PUBLIC SAFETY TECHNOLOGY

Images courtesy NIST staff

Top to bottom: Horizon West Apartments in Boulder, Colo.; Colorado Convention Center in Denver; NIST building in Boulder
Right: Republic Plaza building in Denver

In-Building Signal Tests

Researchers measure 700 MHz radio signal penetration into large buildings to track the propagation environment in emergency response situations.

By Kate A. Remley, Christopher L. Holloway, William F. Young

The National Institute of Standards and Technology (NIST) in March released the sixth in a series of NIST technical notes (TN) on penetration of radio signals into large building structures, including apartment complexes, hotels, office buildings, sports stadiums and shopping malls. The reports are intended to give emergency responders and system designers a better understanding of what to expect from the radio-propagation environment in emergency response situations. The goal of the project is to create a large set of public-domain data describing the attenuation and variability of radio signals within various building types in the public-safety frequency bands.

The first, second and third NIST TNs — NIST TNs 1540, 1541 and 1542 — described experiments related to radio propagation in a structure before, during and after implosion. The next two notes — NIST TN 1545 and 1546 — focused exclusively on RF

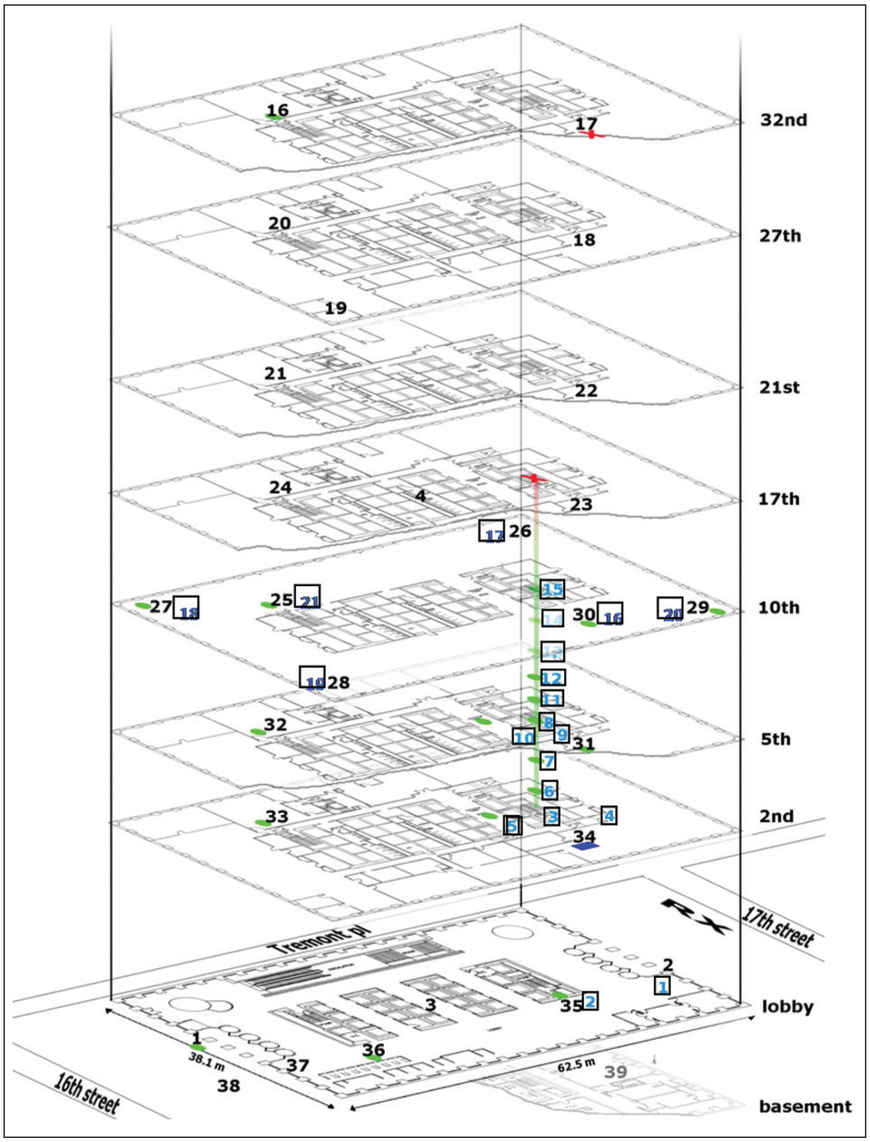


Diagram of the lower floors of the Republic Plaza building, showing the radio-mapping transmitter locations by black numbers, as well as the synthetic pulse measurements, shown by blue numbers inside the squares.

signal penetration into large buildings, with no implosion results.

