Phoenix Fire Department Radio System Safety Project

Final Report

Version 1.7

October 8, 2004

Phoenix Fire Department
Radio System Safety Project

Executive Summary

The purpose of this summary is to provide a simple overview of the Fire Department's Radio System Safety Project Final Report.

The City of Phoenix contracted with Motorola to build a Digital Trunked Radio System to provide communications for all city departments. The system utilizes the APCO Project 25 standard, a non-proprietary digital format. This open architecture allows the use of portable and mobile radios from multiple manufacturers. The system has a service area of approximately 2000 square miles. Trunked radio systems allow efficient use of the frequency spectrum and provide wide area communications capabilities; however, the Phoenix Fire Department has questioned the application of trunked radio technology to firefighting.

Trunked Radio Factors

Trunked radio systems have factors that negatively affect safety issues related directly to firefighting operations. These factors are:

1. **Repeated System** -The radio must be in contact with the system infrastructure to complete communications with any other radio. This causes radio’s operating in some buildings to lose communication with command and crews operating on the emergency scene.
2. **In-Building Coverage** -The system infrastructure provides varying levels of in-building coverage and does not provide coverage in all buildings.
3. **In-Building Treatment**- Buildings that do not have interior coverage must be identified and have communications equipment installed. The cost of identifying and treating all affected buildings is cost prohibitive. Also, while this equipment provides communications in a normal environment it may not survive the high temperatures during a fire.
4. **System Delays** - The trunked system has inherent system delays (0.5 – 1.0seconds) that are required to allocate system resources to make a radio call.

These delays are not tolerable in some time sensitive operations for public safety.

5. **System Failure Modes** - The system has modes of failure that allow users to communicate but may isolate users operating on a single talk-group from one another during emergency operations.
6. **System Capacity** - The system does not have the same call handling capacity system wide. In addition, other system users creating high traffic loads may cause the system to become overloaded and give busy signals to firefighters and police officers operating on the emergency scene.
7. **Radio Equipment** -The Project 25 radios are complex and utilize software to interact with system infrastructure. Different versions of software have caused inconsistency in radio performance.

Testing

Testing was developed to determine if the application of this technology was appropriate. The testing was performed over an eight-week period. The testing provided an opportunity to test alternatives to the trunked radio system. Testing was performed using the Trunked Radio System, 700/800 MHz Analog Simplex, 700/800 MHz Digital Simplex and VHF Simplex radios. The tests were conducted in 30 buildings that consisted of the five different NFPA construction types. Approximately 1,500 talk paths were tested. The same test participants were used throughout the testing to provide consistency in the grading process. Results of the tests showed an overwhelming preference for analog (versus digital) modulation. Performance differences between the frequency bands were negligible in the analog mode. Digital modulation and Trunked Radios had a higher failure rate and the audio quality scored below the ratings in analog mode.

During the testing process, NIST (National Institute of Standards and Technology) became aware of the Phoenix Fire Department testing and asked to participate. A team from NIST spent a week doing radio signal measurements and determined that predicting in-building coverage is a difficult proposition. The NIST measurements showed large signal variations, often greater than a factor of two over the limited distance of a single floor in the structure. This information contradicts vendor claims that buildings within certain geographical areas should have specific decibel strengths in order to have adequate in-building communication.

Recommendation

Based on testing conducted in buildings within Phoenix, and the experiences of other fire departments, we recommend the use of 700 or 800 MHz *simplex* channels with *analog* modulation specifically for firefighting during hot zone operations. Simplex channels provide incident commanders and firefighters a safe and consistent communications system that is not dependent on infrastructure in order to speak to other units on the incident. A network of receivers and transmitters will be needed to provide the wide-area component of the simplex system necessary to allow the communications center to communicate with field users. The Computer Aided Dispatch system will assign the appropriate type of channel based on the incident type. It is recommended that the trunked radio system be used on incidents and for tasks (such as Dispatch, EMS, Command Structure Expansion & Logistical Coordination) that are lower-risk and appropriate for this type of system.

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Abstract
Firefighters often work under hazardous conditions during the performance of their duties. Their radio communications equipment must extremely reliable and the communications functions it provides must be predictable. There is concern that the trunked radio system that is being deployed by the City of Phoenix will not meet the critical communications requirements of the Phoenix Fire Department. Several factors contribute to this concern. Among these is the ability of the system to provide crew and command communications within buildings and the predictability of system operation during system failure modes. The Fire Department has undertaken a qualitative study of operational communications on the fire ground to assess the suitability of trunking and conventional radios systems for fire fighting operations and produce a recommendation on the best system for these operations.

Background
Reliable communication between units operating in hazardous situations is critical to the safety of personnel, and the success of their mission. Loss or degradation of communications in these situations is unacceptable.

The Phoenix Fire Department's current radio communication system is a VHF simplex system with multiple base transmitters and a voter receiver system. Individual radios in the field, both mobile and portable, can communicate directly radio to radio. Communication between the dispatch center and field units is via one of several fixed transmitters in the outbound direction, and via a voted selection of one of a large number of receiver sites in the inbound direction. This provides, in most situations, optimal unit-to-unit communications, and best effort unit-to-dispatch communications. Unit-to-unit communications may not always be optimal due to the signal loss traveling through many floors of a large multi-story building.

The City of Phoenix contracted with Motorola to design and build a digital trunked radio system to provide radio communications for all public safety and municipal departments. This system provides an opportunity to provide high capacity and increased levels of interoperability for all City of Phoenix departments. Trunked radio systems provide high capacity by using complex computer-controlled systems to allocate frequencies and control radio access to the system. In addition, these systems are inherently duplex requiring all transmissions between radios to travel to fixed infrastructure and back to complete the communications path. This type of communications system design may limit communication between units inside buildings because the signal must travel through the building structure twice and overcome the distance to the nearest transmitter/receiver site. The Phoenix Police Department has completed transition to the new system with other city departments soon to follow.

The system was expanded to provide communication for other Phoenix area fire departments. The other participating agencies have provided funding for this system expansion. The City of Phoenix system, referred to as the Phoenix Regional Wireless Network (PRWN), is directly connected to the City of Mesa system (TOPAZ). The interconnection of these systems provides radio communications over a 2000 square mile area with a population of 2.7 million.

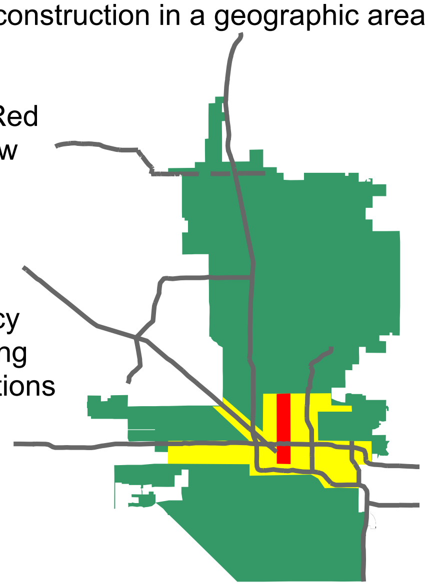
The system was designed to provide all city departments with the needed coverage and capacity to conduct the city's business. The design process did not address the special tactical communications requirements of the Fire Department. While the system addresses the capacity needs of the Fire Department, some performance issues remain unaddressed.

Key System Design Features

1. *Trunked*- this feature provides capacity by sharing a pool of frequencies and allows communications over a wide geographic area. Frequencies are assigned and managed by computerized system controllers. The trunked radio system provides the needed capacity and communication over the geographic area it is designed to cover. Being trunked, it is a repeated system, meaning that portable units communicate with one another through infrastructure and not directly with each other.
2. *Geographic Zones*- the area this system covers is so large that it had to be broken up into subsystems. The system consists of 5 separate simulcast zones (A, B, C, D & E) and multiple Intelli-repeater sites. These simulcast zones have varying capacity and performance characteristics and Intelli-repeaters have even less capacity than the simulcast subsystems. All subsystems and Intelli-repeater sites are connected by data links so that they can operate as one system.
3. *In-building Communications capabilities*- the system has been designed to provide in-building communications. This is achieved by the system transmitting at different power levels based on the building construction in a geographic area.

   The system has 3 coverage levels:
   1. 23 dB -High Rise/heavy construction - Red
   2. 17 dB -Large Industrial buildings - Yellow
   3. 12 dB -Residential construction - Green

   Each different zone has different radio frequency (RF) penetration capabilities. A particular building type in one zone may have interior communications where the same building type in a different zone may not have interior communications.



Factors that Affect Fire Operations

System Factors

Repeated System
In a repeated system, communication occurs when a portable or mobile radio transmits to the trunked system, which then retransmits the radio signal to a second portable or mobile unit by receiving the message on one frequency then retransmitting the message on a second frequency. The portable radios must overcome the attenuation of the building and the distance to the nearest radio site. Portable and mobile radios are not in direct communication and rely on system infrastructure. Trunked radios must also be in contact with the system controller to operate.

Repeated systems, when properly designed, are configured to provide equal talk-in and talk-out to and from the system. If the system is out of balance, users may encounter situations where the portable radios do not indicate out of range because the system's talk out ability on the control channel is greater than the talk-in (receive) capability. In this situation users are not able to communicate, and may be unaware of their inability to communicate.

In-Building Coverage
Repeated systems have a direct impact on operations on the interior of buildings. The PRWN system was designed to provide some level of in-building coverage. Even though the system was designed to provide in-building coverage, no system will provide complete coverage in all buildings. This is a common problem in trunked radio systems. Some jurisdictions utilize direct radio channels to provide communications in areas of marginal coverage[1] [2] [3] [4].

In-Building Enhancements
800 MHz trunked systems typically utilize bi-directional amplifiers (BDA's) to achieve communications on the interior of buildings. This equipment, like any other electronic equipment, will fail when subjected to fire. Structural failures and firefighting actions themselves may also render these systems unusable.

In a fast growing metropolitan area many man-hours of testing are needed to identify buildings which require treatment. Surveying new and existing buildings to assess coverage will be an ongoing task and the costs necessary to treat all deficient buildings are essentially unbounded.

