Radio Propagation Measurements Before, During, and After the Collapse of Three Large Building Structures*

Christopher L. Holloway[1], Galen Koepke[1], Dennis Camell[1], and Kate A. Remley[1]

[1] National Institute of Standards and Technology (NIST), Electromagnetics Division
325 Broadway, Boulder, CO 80305, USA, 303-497-6184: holloway@boulder.nist.gov

Abstract

NIST is investigating various schemes for detecting emergency responders and civilians with portable radios or cell phones who may be trapped in voids in a collapsed or partially collapsed building. The first part of this effort is to understand radio propagation in collapsed structures. Buildings scheduled for implosion provide the ideal research environment for investigating radio-wave propagation issues in fully or partially collapsed structures. The experiments reported here were performed before, during, and after the implosion of three large building structures and consist of measurements of the attenuation of radio signals caused by the building materials and structures. Measurements were performed at various frequencies of interest to emergency responders, namely, frequencies near the public safety and cell phone bands (approximately 50 MHz, 150 MHz, 225 MHz, 450 MHz, 900 MHz, and 1.8 GHz).

1. Introduction

When emergency responders enter large structures (e.g., apartment and office buildings, sports stadiums, stores, malls, hotels, convention centers, warehouses, etc.) communication to individuals on the outside can be problematic due to reduced signal strength from attenuation caused by the building materials and scattering by the building geometry. This problem was very evident in the rescue efforts at the World Trade Center Towers in September 2001[1].

The National Institute of Standards and Technology (NIST) has investigated communication problems faced by emergency responders (firefighters, police, and emergency medical staff) in disaster situations such as collapsed buildings. As part of this effort, we investigated the propagation and coupling of radio waves into large structures. We are also investigating various schemes for detecting emergency responders and civilians with portable radios or cell phones who are trapped in voids in a collapsed or partially collapsed building. Buildings scheduled for implosion provide the ideal research environment for investigating radio-wave propagation issues in fully or partially collapsed structures.

Two types of data were collected during the experiment. The first set of data, which we refer to as a “radio mapping,” was collected a few days before the structures were imploded. This involved carrying transmitters (or radios) tuned to various frequencies throughout the structures while recording the received signal at sites located outside the structures. The purpose of the radio-mapping measurements was to investigate how the signals at the different frequencies couple into the structures, and to determine the field strength variability throughout the structures. The second set of data was gathered from radios placed at fixed sites throughout the structures. Received signals were collected before, during, and after the implosion. The receiving systems in this case were both at fixed sites and mobile. The mobile receiving system consisted of measurement instruments and antennas mounted on a modified garden cart (approximately 1 m^3 in size). The cart was pulled around the perimeter of the structures both before and after the implosion, enabling direct comparison of signal strength as a function of azimuth angle (a) through the standing structure and (b) through the resulting pile of rubble after the collapse.

The experiments reported here were performed on three large building structures: a 13 story apartment complex in New Orleans, the Veterans Stadium in Philadelphia, and the old Convention Center in Washington, D.C. Measurements were performed at frequencies of interest to emergency responders, including public safety and cell phone bands (approximately 50 MHz, 150 MHz, 225 MHz, 450 MHz, 900 MHz, and 1.8 GHz). We briefly summarize of the data collected, including propagation statistics, and discuss some of the interesting propagation and attenuation effects we observed. More detailed data are given in [2-4].

2. Experimental Results

We used portable radios similar to those used by emergency responders, hardened against falling debris and modified to transmit over long time periods. These radios were either carried through the building structures, for the radio mapping experiments, or were placed at fixed locations in the structures before implosion. The measurement system consists of a portable spectrum analyzer, a GPS receiver, and a laptop computer. The data collection process was automated by use of software designed to control the analyzer, and to collect, process, and save data at the maximum throughput of the equipment. GPS information was recorded in order to track the position of the mobile cart during perimeter measurements around the buildings. We assembled four antennas on a 4-meter mast. The radio-frequency output from each antenna was fed through a 4:1 broadband power combiner, giving us a single input to the 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 measured frequency bands. 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 receiving sites, or it could be inserted into a modified garden cart for portable measurements.