In the most recent NIST TN 1552, additional measurements were carried out in the 750 MHz frequency band. Because the FCC is in the process of auctioning the D block spectrum with plans for public-safety shared use, NIST researchers studied radio signal penetration in this frequency band into four different large building structures: a convention center, a high-rise office building, an apartment building and a laboratory/office building. Two different types of signal measurements included:

■ Radio mapping, where RF transmitters were carried throughout the structures and signals were received at fixed sites outside the structures, and

■ Broadband measurements that provided the time-response characteristics of the radio environment.

These latter measurements are useful in understanding the level of reflectivity or multipath in a given structure. This article overviews the measurement methods, an example of the measurement data collected and a brief interpretation of the results.

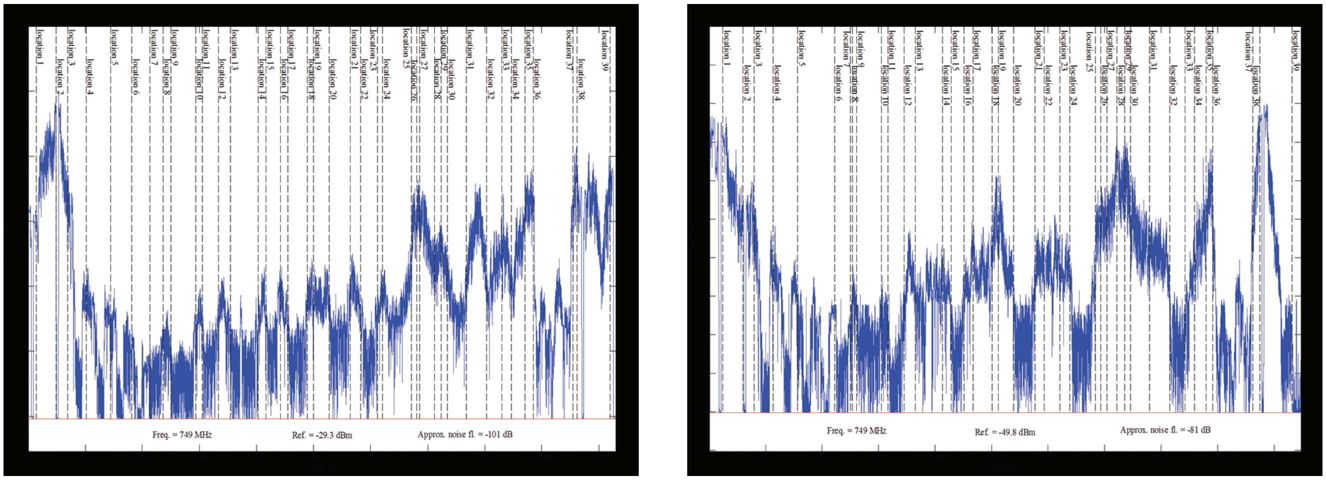
Measurement Methods

A fundamental challenge to radio communications into and out of large buildings is the strong attenuation of radio signals caused by losses and scattering in a building's materials and structure. A second issue is the large amount of signal variability because of multipath that occurs throughout the large structures. The NIST measurements were conducted in four large building structures in an effort to quantify radio-signal attenuation and variability in scenarios encountered by emergency response organizations.

The NIST measurements were intended to simulate an incident command scenario where a fixed-location incident command station is located outside a structure while a mobile unit is carried within the building. The data presented in the NIST study can be used to describe the radio channel from outside a building to inside in point-to-point communications situations. With some additional modeling work, they can also be used to develop models of emergency response trunked or cellular systems. In the latter case, the data would form the last leg of the communications link.

The first type of measurements, referred to as radio mapping, provided a continuous recording of received signal strength at a fixed location outside the structure while a transmitter was carried through the structure. The transmitter emitted an unmodulated, 749 MHz radio signal from within the structure. The goal with these measurements was to cover as much ground in the structure as possible to provide a detailed description of the statistical variation in received signal strength from signals transmitted within a given structure. By covering the routes that would be walked by emergency responders within a structure, public-safety officials and researchers can understand how strong or weak a signal will be, in terms of the average, maximum and minimum received signal levels. Equally important, the expected variance in signals in the 750 MHz band can be determined.