System Delays
Trunked radio systems have inherent delays. These delays are required for the computers to assess the resources needed to complete a radio call, setting up the call and distributing the message to the appropriate radio sites. These delays are typically

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[1] "Operating Guideline." Seattle Fire Department. Sec. 5006, 5007, 5009. November 21, 2002 (Attachment 1)
[2] Esparza, Hugo R. "Proposal for the Use of Simplex Radio Channels in the Operations Division." Fort Worth Fire Department. January 12, 2004 (Attachment 2)
[3] "Michigan State Police System." Transcript. WLNS, Lansing, MI. May 20, 2004. (Attachment 3)
[4] "Palmetto 800 Radio System." Columbia Fire Rescue Newsletter. Columbia, SC. Fall Issue 2003 (Attachment 4)

0.5 second to 1.0 second and delays of this magnitude are unacceptable in some operational situations. The Phoenix Police Department has found this to be true and Special Assignment Unit (SAU) operations no longer use the trunked system when the tactical situation dictates a need for delay free communications.

System Failure Modes

Digital trunked radio systems are complex computer networks that have an RF component to distribute voice messages wirelessly. The PRWN system has several modes of operation that allow operations to continue in the event of system degradation. These system failure modes introduce dangerous factors into fire ground operations.

Site Trunking

Portable and mobile radios roam seamlessly throughout the coverage area. Units on a single incident may affiliate to different geographic zones based on the signal level that particular radio receives. If a zone or subsystem is isolated by a data link failure (Site Trunking), and the portable unit does not have an adequate signal from any other zone, the radios affiliated to that affected zone are isolated from the rest of the system. In this scenario it is possible to have units on an incident that cannot talk to one another despite the fact that they are on the appropriate talk group. Incident commanders on scene may not realize that this situation has occurred.

Fail Soft

In Fail Soft the radio site has lost data communication with the zone controller as well as the control channels. In this mode the system has lost trunking functionality including all capacity-enhancing features, talkgroups, and enhanced features such as PTT ID and emergency. The radio site acts like a conventional repeater on fixed radio channels. The users serviced by the failed site are required to adhere to a “Fail Soft Plan”. This plan is not a system wide plan and will be different for each geographic coverage zone (A, B, C, E and each Intelli-repeater site). This mode presents a complex communications problem for any fire department operation.

System Capacity

The PRWN is a large system that is divided into several coverage zones. These zones have different traffic capacity capabilities. Incident commanders may encounter situations where the number of trunked talk groups to support an incident may need to be reduced. The reduction of talk groups may be required to prevent users from encountering “system busies”. The limited capacity on Intelli-repeater sites has caused problems during large incidents.[5] [6]

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[5] “County asks for Emergency Radio System Review.” North County Times, San Diego, CA. December 9, 2003. (Attachment 5)

[6] Gao, Helen. “Crisis System Upgrades Urged.” San Diego Union Tribune, San Diego, CA. April 7, 2004. (Attachment 6)

Subscriber Factors (Portable Radios)

Out-of-Range Indicator
The portable radio design presumes that the radio will not encounter large fluctuations in signal strength from the control channel. The computations the radio performs to determine out-of-range filters out large fluctuations of signal strength. Firefighters may encounter large signal strength fluctuations that could delay an out-of-range indication.

Portable Software
The complexity of trunked radio systems, and of the portable radio software, has caused inconsistency in portable radio performance. During the transition to the new radio system the Police Department encountered several software problems that degraded radio performance. Use of direct channels on the fire ground will minimize the effect of complex trunked radio software on radio performance.

Trunked System Alternative

Due to the complications a trunked system introduces into the firefighting problem, an alternative to trunked talk groups needed to be investigated. It was anticipated that the use of simplex (direct) channels would meet the fire ground communications requirements. Tests were developed to investigate possible alternatives.

Test Development

The primary purpose of the testing was to prove the concept of using simplex/direct channels as the communications medium for firefighting operations. Testing focused on the ability of interior positions being able to communicate with a command position on the exterior of the building. Secondarily, it was to determine if there were any significant performance differences between frequency bands and digital versus analog modulation.

Many quantitative studies have been conducted on the performance of base transmitter RF penetration of various buildings. These studies have been conducted in the UHF, 800 MHz, 900 MHz and 1400/1500 MHz band using analog modulation[7]. We are not aware of any qualitative study of performance of communications systems as applied to the way that firefighting agencies conduct business. The goal of the testing was to conduct qualitative tests of various common communications systems in typical firefighting scenarios. This study compared the performance of VHF high-band simplex, 700 MHz simplex, and 800 MHz simplex and trunking. The 800 MHz and 700 MHz frequency bands and modes were tested using both analog coding and modulation and P25 digital coding and modulation.

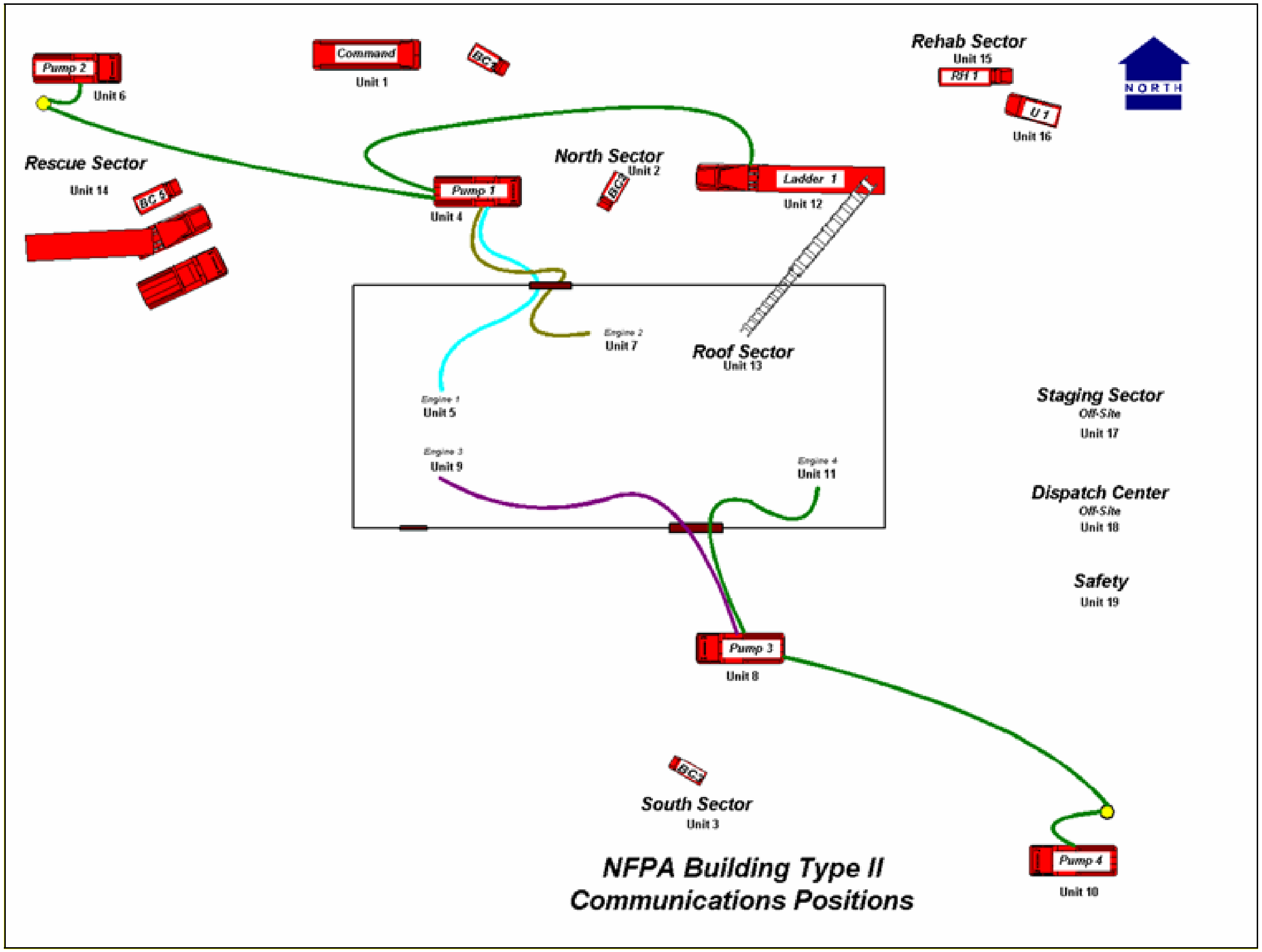
[7] Davidson, Allen and Casey Hill. "Measurement of Building Penetration Into Medium Buildings at 900 and 1500 MHz." IEEE Transactions on Vehicular Technology. Vol. 46 No. 1. February 1997 (Attachment 11)

Fire Ground Communications Analysis
An analysis of fire ground communications was performed for four Incident types. All responses were based on the Phoenix Fire Department Standard Operating Procedures (SOP's) to a specific National Fire Protection Association (NFPA) building type.

<u>NFPA Building Types</u>

1. Type 1 Fire-Resistive Construction
    a. Reinforced concrete and structural steel
2. Type 2 Non-Combustible/Limited Combustible Construction.
    a. Metal-Frame covered by metal exterior walls
    b. Metal frame enclosed by concrete block, non-bearing exterior walls
    c. Concrete block bearing walls supporting a metal roof
3. Type 3 Ordinary Construction/Brick and Joint Construction
4. Type 4 Heavy Timber Construction
5. Type 5 Wood Frame Construction

A command structure was developed for each response. Analyzing the command structure and determining the logical fire ground communications paths led to the development of the talk matrix. A test script was developed for each unique communications path identified in the talk matrix. Each communications path was categorized as either fire ground communications or wide-area communications, with the majority of the paths being fire ground. Each building type has an associated test plan that includes a description of the response, incident drawing (Figure 1), command structure (Figure 2), talk matrix (Figure 3) and test scripts.