2.1 Experiments Before the Collapse

Figure 1 shows typical sets of data collected during the radio-mapping experiments (moving transmitter, fixed receivers) for the sports stadium and the convention center. We see that propagation through the building can reduce the radio signal by as much as 60 dB for the stadium, depending on the location of the transmitter, and by as much as 70 dB for the convention center, depending on the location of the transmitter. These results also illustrate that field strengths varied by as much as 60 dB to 70 dB. In communication system 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. Tables I-III summarize the mean normalized received signal strength and the standard deviation for each building structure. More data are given in [2-4].

2.2 Experiments During the Collapse

Figure 2 show the pre- and post-implosion data for the receiver located at one of the fixed receiving sites for two different structures. The dramatic change in the received signal level indicates the time of the implosion. In some of the data sets no received signal was detected after the collapse, due to the high of attenuation caused by the building rubble after the collapse. This finding was verified by the fact that the transmitters were later recovered and were still functioning.

2.3 Experiments After the Collapse

After the implosion, the mobile cart was used to move a receiving system around the perimeter of the building to record the received signals. The path used was generally the same path as that used in the cart measurements before the implosion. By comparing these pre- and post-implosion mobile cart data, the effect of the building collapse on the signal strength can be investigated. Figure 3 shows the comparison of these datasets for the convention center for a few frequencies. Note that the azimuth angles on the horizontal axis correspond to the compass bearings with respect to the geometric center of the building. In these comparisons, we see a wide range of effects cause by the partial collapse.

3. Conclusion

In this paper, we report on a series of measurements performed before, during and after the collapse of three large building 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. We have measured an additional 20 to 80 dB of attenuation after the collapse, depending on building type and location of transmitter. Thus, if someone is trapped under such a rubble pile and is trying to communicate with an emergency responder with a two-way radio or cell phone, their communication link may have to overcome 20 to 80 dB of additional attenuation caused by the building collapse. More detailed data based on the experiments reported here are given in [2-4]. 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, an oil-refinery, and warehouses. The results of the signal strength measurements and statistical distribution for these radio-mapping experiments are given in [5, 6]. The data presented in [5, 6] also include results for the 2.4 GHz and 4.9 GHz frequency bands. Also, [6] presents data on excess path loss, RMS delay spread, and the effects of channel fading on wideband digitally modulated signals for an apartment building, office corridor, oil refinery, and a subterranean tunnel.

Table I: Normalized Received Signal Strength for the New Orleans Apartment Building.

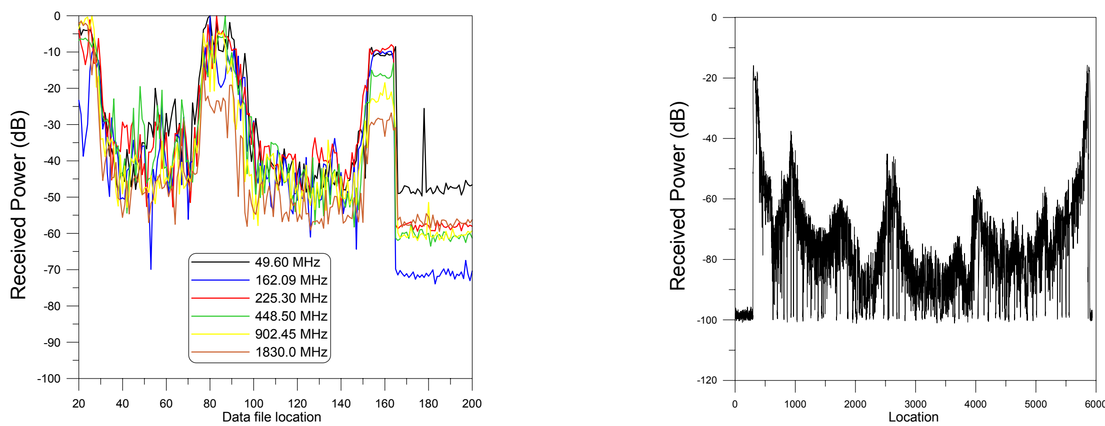
Frequency (MHz)	Mean (dB)	Standard Deviation (dB)
49.6	-38.6	12.1
162.0	-28.4	11.2
225.375	-33.9	10.4
448.6	-40.7	9.2
902.6	-35.2	13.1
1832.5	-38.4	12.5

