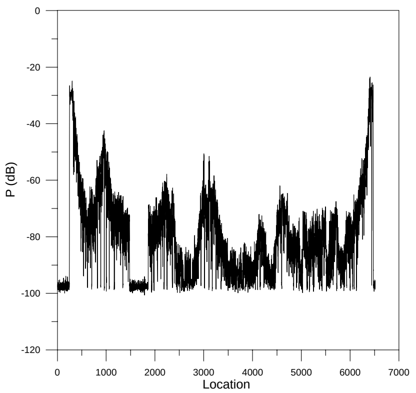

Figure 12: Radio-mapping result for the convention center at 902.45 MHz.

These results illustrate that the field strengths varied by as much as 60 dB to 70 dB. In communication systems design, the variability of the field strength is as important as the field strength itself. Knowing the variability allows the system designer to develop devices for first responders that must be capable of operating in an environment with large dynamic range in signal strength. Some statistics of the field strength variability inside and outside the structures were investigated. The histograms (2 dB bin size) for some of these datasets are shown in Figures 13-18. Tables I-III summarize the mean normalized received signal strength and the standard deviation for each building structure.

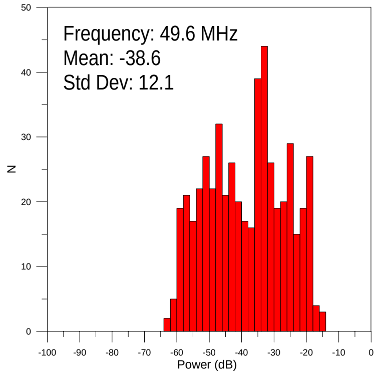

Figure 13: Histogram for apartment building.

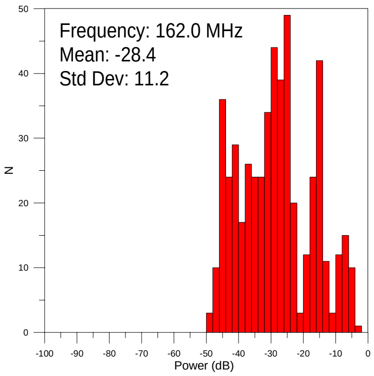

Figure 14: Histogram for apartment building.

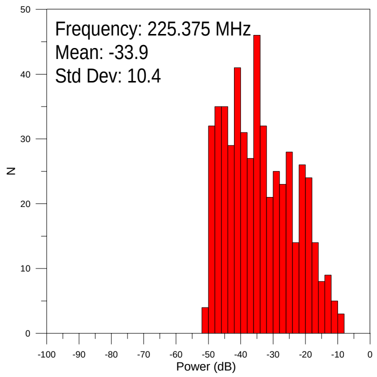

Figure 15: Histogram for apartment building.

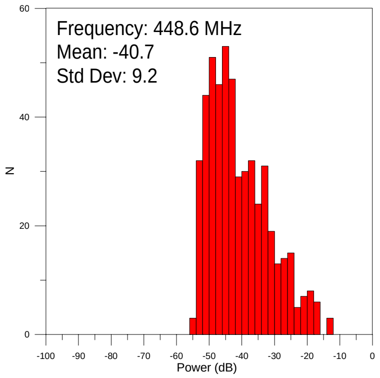

Figure 16: Histogram for apartment building.

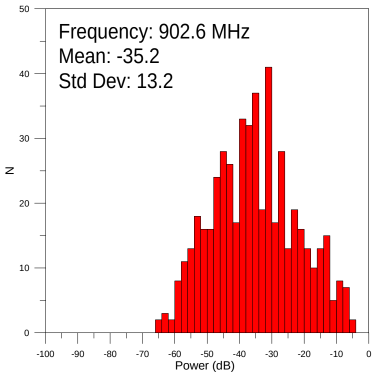

Figure 17: Histogram for apartment building.

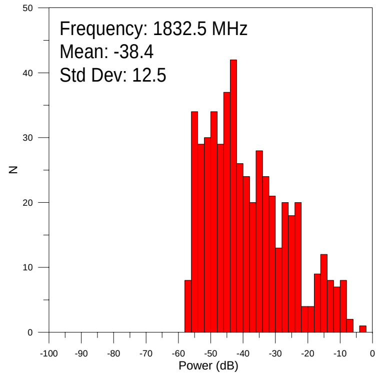

Figure 18: Histogram for apartment building.

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Table I: New Orleans apartment building.

Frequency (MHz)	**Mean (dB)**	**Standard Deviation (dB)**
49.6	-38.6	12.1
162.0	-28.4	11.2
225.375	-33.9	10.4
448.6	-40.7	9.2
902.6	-35.2	13.1
1832.5	-38.4	12.5

Table II: Philadelphia sports stadium.

Frequency (MHz)	**Mean (dB)**	**Standard deviation (dB)**
49.60	–30.6	15.0
162.09	–34.4	15.2
225.30	–30.0	13.9
448.50	–33.5	14.4
902.45	–37.2	13.8
1830.00	–43.6	12.0

Table III: Washington, DC convention center.

Frequency (MHz)	**Mean (dB)**	**Standard deviation (dB)**
49.60	–51.8	14.5
162.09	–63.2	14.0
226.40	–59.3	14.8
448.30	–58.6	13.8
902.45	–56.5	14.4
1830.00	–56.6	15.0

IV. DISCUSSION

The mean attenuation of the signal for a wide range of locations throughout the apartment building ranged from 25 to 50 dB. The standard deviation ranged from 6 to 14 dB, depending on frequency.

Maximum signal attenuation for the stadium, which was on the order of 75 dB, was observed by just moving the transmitters around the outside perimeter of the stadium while monitoring signals at external receive sites. The mean signal attenuation for a wide range of transmitter locations located in the interior of the stadium to an external receive site ranged from 25 to 50 dB. The standard deviation for the stadium propagation measurements ranged from 6 to 14 dB, depending on frequency.

For the convention center, we see that the mean attenuation ranged from 51-63 dB, depending on frequency. The standard deviations are on the order of 14-15 dB.

V. CONCLUSION

In this paper we present experimental results for an investigation of the shielding and attenuation properties of large buildings and public structures. These results illustrate the large attenuation or high shielding that can occur in these types of public structures. The results also indicate that large variability in attenuation or shielding does occur depending on the location in the structures.

In the three structures discussed in this report, we have also performed radio-propagation measurements before, during, and after the implosion of these structures. Results of these implosion measurements can be found in [4-6]. We have also performed radio-mapping experiments in various other large structures, including apartment and office buildings, stadiums, stores, shopping malls, hotels, a convention center, and warehouses. The results of the signal strength measurements and statistical distribution for these radio-mapping experiments will be published separately.

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