Pump 2
Unit 6
Command
Unit 1
BC 1
Rehab Sector
Unit 15
RH 1
U 1
Unit 16
NORTH
Rescue Sector
Unit 14
BC 5
Pump 1
Unit 4
North Sector
Unit 2
BC 2
Ladder 1
Unit 12
Engine 2
Unit 7
Roof Sector
Unit 13
Engine 1
Unit 5
Staging Sector
Off-Site
Unit 17
Engine 3
Unit 9
Engine 4
Unit 11
Dispatch Center
Off-Site
Unit 18
Safety
Unit 19
Pump 3
Unit 8
BC 3
South Sector
Unit 3
NFPA Building Type II
Communications Positions
Pump 4
Unit 10

Figure 1

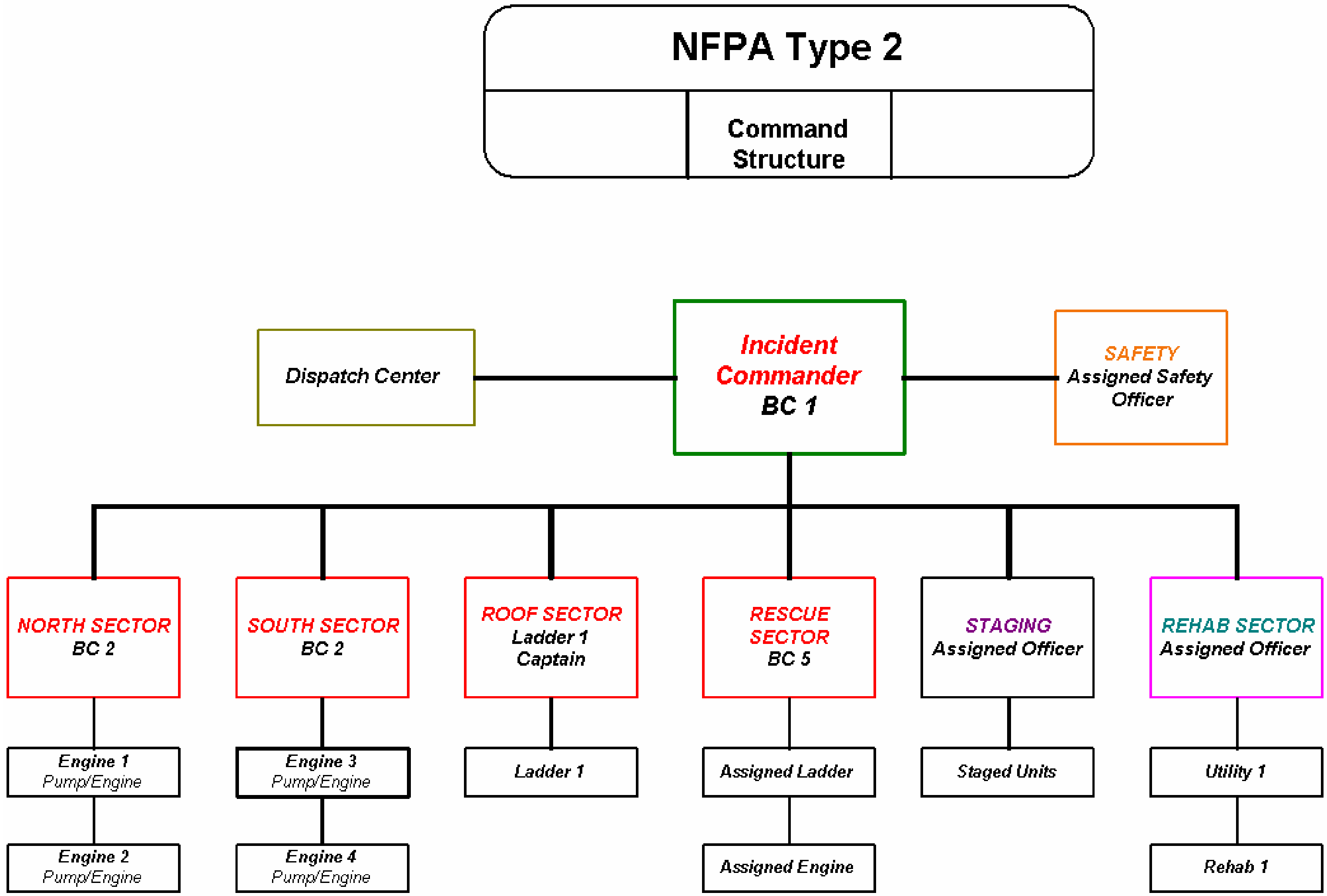

NFPA Type 2
Command Structure
Dispatch Center
Incident Commander BC 1
SAFETY Assigned Safety Officer
NORTH SECTOR BC 2
SOUTH SECTOR BC 2
ROOF SECTOR Ladder 1 Captain
RESCUE SECTOR BC 5
STAGING Assigned Officer
REHAB SECTOR Assigned Officer
Engine 1 Pump/Engine
Engine 2 Pump/Engine
Engine 3 Pump/Engine
Engine 4 Pump/Engine
Ladder 1
Assigned Ladder
Assigned Engine
Staged Units
Utility 1
Rehab 1

Figure 2

NFPA Building Type 2

Talk Matrix

Position	26. Safety	25. Dispatch	24. Staging Sector	23. Utility 29	22. Rehab Sector	21. Rescue Sector	20. Roof Sector	19. Ladder 9	18. Ladder 20 Roof	17. Ladder 20	16. West Sector E5	15. Pump 5	14. West Sector E9	13. Pump 9	12. South Sector E12	11. Pump 12	10. South Sector E18	9. Pump 18	8. North Sector E20	7. Pump 20	6. North Sector E17	5. Pump 17	4.West Sector	3. South Sector	2. North Sector	1. Command
1. Command	F	W	W	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	
2. North Sector	F	W	W	F	F	F	F	F											F	F	F	F	F	F		
3. South Sector	F	W	W	F	F	F	F								F	F	F	F					F			
4. West Sector	F	W	W	F	F	F	F		F	F	F	F	F	F												
5. Pump 17	F	W					F	F											F	F	F					
6. North Sector E17	F	W				F	F								F		F		F							
7. Pump 20	F	W						F											F							
8. North Sector E20	F	W				F	F								F		F									
9. Pump 18	F	W													F	F	F									
10. South Sector E18	F	W				F	F								F	F										
11. Pump 12	F	W													F											
12. South Sector E12	F	W				F	F																			
13. Pump 9	F	W							F	F	F	F	F													
14. West Sector E9	F	W				F	F		F		F															
15. Pump 5	F	W							F	F	F															
16. West Sector E5	F	W				F	F		F																	
17. Ladder 20	F	W					F		F																	
18. Ladder 20 Roof	F	W				F	F																			
19. Ladder 9	F	W																								
20. Roof Sector	F	W				F																				
21. Rescue Sector	F	W	W	F																						
22. Rehab Sector	F	W		F																						
23. Utility 29	F	W																								
24. Staging Sector	W	W																								
25. Dispatch	W																									
26. Safety																										

F = Fireground communications (local area)
W = Wide Area communications.
RED = Test Path
BLACK = Redundant path

Figure 3

Testing

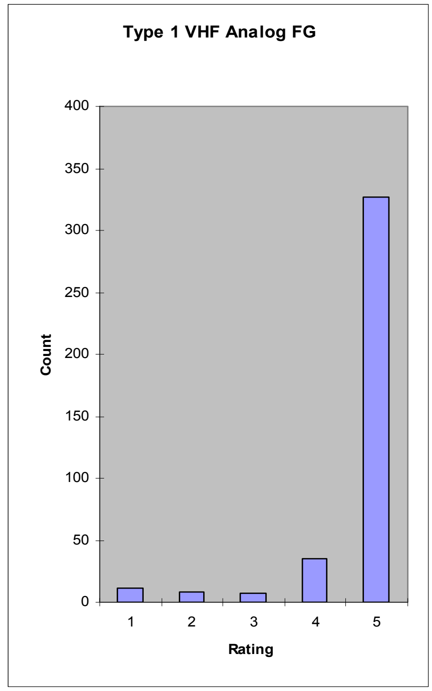
Testing was performed in 30 buildings over an eight-week period. Testing was performed in 4 of the 5 NFPA building types, Types 1, 2, 3 and 5. Type 4 construction (Heavy Timber) was excluded because it is rarely used in the Metro Phoenix area. Approximately 1,500 talk-paths were tested and graded. Testing was performed in the PRWN 23 dB, 17 dB and 12 dB coverage zones.
Each building was pre-planned for the test session. Personnel were placed in the buildings to represent fire companies on an incident response. The personnel followed the test plan and graded each communication path. Each path was graded on a 1-5 scale with 1 representing poor communications and 5 being the best audio quality. Participants also determined if the communications were useable on the fire ground on a pass/fail basis.

Test Results
Upon completion of testing each day, the building's test results were entered into an Excel spreadsheet and placed into the "Phoenix Fire Department, Radio Safety Project Results" books. The spreadsheet contains the bi-directional grades for each communications path. Using the spreadsheet data, histograms were created for each building type and path category. Type 1 buildings were found to have the most variability in the histograms, and are also the buildings with the highest-risk environments, most complex interiors and largest operational structure. The following pages show the histograms for fire ground operations in Type 1 buildings.

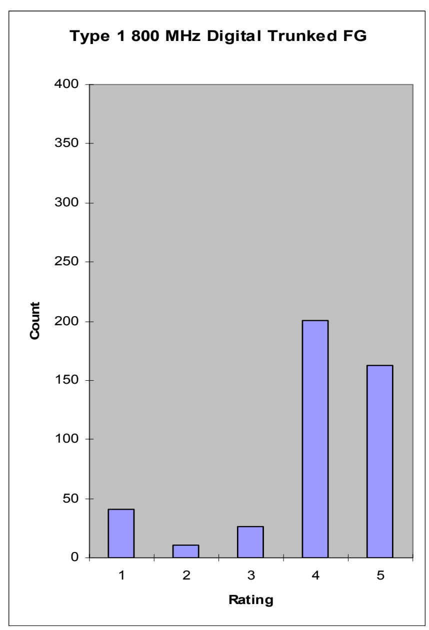
<u>Communications Path Categories</u>

- Fire Ground- Interior to Interior
- Fire Ground- Interior to Exterior
- Fire Ground- Exterior to Exterior
- Wide Area- Interior to Exterior
- Wide Area- Exterior to Exterior

VHF Analog Simplex
The VHF analog simplex mode provided adequate communications to support fire ground operations. In the majority of testing, it was possible to communicate from the interior of the structure to command on the exterior. In the event that communications was not possible, other test positions could relay the information to command. This ability to relay information is a major benefit of simplex communication. VHF was also used as a coordination channel for the trunked radio system testing. It was found that the VHF system would provide communications from command to the interior test positions when trunked radio system communications were not possible.



Trunked Radio System
The trunked radio system provided useable communications when adequate RF signal levels were present. The system provided coverage in most buildings but, when the system did not provide coverage, fire ground communications were severely hampered. Participants in areas of no coverage could not communicate at all. The VHF simplex/direct channels were used for coordination when the trunked system did not provide coverage. In the current fire department VHF simplex radio system messages can be relayed from interior crews to the incident commander.