Table II: Normalized Received Signal Strength for the Philadelphia Sport 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

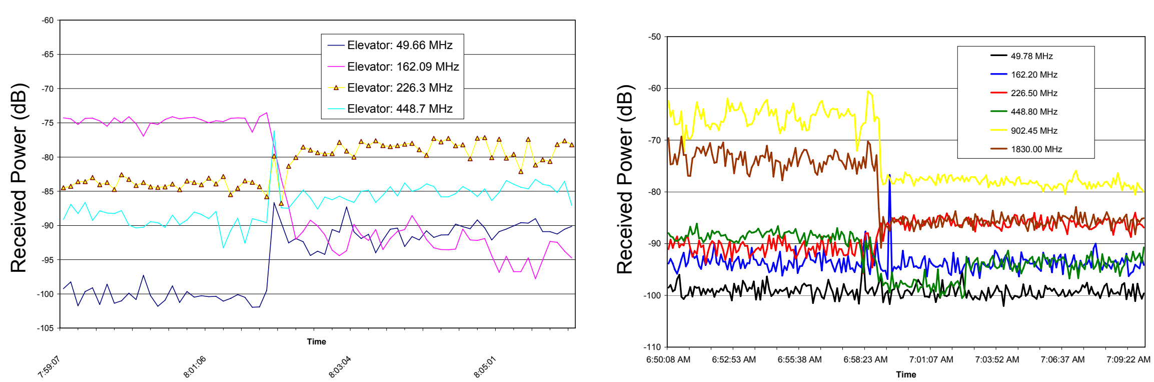
Table III: Normalized Received Signal Strength for the Washington, DC Convention Center.

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



(a) (b)

Figure 1: Radio-mapping results from the: (a) sports stadium and (b) convention center at 226.40 MHz.



(a) (b)

Figure 2: Received power verses time during the collapse of the: (a) apartment building and (b) sports stadium.