The second type of measurement tested the time-domain response of the channel at particular locations within the buildings by use of a



Republic Plaza building receive site three (left) and receive site one (right). Normalized received signal power as the 749 MHz transmitter is carried through the building.

synthetic-pulse measurement system. These measurements used a vector network analyzer with its output port tethered to the receive antenna by a fiber-optic cable to allow reconstruction of the time-domain response of the propagation channel. With this system, we can effectively reconstruct a short-duration pulse in post processing. The short pulse enables the study of the multipath in a given environment. Figures of merit such as the root-mean-square (RMS) delay spread may be calculated and used to quantify the time required for multipath reflections to decay below a given threshold level.

Penetration into Structures

Large public buildings were chosen for the research because they are expected to present the biggest challenges to emergency response communications. For the measurements at Republic Plaza, a 57-story office building in downtown Denver, three receive sites were used that varied substantially in distance from the building. Receive site one was located about 11 yards (10 meters) from the building; receive site two was about 27.3 yards (25 meters) from the building; and receive site three was located on the roof of a parking garage about 235 yards (215 meters) away. These locations were intended to simulate the locations of command vehicles in an emergency response scenario.

The graphs on Page 38 show two examples of the radio mapping results for the Republic Plaza building. These graphs show the relative received signal levels for two different receive-site orientations with respect to the building. The line-of-sight reference signal is clearly seen by the distinct largest peaks in the plots. In the table above, the additional free space path loss for receive site three is evident in the approximately 18 dB reduction in the reference value compared with values obtained at receive sites one and two. The table also shows that the variation in the received signal levels at all three receive sites given by the standard deviation is similar. Note that the data are normalized by the reference value, which is a line-of-sight signal, so that we can study the propagation effects due to the building. The median and standard deviation results are for the normalized data.

Synthetic pulse measurements were also carried out at positions marked by numbers in rectangular boxes in the diagram, with the vector network analyzer (VNA) located at receive site one. We calculated the RMS delay spread from the data. Twenty-one positions within the building were tested, and 18 of those positions had sufficient dynamic range to provide useful results.

The RMS delay spread was calculated for several different frequency bands. The measurements were made in the stairwell between floors. The RMS delay spread was lowest at the landing of each floor, where a window was located. The delay spread increased moderately as the height increased from around 50 nanoseconds on floor one to around 150 nanoseconds on the highest floor. But when the measurements were made deeper within the building on floors five and 10 (positions nine, 10 and 16), the RMS delay spread increased significantly to between 300 and 450 nanoseconds, depending on the location and the frequency band used to calculate the RMS delay spread.

Results from the Structures

The measurement data showed a wide range of received signal levels and a high variability for these. For the radio mapping experiments, the median values for all four buildings calculated for data normalized to a direct line-of-sight path ranged from

Aggregate Statistics for Radio Mapping Results

	Median (dB)	Std.Dev (dB)	Ref.(dBm)
Republic Plaza Receive Site One	-68.3	20.3	-29.3
Republic Plaza Receive Site Two	-60.0	21.5	-32.7
Republic Plaza Receive Site Three	-49.3	17.8	-49.8

-25.1 dB to -98.5 dB, and the corresponding standard deviation values ranged from 6.8 dB to 30.1 dB. These factors can complicate radio system design because engineers need to design systems that will provide reliable reception in weak-signal conditions, but also systems that will track signals that vary from weak to strong.

The synthetic pulse measurements show that the level of reflectivity — multipath — in the structures was negligible to moderate. The RMS delay spread results ranged from 15 to 450 nanoseconds at various test locations within the four buildings. The RMS delay values for measurements made in large open floor plan buildings were two to five times that of measurements in buildings with relatively narrow corridors. Many radio technologies can handle this level of multipath, although these numbers could change significantly if a trunked or cellular system design were used, rather than the point-to-point systems described in this research.

The measured results provide key parameters that describe the wireless propagation environment in representative responder environments. NIST hopes that improved channel descriptions provided by these measurements will be useful for assessing current and future wireless technology in emergency scenarios, for standards development and for qualifying wireless equipment in environments such as those studied in this research project. ■

More Information

■ For the full NIST TN 1552 and other technical notes, visit: www.nist.gov/eeel/electromagnetics/rf_fields/wireless.cfm

■ For more figures and graphs, visit www.MCCmag.com.

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