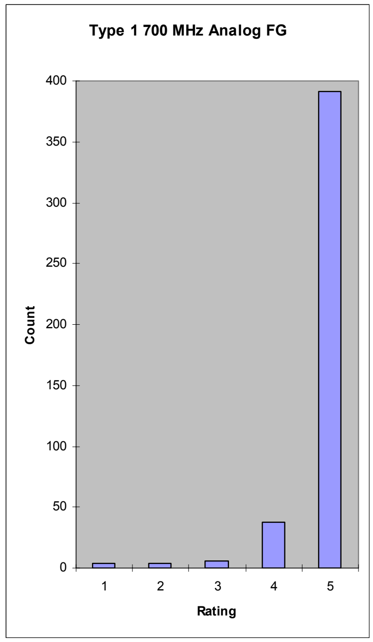
The trunked system provided excellent wide area communications capability on the exterior of buildings. When interior signal levels were adequate, the system allowed wide area communications from interior positions.

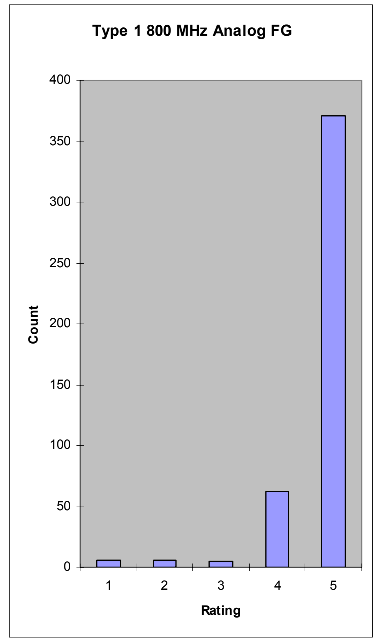
Interior communications were often inconsistent. Radios that were in close proximity did not receive all messages. Sometimes all of the radios would receive the message and other times only one radio in an area would receive the message. The Police Department has also encountered this problem in actual use. Motorola speculates that there is a problem with the roaming or site-affiliation routines. The portable radio firmware will be upgraded in the near future. This observation shows the complex nature of roaming within wide-area trunked radio systems.

Below-grade and elevators consistently posed communications problems for the trunked system.

700/800 MHz Analog Simplex

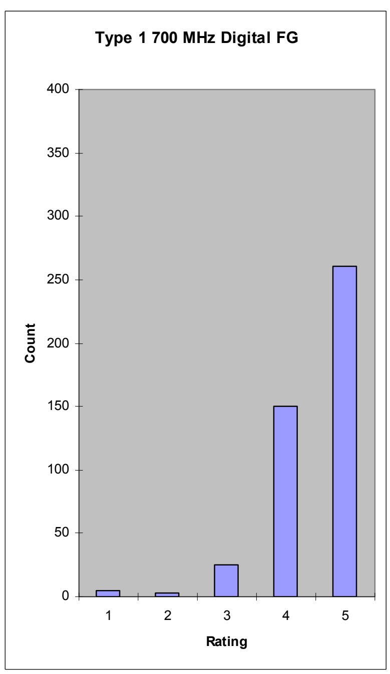
The 700/800 MHz simplex channels provided clear, consistent communications in most test situations. The test participants preferred this mode of operation over all others. Before testing commenced it was expected that there would be differences in penetration capabilities between RF frequencies. The penetration differences between RF bands were negligible. We did however note that in some particular instances the 700/800 RF band did outperform the VHF analog channel. The ability to communicate was more predictable in all simplex modes of operation.

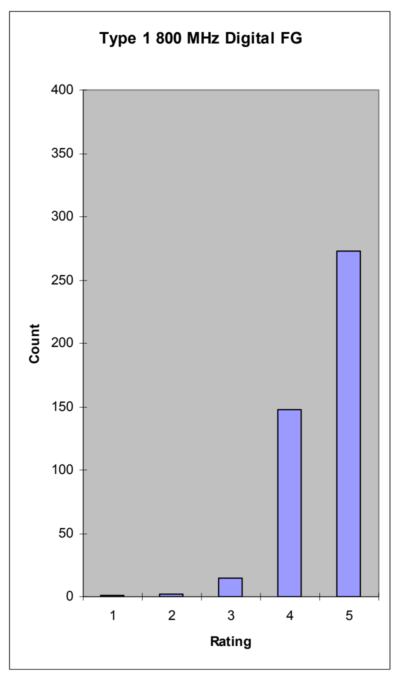




700/800 MHz Digital Simplex

The 700/800 MHz Digital simplex channels provided consistent communications. Test participants did note that the majority of transmissions had some level of digital distortion as reflected by the large number of 4 ratings and increase in 3 ratings. The typical level of distortion did not render the communications unusable. Users did encounter more situations where a repeat was needed to interpret the message. Users tended to prefer all analog modes to any digital mode. Digital modulation did outperform analog modulation in very low signal level situations. The digital mode would capture the signal and provide clear communication when the same analog path would be scratchy and barely readable.





General Observations and Qualitative Measurements

Initially it was hypothesized that there would be some correlation between construction type and the ability to communicate. This hypothesis proved to be partially true. In general, Type 1 and Type 2 buildings posed the most difficulty in communications, while Type 3 and Type 5 buildings posed few impediments to communication.

Early in the testing process, the US National Institute of Standards and Technology (NIST) in Boulder, Colorado, became aware of the work being conducted. NIST is currently conducting research into signal propagation in buildings before, during and after structural collapse. The NIST team has collected data at several sites around the US, and believed that the Phoenix testing could assist in their research. They sent a team to investigate the testing process and to collect some qualitative data in an attempt to relate numerical signal level measurements with the subjective audio ratings recorded by our members.

The NIST team collected data during several of the regular testing activities, and also requested some special tests to assist in equipment calibration and reference data gathering. The team also conducted tests in buildings around Boulder, Colorado after their return home. They have shared their preliminary findings both on the Phoenix area tests and the Boulder tests[8]. These tests show a large variability in the received signal levels as the transmitter travels throughout a building, even over the limited distance of a single floor. This variability shows that the prediction of signal levels within a building will be an extremely complex task.

There are many factors that influence the ability of a radio user to communicate within a building. Several of these factors, such as system signal strength, are under the control of the communications system designer; others, such as building construction or terrain, are not. Factors affecting radio communications performance are contained in the following list.

Interior Coverage Factors

1. System Coverage Area - the location of the building in the trunked system and the signal level provided at the location 23 dB, 17 dB and 12 dB.
2. Geographic Distance - The distance to the nearest transmitter/receiver site.
3. Building Material - different construction materials have different levels of RF attenuation. Lighter weight materials posed few problems. As the density of the material increased more communications failures were noted.
4. Building Features - Windows, open areas inside, number of interior walls, elevators, below grade areas, metalized film on glass, insulating material all had an effect on communications.
5. Building Construction - the inherent characteristics of different building types had some effect on the ability to communicate.
6. Building Density - the number and type of surrounding structures has an effect on the ability of the system to provide interior communications. Surrounding structures can have a “shadowing” effect.
7. Terrain - Small changes in terrain, from rolling hills to large peaks, in the vicinity of a structure can “shadow” the building from infrastructure sites.

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[8] Rutschlin, Marc, et. al.. A Calibrated Communications Receiver System for the Measurement of Weak Signals. October, 2004. (Attachment 10)

Conclusions and Recommendations

The Nature of Fire Ground Operations

Structural fire fighting operations, and other similar public safety operations, have the majority of their tactical workers and their communications are concentrated in a relatively small geographic area. The fire fighters work as teams and all operations are coordinated by an incident commander that is located in close proximity to the incident.

The concentrated nature of fire ground tactical operations, and the fact that the fire fighters are in close proximity to life hazards requires that the communication between the workers involved in these situations have the highest level of reliability, coverage and survivability. In our testing, we have found that the direct radio-to-radio mode of operation provides the most reliable communications for fire ground operations. In cases where even direct radio-to-radio communications was not possible, users were able to relay messages between users, filling coverage gaps. This is not possible using a duplex radio system.

Some fire departments currently use duplex radio system for their operations. However, we have found that the majority of these also have a direct mode of operation that is used when duplex communications are not possible, particularly inside buildings. This mode uses the same frequency as the duplex communications, but allows direct communications for those units that switch to the direct mode. This type of operation is not possible in a trunking system because the frequencies used by the trunking system change with each message or transmission.

Some operations on the fire ground, such as logistics and staging, work well with the wide area communications provided by duplex and trunked radio systems. In addition, communications on incidents that are by nature wide area are also suitable for duplex communications, although many, such as wildland firefighting, have a tactical component that is best served by direct radio-to-radio communications.

While the majority of communications on a fire ground are best served by direct communications, it is important that these communications are monitored by a communications center and recorded when possible. Communications center operators act as an extension of the incident organization and are used to provide backup command and control and for the ordering of additional resources. Center operators will make notifications and calls for assistance based on information they passively receive from monitoring incidents. Recording communications traffic assists the organization with incident reviews, training and legal matters. Generally one of the first activities after a major incident is a review of all telephone and radio traffic from the incident.

700/800 MHz Simplex Channels
To support firefighting operations, the use of 700/800 MHz simplex channels is the recommended option. This is based on test results that prove that 700/800 simplex channels meet the communications requirements on the fire ground. Staying in the VHF band would limit interoperability with all other city departments and many other agencies. To maximize efficiency it is recommended that the trunked radio system be utilized

where appropriate. The application of trunked system talk groups should be based on the need for wide-area communications and the operational situation. This option assigns firefighting operations on the interior of structures to simplex channels (direct). This use of simplex channels has several advantages over trunked talk groups (repeated) for firefighting as described below.

Non-repeated- this allows the firefighters to talk directly to each other without reliance on system infrastructure. Radios on the interior can communicate directly to each other without having to overcome the resistance of the building and distance to the nearest tower.

In-Building Treatment Not Required- Interior crews are not reliant on building systems for communication on the fire ground. Building treatments that provide interior communications are susceptible to failure in fire situations. Interior communications on direct channels are more consistent and reliable.

No System Delays- Simplex/Direct channels are not reliant on the system for the assignment of resources and therefore do not have system induced delays.

Predictable System Failure Modes- Simplex/Direct channels are independent of the trunked radio system and are not affected by system failure modes. Use of Simplex/Direct channels will provide an additional level of communications redundancy for the Fire Department.

Predictable Capacity- Capacity on simplex/direct channels is limited by the physical number of channels that are allocated for fire ground use. Users will not encounter "system busies" due to system congestion due to other system users. The simplex/direct channels are assigned as needed and are not pooled for system use. This provides highly predictable system behavior during periods of high incident activity.