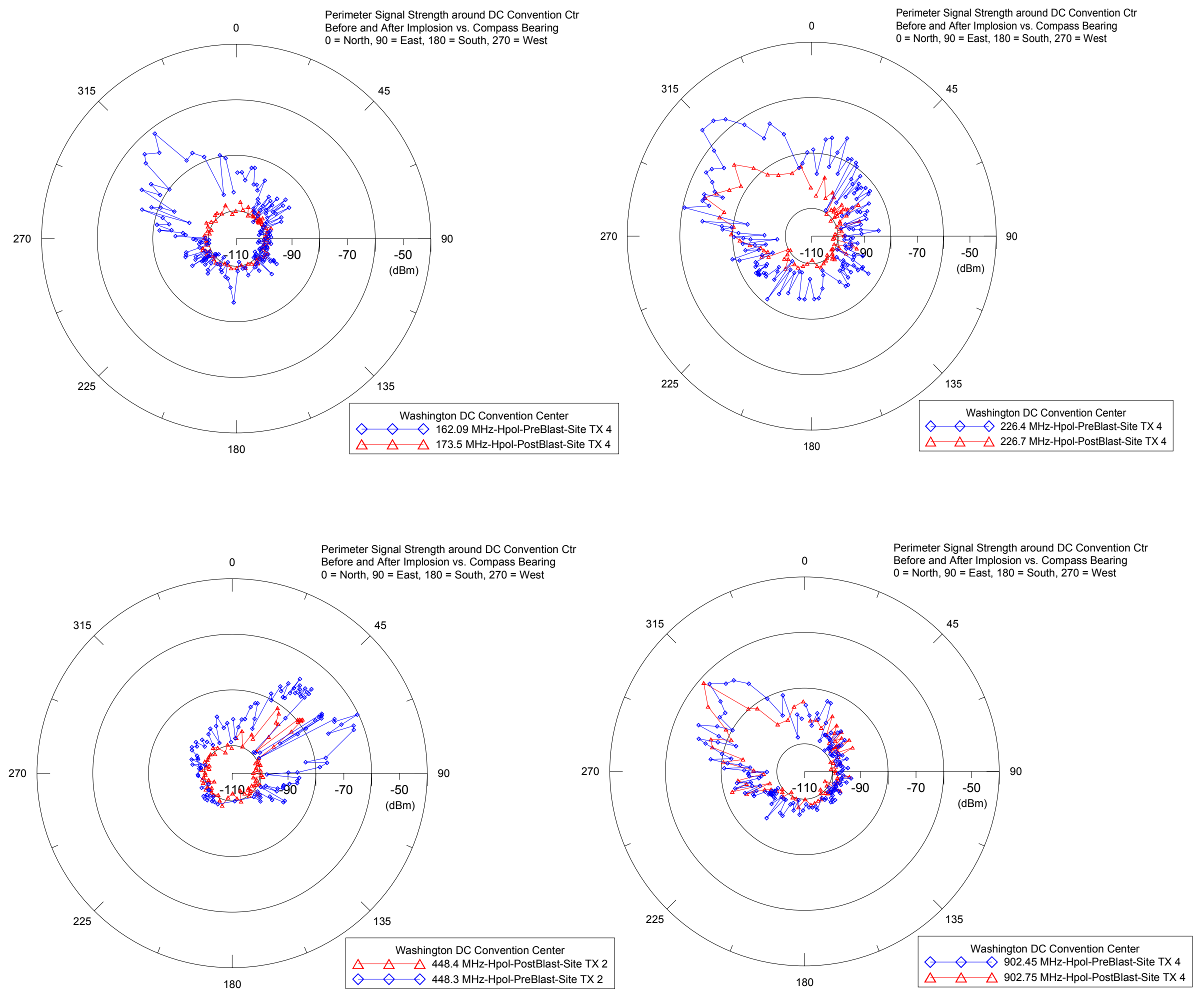


Figure 3: Comparison of pre- and post-implosion received signal level, as measured with the mobile cart for the convention center.

4. References

1. "Final report for September 11, 2001 New York World Trade Center terrorist attack", *Wireless Emergency Response Team (WERT) WERT,* October 2001.
2. C.L. Holloway, et al., "Propagation and Detection of Radio Signals Before, During and After the Implosion of a Thirteen Story Apartment Building," *NIST Tech. Note 1540*, Boulder, CO, May 2005.
3. C.L. Holloway, et al., "Propagation and Detection of Radio Signals Before, During and After the Implosion of a Large Sports Stadium (Veterans' Stadium in Philadelphia)," *NIST Tech. Note 1541*, Boulder, CO, October 2005.
4. C.L. Holloway, et al., "Propagation and Detection of Radio Signals Before, During and After the Implosion of a Large Convention Center," *NIST Tech. Note 1542*, Boulder, CO, May 2006.
5. C.L. Holloway, et al., "Attenuation, Coupling, and Variability of Radio Wave Signals Into and Throughout Twelve Large Building Structures," *NIST Tech. Note 1545*, Boulder, CO, February 2008.
6. K.A. Remley, et al., "Measurements to Support Modulated-Signal Radio Transmissions for the Public-Safety Sector" *NIST Tech. Note 1546*, Boulder, CO, February 2008.