Operational Considerations- Fire Department personnel are required to wear protective clothing that restricts movement and access to portable radios. This protective clothing is required to operate in the extreme environmental conditions of firefighting i.e. zero visibility, high temperatures, low oxygen and poisonous gases. When firefighters find themselves in May Day situations (trapped, lost, and low or no air), it is difficult to perform tasks that require the manual dexterity such as changing radio channels. This is compounded by the possibility of being in a hypoxic state. Hypoxia often does not allow an individual to think logically and perform at the mental levels of a person in a normal atmosphere. Use of direct channels will reduce the need to change channels due to loss of communications[9]**.**

Interoperability- Use of 800MHz simplex/direct channels for firefighting will be in addition to using trunked radio talk groups for other purposes. This option allows interoperability with other agencies on 800 MHz trunked systems and the other city departments on PRWN while still meeting the operational requirements of the fire department.

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[9] "Palmetto 800 Radio System." Columbia Fire Rescue Newsletter, Columbia, SC. Fall Issue 2003: 2, 4 (Attachment 4)

Simplex Channel Infrastructure
Fire ground operations require wide-area capability to communicate with the Dispatch Center. This communications path allows the Dispatch Center to monitor, record and document the incident. The Dispatch Center also provides a dedicated listener that is not on incident. A dedicated listener is not distracted by what is happening on the fire ground and is able to focus on the radio communications. This provides another layer of safety for the fire ground. To meet this wide-area communications requirement an infrastructure for a simplex system would need to be designed and built prior to firefighters utilizing simplex channels. The infrastructure would include transmitters and a voter-receiver network to provide talk-in and talk-out capability for the dispatch center.

On-Scene Communications Support
Currently fire ground communications are unsupported except for the infrastructure that is in place. Simplex systems allow the deployment of stand-alone on-incident communications support. On the fire ground, fortifying a position with more manpower and hose lines to make an operation safer is a common practice. It is also possible to fortify on-scene communications. On-scene communications support would increase the safety of fire department personnel by bringing a receiver site to the incident. This increases the possibility that the interior crews will be able to communicate with the exterior. In addition an on-scene communications support component would be able to provide tactical level communications interoperability if needed. This concept was part of the communications solution from the "9/11 Commission Report"[10] and McKinsey Report "Increasing FDNY's Preparedness"[11].

Digital versus Analog
The results of the testing exhibited user preference for analog modulation in all frequency bands. The incidence of scores of 3 and below in the digital mode identify a performance difference between digital and analog modulation. This performance difference was a prime reason that the New York City Fire Department (FDNY) recalled digital radios from field use. FDNY had deployed digital radios and had to remove them from service after experiencing unreliable communications in the digital mode. Thomas Von Essen, former Commissioner of the New York City Fire Department stated in his testimony to the 9-11 Commission that:

> "In March 2001, we gave all the units the new digital versions of the radios. Although the radios appeared to be the same, the digitals performed differently from the analogs. There were some problems reported in the field and safety concerns were expressed by the firefighters and chiefs. I immediately recalled the digitals and had everyone go back to the radios they were using before. One of the reported problems with the digital radios was that messages transmitted

[10] United States. National Commission on Terrorist Attacks Upon the United States. 9/11 Commission Report. 2004: 397 (Attachment 7).
[11] McKinsey and Company, Increasing FDNY's Preparedness, Recommendations - Section 2.1.2. 2003: 90 (Attachment 8).

simultaneously cancelled each other out- the transmissions were "stepping on each other".[12]

Testing was performed to reproduce the symptoms that FDNY had encountered. Phoenix Fire Department testing was able to reproduce the same symptoms that Commissioner Von Essen had described. Based on our own findings moving to digital modulation on the fire ground may increase occurrences of lost communications. In analog mode while the interfering communication may not be intelligible, the receiving radios could detect that an attempt to communicate was being made.

Digital modulation provides added features that are not available in analog. These features can still be implemented in an analog radio by utilizing a digital header or trailer with the analog voice transmission. Utilizing this format, the digital features would be available for fire ground use.

While it is most logical to move to digital modulation based on the possibility further narrow banding in the future, the reliability of analog communications currently outweigh the benefit of meeting any future FCC requirements. It may be necessary to address these operational concerns with the FCC if a future mandated move to digital is presented.

[12] "Testimony of the Former Commissioner of the New York City Fire Department, Thomas Von Essen." The National Commission on Terrorist Attacks Upon The United States. 11th Public Hearing. May 18, 2004: 7 (Attachment 9).

Conclusion

Based on testing and the past history of other fire departments operating on trunked radio systems we recommend:

1. 700 / 800 MHz Frequency Band
    a. Trunked Digital Talkgroups to provide wide-area communications for dispatch and incident support.
    b. Simplex/Direct Analog Channels to provide tactical incident communications in direct support of any operation where the users are utilizing SCBAs, other life-safety situations, or when delay-free communications are required.

2. Construction of a Transmitter/Receiver Network to support the wide-area communications needs of the Simplex/Direct Analog channels and for safety monitoring of the incident activity.

3. On-Scene Communications Support Units that would be dispatched to incidents to improve firefighter safety through communications support and provide interoperability if needed.

Simplex channels provide incident commanders and firefighters a safe and consistent communications system that is not dependent on infrastructure to speak to other units on the incident. The firefighter on the end of a hose line will be able to speak to other members of their crew regardless of the trunked system status. Firefighters in trouble will have communications with other firefighters on the incident. The firefighter in trouble will not need to worry what that “Honk” or “Bonk” means and will not have to change channels to communicate. His only task will be to press the button and call for help.

Attachment 1

Seattle Fire Department

“Operating Guidelines”

Sections 5006, 5007, 5008

Revision Date: November 21, 2002

OUT OF QUARTERS

Unit Officers are responsible for proper receipt of responses and other information. Officers may elect to place a member on radio watch while out of quarters.

A member assigned to radio watch should remain within listening distance of a radio (mobile or portable) and is responsible for receiving response information or other messages.

While on an alarm, messages concerning a unit or a group of units should be directed to the Incident Commander.

During training or other situations, one unit should be designated as “answering”. Responses or other messages concerning the group or any unit of the group are then directed to the unit answering.

It is the responsibility of the answering unit to receive and relay responses or other messages to the group or any unit of the group. If it is necessary for a change to be made regarding the unit “answering” the FAC should be notified.

FOR EXAMPLE
“Dispatcher from B-5. Attack 28, Engine 33, and Battalion 5 are at 7612 - 42 Avenue S. drilling. Battalion 5 answering.”
Battalion 5:
“Dispatcher from Battalion 5. Battalion 5 returning, Ladder 12 answering.”

CHANNEL ASSIGNMENTS

Units should normally monitor Channel 4-A when in service.

Unless otherwise directed by the FAC, designated channels are to be used for operations as defined in the appendix of this guideline.

DIRECT CHANNELS

A Direct channel is one that does not go through a repeater and is not monitored by the FAC.

Whenever possible, members should use the appropriate trunked channels. This will allow Dispatchers to monitor communications and keep trunked radio features available to the members.

Incident Commanders should avoid having all units switch to a direct channel as a routine procedure.

As soon as possible after command is established, Incident Commanders should monitor or assign a member to monitor the appropriate direct channel.

Members should switch to a direct channel:

- In known poor radio reception or transmission areas.
- When radios "bonk" indicating they are out of range.
- When they cannot communicate with anyone on the trunked channel.

Members should use the direct channels that correspond to the assigned incident channel on the Zone B bank behind channels 1A, 2A and 3A.

- Example: When the incident is assigned to channel 1A, the direct channel is 1B. The same for 2A (2B) and 3A (3B).

When the incident is assigned to any channel other than 1A, 2A, or 3A the direct channel is 1B.

Members that experience poor radio reception or transmission should change their location, use a cell or house phone, use runners, etc. to establish communication.

CHANNEL ASSIGNMENTS

Channel 1-A	Primary channel for fire responses.
Channel 2-A	Secondary channel for fire responses/incidents.
Channel 3-A	Tertiary channel for fire responses/incidents.
Channel 4-A	Primary channel for dispatching. Department radios will normally be tuned to this channel when units are in-service and not on responses or on other assigned channels.
Channel 5-A	Primary channel for aid and medic responses/ incidents.
Channel 6-A	Secondary channel for aid and medic responses/ incidents.
Channel 7-A	A channel used by paramedics to talk to the Trauma Doctor.
Channel 8-A	A channel used by paramedics to talk to the Medic One Doctor.
Channel 9-A	A channel monitored by the ambulance company. SFD personnel are to use this channel to contact the ambulance dispatcher to request an ambulance and to assist ambulance crews with additional directions.

the emergency communication and prioritize responses within the Battalions so a manageable system of triage can be performed from the Battalion to the citywide level. Each Battalion Chief will prioritize, dispatch, and monitor the response activities of the companies directly under their span of control.

If the Battalion Chief is out of quarters, unavailable, or unable to perform as the Battalion focal point, the senior or ranking Company Officer in the Battalion Headquarters will assume the responsibilities. Officers assuming this position must attempt to make contact with their Battalion Chief and re-assign coverage of their inspection route to another company.

The triage information gathered by the Battalions will now be transferred to the RMC. This information must be relayed as soon as possible in order to maintain a quick City-wide incident and resource assessment.

However, it is important to remember that certain areas may have high life safety or conflagration concerns that will require companies to stop and perform emergency operations. Company Officers must immediately contact their Battalion Headquarters and report their location, reason for stopping, and where the Damage Assessment Route was left incomplete. Battalion Chiefs may then dispatch resources within their Battalion and continue to relay information to the RMC. The RMC will have the ultimate decision making responsibility for additional resource allocation and multiple incident management within the City.

For example, Engine 27 discovers a severely damaged apartment complex with several people trapped. Battalion 5 will dispatch intra Battalion resources to this incident. Additional resources may be needed. Battalion 5 will relay this information to the RMC on Channel 1A and the Resource Manager within the RMC will make decisions on inter-battalion resource allocation.

COMMUNICATIONS

The 800 MHz Radio system will be divided during Level 3 Operations. Each Battalion has its own channel and must monitor the following Channel assignments while the Department is in Level 3 Operations.

	Primary	Backup	Site Trunking
Battalion Level, RMC & FAC Resource Allocation	Channel 1A	Channel 1B	Channel 14A
Battalion 2	Channel 2A	Channel 3B	Channel 15A
Battalion 4	Channel 4A	Channel 2B	Channel 15A
Battalion 5	Channel 5A	Channel 3B	Channel 15A
Battalion 6	Channel 6A	Channel 2B	Channel 15A
Battalion 7	Channel 7A	Channel 3B	Channel 15A

After a declared Level 3 catastrophe, companies are to report their status (station damage, personnel accountability, and service status of apparatus) to their Battalion Chief by phone if possible. If the station phone is unavailable, companies are to use their assigned Level 3 Operations channel. If the assigned channel is not working, Battalions 4 and 6 will use Channel 2B and Battalions 2, 5, and 7 will use Channel 3B.

Companies may have to relay information on the B channels from company to company until the Battalion is reached. Cellular phones or other means of communication may also have to be used to maintain contact with the Battalion Headquarters.

Medic units stay under control of the Battalion where they are assigned and will follow the established communication procedures outlined in this guideline. Medic 1 and Medic 10 will be assigned to Battalion 2.

Channel 1A will be the Citywide channel for resource coordination and incident management between the Battalions, RMC and the FAC. Battalion Chiefs will report the status of their companies to the RMC and the FAC on Channel 1A only. Channel 1B may be used if Channel 1A is not working properly or if directed by the FAC.

Companies must monitor their primary, backup, or site trunking channel. Seattle Fire Department members should use face to face communications as much as possible while operating at an incident. Remember, the assigned channels are for communications between the Company level and Battalion level for resource requests and status updates. Use of the assigned channel for fire/incident ground communication should be kept to a minimum in order to avoid unnecessary congestion of that channel.

If the 800Mhz system is functioning properly and the assigned primary channel is in use (e.g., 5A, for Battalion 5), companies should consider using the assigned backup B channel (3B) for fire/incident ground communications. Incident commanders will have to procure (2) radios to monitor the Battalion level channel and the on-scene Company level channel. The Incident Commander of the specific emergency must notify all personnel under their control they will be operating on the B channel.

Notes –	The emergency button does not work on the B Channels. Units that are directed to respond outside their Battalion are responsible for monitoring the appropriate channel assignment for that area. The FAC will field incoming emergency information transmitted by civilians and relay it to the RMC on the assigned channels.

Site Trunking – If the 800Mhz system is in site trunking, the Citywide Resource Allocation channel between the FAC, RMC, and the Battalions will be Channel 14A. Communications between the Companies and the

Battalions will be assigned to Channel 10A.

It is extremely important to limit the use of radio communications during Level 3 Operations. The Department will be under a tremendous demand and communications must be limited to what is critical to incident mitigation. Fire/Incident ground communication shall be face to face or limited to the assigned B Channels as much as possible while in site trunking.

In the event of a 800Mhz system failure the old 450Mhz radio system has been retained by the city, but with significantly reduced capability. The SFD has been allocated one repeated, citywide channel (channel 7) for emergency use as a Command and Control channel. Each Battalion Headquarters, the Fire Alarm Center, the RMC, and the Command and Control Van each have one Motorola 450Mhz Saber radio with two batteries and one charging unit. At Battalion Headquarters, they should be placed in their charger and maintained adjacent to the Battalion Chief's 800Mhz base station radio. The radios are prominently marked "450Mhz-Ch. 7 DEM1" and "Command/Control." At the direction of the FAC or RMC during an emergency, these radios may be utilized as the Command and Control network.

COMPANY PROCEDURES

Company Officers are to follow the procedures outlined in the Station Damage Control Plan located in the back of the Pre-fire book, Inspection File Index book, and in the Watch Office. The outline will serve as a station-specific plan to address the facility concerns designated by the Station Captain.

Immediately following a citywide event, personnel within the Fire Stations are to be accounted for by the Officer.

Officers are to determine the service status of their apparatus and care for injuries sustained by Fire Department personnel.

- If needed, the apparatus should be removed from the station to a designated safe area away from hazards. Be prepared to have the apparatus remain outside for an extended period. In the case of an earthquake, it may be necessary to remove fallen or jammed doors to move the apparatus.
- If there is known or suspected damage, Station utilities like water, electrical, gas and heating plants, must be secured. The status of the utilities must be noted in the Watch Desk Journal. Secured utilities must have a lock out/tag out sign to denote that they are shut off and may not to be turned on unless the Officer in charge is consulted.
- Companies that are out of quarters at the time of the incident are to return to quarters and initiate the Station Damage Control Procedures.
- Companies must place extra supplies and equipment on the apparatus such as hose, batteries, water, additional first aid equipment, food bars, and extra clothing after any Level 2 or Level 3 Alert. In addition, Engine companies must place hard suctions on their apparatus and reserve units also.

AUTOMATIC RECALL

Elevators equipped with automatic recall (which recalls the elevator to the ground floor lobby when the building goes into fire mode), should have the "elevator recall" switch (located on the Elevator Recall floor or in Fire Control Room) placed in the "on" position.

At any significant incident involving high-rise buildings, elevator repair personnel should be called to the scene as soon as possible.

Companies capturing elevators should notify the Incident Commander by radio that they have "elevator control" thereby alerting the entire response.

The elevator operator should brief "up-going" companies concerning stairwell locations, staging floor layout, and where to report upon arrival at the staging floor.

COMMUNICATIONS

Fire Department Radios - Members should monitor the assigned channel. Company Officers must use initiative in establishing other communication methods. Radios have a tendency to "bonk" when below grade in high-rise buildings. The Operations Commander should consider using channels 1B, 2B, or 3B.

EMERGENCY TELEPHONES

The building emergency telephone system (e.g. red phones), if possible, will be used to establish communications between the Command Post and the fire floors, staging floor, etc. Do not plug the phone into jack until you wish to communicate with Fire Alarm Control Room.

DOMESTIC PHONE

Domestic telephones should be considered a primary communication system. Elevator operators should distribute phone numbers on critical floors. Once the phone lines are established between critical floors and the Command Post, every attempt should be made to keep these lines open.

PUBLIC ADDRESS SYSTEMS

Public address systems should normally be used to direct evacuation procedures.

Elevator operators should be used as messengers, for transmitting messages from floor to floor, staging floor to lobby, etc.

STAGING

In high-rise buildings, the staging area will normally be located two floors below the fire fighting floor. The location may be adjusted as smoke conditions dictate. Incident or Division Commanders should consider a second staging area in the loading dock area, if the building is so designed.

Attachment 2

Fort Worth Fire Department

"Proposal for the Use of Simplex Radio Channels in the Operations Division"

January 12, 2004

PROPOSAL FOR THE USE OF SIMPLEX RADIO CHANNELS IN THE OPERATIONS DIVISION

Prepared By: Hugo R. Esparza, Deputy Chief of Operations

January 12, 2004

SIMPLEX Radio Channels For Fort Worth Fire Department Radios

Abstract

There is concern as to our portable radio's ability to overcome radio wave (RF) resistant building materials, specifically in-high-rise buildings and buildings with basements. As highlighted in the World Trade Center bombings of 1993 and 2001, quality communications is a key component to safety and efficiency when operating in these types of structures.

The current trunked radio system can be reprogrammed to allow the fire department's mobile and portable radios to communicate directly, from unit to unit, without operating through the repeater system. Doing this would, in most cases, improve fireground communications, thus increasing firefighter safety, accountability, and improve firefighting and rescue coordination in these structures.

Background

Currently, the Fire Department operates on an 800 MHz trunked radio system that is shared with the other City departments and external agencies and Cities as well. For voice transmission, the system relies on four sites which are located throughout the City – one site is located on top of the high rise building at 801 Cherry Street; a second site is located on the extreme north side on North Beach Street; a third site is located at the Rolling Hills Water Treatment Plan and the fourth site is located on the extreme east side of the City just east of the Bell Helicopter plant. A fifth site is planned to come on line in the 4th calendar quarter of 2004, but is currently being delayed because of FAA airspace issues. It is planned for the Eagle Mountain area.

The inventory of radios, specifically in the Operations Division, is substantial. There are approximately 240 portable radios and some 86 mobile radio units.

The radio communications system is a trunked public safety radio system (Motorola SmartNet II). As with most systems, communications takes place when a portable or mobile radio transmits to a repeater, which then retransmits the radio signal to a second portable or mobile unit by receiving the signal on one frequency and retransmitting the same signal on a different frequency. The system is limited by the range and strength of the transmitted signal from a portable, or mobile, radio to be emitted and reach a repeater/site in the system. The Fire Department's portable radios transmit a signal with strength of 3 watts and mobiles transmit at 15-watts. The theoretical line-of-sight maximum portable-to-portable, at the height of five feet… with no obstructions is 6 miles, communications range; however, can be greater with additional radio elevation and to a lesser extent by increasing output, or less with physical obstructions between the transmitter and the receiver. As a practical matter, if the portable radio (RF) cannot overcome the resistance of the structure then the usable signal may only extend a few blocks.

The Problem

It is not an uncommon experience for the Fire Department to have poor communications between fire companies working inside most high-rise buildings and the incident commander who is typically located outside the structure. Again, this occurs because a radio signal must penetrate concrete, steel, and other structural features in a building, and then overcome distance to reach a repeater before being retransmitted back to the IC, and others, on the Fireground. This severely reduces or, in some cases, eliminates radio communications. When this occurs, the incident commander's ability to coordinate fire rescue, attack, support functions, and evacuation is reduced as well. This results in decreased safety for firefighters and victims inside these structures.

Analysis and Options

Because of the communication problems encountered at most high-rise incidents, a committee was formed to address the problem of communications in high-rise buildings. The central goal was to improve firefighter safety at high-rise structures through improvement of radio communications. The committee was composed of the following people: Battalion Chiefs Wendell Lancaster and Gary Parker; Captains Sam Greif and Pat Vasquez; Mark Bottorff from IT Solutions; Cynthia Tyree from the Fire Alarm Office; and Deputy Chief Hugo Esparza. The committee met on September 4, 2003 and developed two options to address diminished radio capability at high-rise buildings:

1. Install Bi-Directional Amplifiers (BDA's) in each high-rise building.
2. Reconfigure our radios so that Simplex or "direct" channels are programmed into each portable radio and selected mobile radios. Initially limit the use of the three Simplex to incidents involving high rise buildings or other large, dense buildings where regular radio communications do not work or; unusual, catastrophic incidents such as the March 2000 tornado. It should be noted that these Simplex Channels are available to agencies throughout the Metroplex. Any agency operating an 800 MHz solution (conventional or trunked) can also implement the Simplex Channels. Since there is no coordination of the deployment and use of the Simplex Channels across the Metroplex, it is possible that Fort Worth and a neighboring agency could be working separate incidents simultaneously on the same Simplex Channel and some bleed-over radio transmissions between incidents could occur. Operational procedures should be developed in order to minimize this occurrence; however, a simple fix would be to simply go to one of the other Simplex Channels.

Option 1

The first option (an internal repeater (BDA)or passive antenna, if you will), while being the ideal solution, is the most expensive. At a cost of approximately $60,000 per building, this option is expensive to the building owner and unlikely to occur. In a Motorola SmartNet II system, such as found in our communications system, stand-alone repeaters that integrate into the overall trunked radio system cannot be implemented. It should be noted that some municipalities are making the installation of BDA's part of their building code for appropriate buildings.

Option 2

The second option is a viable solution that is cost effective and enhances firefighter safety. A Simplex channel is one in which the radio would transmit a signal directly from one unit to another unit rather than through a repeater. Because of this, the radio signal only needs to travel the physical distance from the transmitting radio to the receiving radio. Because it does not have to penetrate the interior construction members and exterior skin of a high-rise building and then reach any one of the four sites, communications (in most cases) is improved. Simplex operations removes the distance factor from the structure to the remote site.

To field test this option, the City's IT Communications Services Group reprogrammed four Fire Department portable radios with the Simplex Channels, which were then used in various locations. Three high-rise buildings were utilized to perform the tests (Harris Hospital Downtown, Radisson Hotel, City Jail Complex). These three buildings were identified by fire personnel as common problem areas for radio communication. In Harris Hospital and the Radisson Hotel, a radio was positioned in the basement, mid-level, top floor, and on the street within 2 blocks of the building. Due to the security concerns at the City Jail Complex, only one portable radio was located in the basement underneath West Belknap Street and one outside approximately two blocks away. Radio communication between all radios was successful in each test except two locations. When a radio was in the tunnel of Harris Hospital underneath Pruitt St, there was no communication to any of the other radios on the street; however, communications was established with other FD radios within the building providing for relay communications. Radio communication was possible between the basement and upper levels but not between the basement and the street. In the Radisson Hotel test, there was very good communication between each radio from anywhere in the building. It should be noted that there are communication related advantages and disadvantages as listed below that are inherent to both. With direct capability there is some degree of reliability of radio contact between the fire fighters working in a high-rise structure and the IC.

This field test confirmed the communication advantage of the Simplex radios channels over the trunked radios that we currently utilize.

The following is a comparison list of advantages vs. disadvantages relating to the use of Simplex radio channels:

Advantages

1. Improves radio communications in most high-rise/dense structures

Disadvantages

1. Removal from trunked system which then results in the following:
    a. Emergency button disabled
    b. No one outside the range of the transmitting radio can monitor any radio communications, including the FAO
    c. No recording of radio communication by the FAO

2. Up to three Simplex or "direct" channels could be programmed into current portable radios
3. Can use "cookie cutter" template to reprogram radios; thus, this process is fairly simple to carry out

2. Would eliminate up to three trunked talk groups to accommodate the Simplex Channels
3. Cost/Time – Would require the Radio Shop to touch every portable radio and mobile radios in the Fire Department inventory. The cost would be approximately $3,950.00

In order to accomplish the reprogramming of the portable radios, three current talk groups would be eliminated from the "System 1" side of the channel groups. "EMS-2", "EMS-3" and "Fire Command 10" would be removed and three Simplex channels would be installed in their place. These channels would physically be located at the far end of the channel selector. This would simplify going to these channels with gloved hands in zero visibility. On System 2, the channels would look the same as they do on System 1, the only difference being that they would be located on Personality 5.

The template for the channel selector dial on our portable radios would look like the following after reprogramming:

1. FD CH 1
2. FD CH 2
3. FD CH 3
4. FD CH 4
5. FD CH 5
6. FD CH 6
7. FD EMS 7
8. FD CMD 8
9. FD CMD 9
10. FD SPEVNT 10
11. FD PREV 11
12. FD INV 12
13. FD blank (tone). This tone allows FF's to differentiate between the Channel 1 end and the Channel 16 in limited visibility.
14. FD DIRECT 14
15. FD DIRECT 15
16. FD DIRECT 16

In addition to the 240 portable radios in the Operations Division inventory, 10 mobile radios in six-battalion chief vehicles and 4 mobile radios in the mobile command vehicle would also be reprogrammed with the three Simplex channels. According to Mr. Bottorff, in order to reprogram 250 units will require 6 hours for template creation and modification and 63 hours for the actual reprogramming for a total of 69 hours. At $ 57.00 per hour, this calculates to a total estimated cost of $ 3,950.00. This figure is for the actual work done and does not include any time spent waiting for vehicles to arrive. Mr. Bottorff would request that he be given 2 weeks notice prior to the project beginning in order to prepare.

If this option is used, it is recommended that the use of the three Simplex channels be limited to those incidents involving incidents where regular radio communications does not work or is intermittent as with the March 2000 tornado. SOPs need to be modified and incorporated into the fire department's communication standard operating procedure (Fort Worth Fire Department SOP – S 5201 R1, Fire Alarm Office, Communications Procedures).

Recommendation

It is recommended that Option 2 be adopted and implemented.

Implementation

If approved, the plan for implementation of Option 2 would be as follows:

- Work with IT Solutions – IT Communications Services Group to schedule the affected radios to be reconfigured by radio technicians at the City's radio shop.
- Modify the communications Standard Operating Procedure, S 5201 Communications Procedures.
- Publish a preliminary procedure to all personnel through hard copy and e-mail.
- Integrate training of personnel at the earliest opportunity in the CE classes/lessons and any fire officer and engineer schools the department may hold.

Attachment 3

"Michigan State Police System"

WLNS News Report

Lansing, Michigan

May 20, 2004

Michigan State Police System

WLNS, 6 News
2820 East Saginaw Street
Lansing, MI 48912

Main Phone: (517) 372-8282

5/20/04- It's a multi-million dollar state of the art system designed to connect every public safety agency in Michigan. Some say the statewide digital radio network is the best available, while others simply aren't convinced.

When it comes to first responders, communication is critical. Their radios become their lifeline, s o picking what system to use could make all the difference. In fact, some say it could mean life or death. Completed in 2002, it's touted as the biggest and best system around- a 231 million dollar statewide public communications system.

Kurt Weiss, MI Info. Technology: "Our staff has their fingers on the pulse of the system 24 hours a day, seven days a week."

Monitored around the clock, the 800 mega hertz digital radio network helps link public safety agencies all across the state.

Kurt Weiss: "We want to partner with all the local agencies, this is a team effort when we're dealing with terrorism and homeland security, everybody needs to partner together."

So far, more than 450 public safety agencies have bought into the system, and Kurt Weiss from the Department of Information Technology says that number continues to grow.

Kurt Weiss: "We're currently working with some pretty large cities, Detroit is coming on to the system, we're working on negotiations with them, Genesee County, Monroe, Macomb."

But not everyone is looking to link up. In fact, Ingham County has decided to build its own 12 million dollar system after the Lansing Fire Department had problems with the state's system. The department is the first and only agency in the county using it.

Greg Martin, Lansing Fire Chief: "I guess it's wonderful that it can talk to the state police in Detroit, but for the most part, I don't want to, I want to talk to the Lansing engine company across town consistently, and that's more important to me."

More important, but not always possible. Lansing Fire Chief Greg Martin says the state's system didn't meet his expectations, didn't fit the department's needs. In fact, in the case of one emergency, Martin says the radios actually caused an emergency.

Greg Martin: "About 8 months ago, we had 2 firefighters hurt on the west side of Lansing, they sustained some burns, because they didn't receive the radio message, they went to a upper level of this house, when the message was don't."

Chief Martin says the problem is dead zones- places in the city where the digital radios simply don't work, and when it comes to buildings, Martin says the radios are basically useless. I nstead of a bad signal, there's no signal at all. That's because the system to work in cars.

Greg Martin: "You hear it on the air many times, they go, "engine 45, can you repeat, you just went digital," you stop sounding like Greg Martin and more like a robot, then it drops."

But just a county away, Livingston has taken a different approach to the same system.

Don Arbic, Livingston Co. 911: "Livingston County has been adding components, improving the system, improving public safety communications since the original transition in 1998."

The county started with nothing, none of its own infrastructure, basically piggy-backing off the state's system. Just a few short years later, the county's added a dispatch center, and built a million dollar tower south of Howell to help with coverage across the county.

Greg Martin: "Recently we converted our fire service in Livingston County and brought on supervisors form the road commission, medical examiners office, community health and our EMS department is also migrating its communication over as well."

But what about the lack communication inside buildings? Arbic says Livingston County solved that problem by having an incident commander on the scene, stationed outside the building, armed with two radios.

Don Arbic: "We've set up our radios with what we call a direct channel, radio to radio, try to cover maybe a hundred yards top, and that works very well for us."

So during everyday operations or in the case of an emergency, we found the system which works the best really depends on who you ask. As for Ingham County's new system, it's slated for operation in early 2005. It's a 12 million dollar system, with a digital backbone and analog radios. I t was recommended by the 911 advisory committee, passed by the Ingham County Board of Commissioners and funded by the 911 emergency services millage.

John Neilsen, Deputy Controller: "We've designed it so that it will fit our needs in the future with a number of channels and the type of infrastructure we have."

Victor Celentino, County Commissioner: "Se're giving them the tools they need to do their job of protecting our citizens, so everyone wins in the end."

Attachment 4

Columbia Fire and Rescue

“Palmetto 800 Radio System”

Columbia, South Carolina

Newsletter Fall Issue 2003

Columbia Fire Rescue

Columbia, SC

Newsletter
Fall Issue 2003

http://www.columbiasc.net/fire/

Palmetto 800 Radio System

A great deal of research and negotiation is currently underway toward the implementation of a new radio system for the Columbia Fire Rescue Service. The shift from our 400 MHz system to one working in the 800 MHz range has been in the planning stage for some time, and is now about seventy-five percent worked out, according to Assistant Chief Bradley Anderson who is leading the project. Problems with the 400 MHz are many. Each one of us has a story to illustrate how the department's increasing size, efficiency, and evolving mission have overloaded the dated system.

With the current 400 MHz system the department has access to five channels that work off repeater stations (one repeater per channel) throughout the county. Use of each channel is dependent on proximity to its own tower. This creates a "patchwork" of coverage. In the northeast part of the county, channels 2 and 5 can be utilized, while channel 4 must be used in the south. If a unit's radio cannot hit a specific repeater (because of distance or "dead spots" in the terrain) then it cannot use that channel. Environmental conditions can also cause these channels to become "dirty," letting transmissions from nearby agencies "bleed through" across the same frequency.

The 800 MHz system will hopefully alleviate these problems. It is officially called the Palmetto 800 MHz system, owned by Motorola and under contract with South Carolina for local and state government use. It was once owned by SCANA and has, with the addition of repeaters and capabilities, been expanded over the past decade.

The system has greatly improved since its earlier years. But, according to Assistant Chief Anderson, it still carries the "black-eyed" reputation it earned around ten years ago when a series of tornados struck Lexington County. During that incident, the 800 MHz frequencies became gridlocked and dysfunctional as it was overwhelmed by SCANA, Lexington Fire and EMS, and law enforcement. Since then its capacity has significantly improved. The system is capable of handling a heavy volume of emergency transmissions, giving priority to public-safety agencies, on hundreds of talk groups (what we think of as channels). The portable radios that are scheduled for our department can manage 256 talk-groups if so programmed.

Improved Communications

Columbia Fire Rescue's new system will probably operate using twelve talk-groups. Conventional channels operate only on one frequency, while 800 MHz talk-groups utilize a *Trunked* system in which computers instantaneously put one's message on whatever accessible frequency is available and send it through whichever of seven repeaters is nearest. This allows for simultaneous, wide use of the system by multiple units over a large area.

In addition to the twelve talk-groups, there will be four conventional talk-around channels that are independent of repeaters. Each talk-group will be accessible countywide. Though the general idea of our proposed talk-groups have been outlined, a solid listing of the talk-groups and their functions remains tentative.

The first talk-group will be most likely called "DISPATCH," and will dispatch all alarms. Unit radios will probably be programmed with a priority scan to this talk-group. Once companies are dispatched and responding, they will use a talk-group called "OPERATIONS 1." This will carry all unit to central communications, unit-to-unit radio traffic, and initial scene-reports. There will be a second talk group called "OPERATIONS 2," with identical function that will be activated during times of high call volume.

Once on the scene, if the incident is significant (a structure fire, extrication, etc.), the Battalion Chief will request the use of a FIRE GROUND channel, which is one of the talk-around (true) channels. All responding units will then switch from the OPERATIONS talk group to the FIRE GROUND channel. This will clear the OPERATIONS talk-group for additional call traffic, and will give all involved units their own communications frequency for that scene. The IC will have access to another separate talk-group called COMMAND 1 or COMMAND 2 (for which a second radio may be necessary) which will be clear except for IC / Central communications.

Challenges

The benefits of the system will allow for unit to unit communication without interfering with Central's need to dispatch other calls, and will provide fire-ground communication without clutter from extraneous radio traffic. Also, the IC will have an additional clear line to Central for requesting or reporting whatever is necessary.
The drawbacks may require creativity and patience to overcome. The timing of the switch from an OPERATION talk-group to a FIRE GROUND channel will have to be worked out, and will require discipline from all responding units to pay close attention to which talk-group they will utilize. FIRE GROUND (talk around) channels will have coverage of only about a mile, and their efficacy, especially in metal and concrete buildings, will have to be explored. For incidents such as river rescues and large woods fires, a FIRE TACTICAL talk-group may be implemented that will utilize repeaters and be able to cover larger distances.
The actual "physical" department-wide switch from 400 MHz to 800 MHz radios will also bring challenges. Assistant Chief Anderson was not certain of the time frame, or if the change would take place all at once or in phases. There are a number of variables still being worked out including toning out fire stations and volunteer firefighters' pagers, and whether trucks can accommodate both 400 and 800 MHz radio controls in the cabs and on the pump panels. They'll look to the radio installers, he said, for their recommendations and consider the best way to implement the system with minimal confusion or disruption of operations. The Columbia Police Department has been phasing in their regions using portable 800 MHz radios with their 400 MHz mobile radios temporarily on RIC switches that join talk-groups to conventional frequencies, but that might not be the best way for the fire department.

If, for a time, the 800 MHz and the 400 MHz radios have to work together (as they must on the county trucks currently, the source of another black eye for the 800 MHz radios), there is a troublesome delay in 800 MHz message transmissions. A long pause is required between activating the microphone and being able to speak while the radio keys up both a RIC switch and a repeater. The RIC switch first translates the message into the proper frequency, and then the appropriate repeater carries the transmission.

Once the 800 MHz system is fully implemented, the RIC switches will be removed, so the lag-time between keying the mike and transmitting will decrease. As the system is currently planned, the only RIC switch remaining will be one to enable pagers carried by volunteer personnel to monitor the OPERATIONS 1 talk group. The two-channel pagers used by volunteers will monitor the DISPATCH talk group as well, but this will probably not have to go through a RIC switch. Also, the FIRE GROUND talk-around channels will not use a repeater either, so message transmission among units on-scene will be instantaneous.

Preliminary testing of the new system has already begun. Four 800 MHz radios have been put out in the field with Battalion Chiefs who have been challenged to find transmission "dead spots" in their districts. So far none have been identified. This will also give the Battalions a chance to gain confidence in the new system.

The problem that steel and concrete buildings might present may be partially alleviated by placing mobile repeaters in Battalion vehicles. This will boost Battalion transmissions to crews inside a building. Even though interior crews may be using FIRE GROUND talk-around channel, their transmissions may still have trouble negotiating the steel and concrete walls. However, this will be less serious than if the radio signals had to also reach a distant repeater to be heard.

Fire Fighter Safety and Interoperability

The plan is for every on-duty fire fighter to carry an assigned portable radio with a "lapel-mike." This may require a loop to be sewn to the shoulder of all PBI gear. A training program for radio use has not been solidified, but Richland County may help develop an instructional video for the purpose. Fairly strict guidelines will also have to be developed to control the potential increase in radio transmissions.

The portable radios are about the same size as current 400 MHz radios, with many more buttons and possible functions. A screen on the face of the radio lists what talk-group is in use. The radios are capable of accessing various "Zones" of talk-groups. This gives them a quality called "interoperability," meaning that they will be capable of communication with other agencies by directly engaging each agency's functional frequency Zones.

The workings of the 800 MHz system can be imagined as a grid of sixteen columns by sixteen rows. Each column represents a different Zone, and each row represents a different talk-group within that Zone. Our twelve FIRE talk-groups will compose our Zone 1. Zone 2 might be CPD. Zone 3 may be the Richland County Sheriff's Department, Lexington Sheriff, Lexington Fire and EMS, and Irmo Fire. And Zone 4 could hold state wide mutual aid frequencies. Agreements are being made with all of these agencies and others to allow mutual access of each other's Zones when acting together on an incident.

Richland County EMS might not yet have accessible talk groups, but will still be reachable using the PUBLIC SAFETY talk-group. Each agency's Zone will not be a free and open chat- room. We will have to learn the various agency protocols for their use, and how to request use of their frequency space.

When using the radio, pressing the far right button below the screen on the face of the radio chooses the Zone. Talk-groups within that Zone will then be chosen using the conventional dial beside the antennae. An orange Alert-Button on top of the radio, when pressed, will give that unit emergency priority and will clear the talk-group of other traffic.

Each radio will have an ID# that Dispatch will be able to see on their computer screen when that particular mike is keyed. This will clear up unit identification confusion in times of busy radio transmissions. The system may have the capability to signal an individual with a beep when their ID# is keyed into the radio using a keypad below the screen. If confused, or lost in the Zones and talk-groups, there is a "Home" button that will return that radio to its primary talk-group, monitored by central: either DISPATCH or OPERATIONS 1.

Learning from Others

In order to research how the 800 MHz system is working out in other departments, a delegation from Columbia Fire Rescue visited Florence County Emergency Services and consulted both the Charlotte and Greensboro, NC Fire Departments. They learned some tricks that will be incorporated into our system. **One concerns the physical switching from the OPERATIONS talk-group to the FIRE GROUND channel when on an incident scene. Our work environment is often dark, sometimes smoky, and with gloved hands, even if the radio dial can be seen, it cannot be accurately turned when changing channels. To facilitate switching, OPERATIONS talk-groups will most likely be one of the first numbered talk-groups on the radio's dial, and the FIRE GROUND channels will be the very last. So to change from the former to the latter, one will turn the dial all the way till it stops for FIRE GROUND 1, and turn it one click back for FIRE GROUND 2, etc.**

With a hopeful smile Assistant Chief Anderson related a story from their visit to Florence County. He heard something shocking while monitoring their radio there. An accident had occurred on I-95, and as units began to respond, he heard not only Fire units, but also EMS and Highway all talking to each other on the same talk-group. With time, and patience, implementation of this new system will allow similar steps forward in intercommunication and fire fighter safety in Columbia and Richland County.

Attachment 5

"County asks for Emergency Radio System Review"

North County Times

San Diego, California

December 9, 2003

Last modified Tuesday, December 9, 2003 11:27 PM PST

County asks for emergency radio system review

By: North County Times wire services

SAN DIEGO - The Board of Supervisors asked today for a review of how the county's regional radio communications system performed during the wildfires.

The system is meant to provide secure digital communications between public agencies, but glitches have plagued it over the past two years, including gaps in radio coverage and busy signals during the fires. - Most recently, during the massive late-October wildfires, some fire agencies and personnel were on a different radio system than the county's, causing additional problems.

"In this day of cooperation and mutual assistance, it doesn't make much sense that walls exist between our communications systems," said Supervisor Dianne Jacob, who with Supervisor Pam Slater proposed the review.

"As much as the (communications system) was successful in eventually providing service to over 200 agencies, it still doesn't include most state and federal agencies," Jacob said.

Radio communication also was difficult during the 2002 Pines Fire, as the eastern portion of the radio system's coverage area was unable to handle the increased volume of calls.

And while the Viejas Fire was raging in 2001, the system experienced significant busy signals as public safety officials tried to swap vital information.

"During the past three major wildland fires in the county, public safety personnel either had difficulty talking on their radios or just couldn't communicate at all," Jacob said.

As part of today's action by the board, county Chief Administrative Officer Walt Ekard was asked to evaluate the system's performance, then report his findings, recommendations and possible system upgrade options to the board within 45 days.

Attachment 6

“Crisis System Upgrades Urged”
San Diego Union Tribune

San Diego, California

April 7, 2004

Crisis system upgrades urged

Communications network needs $22.9 million in fixes, officials say

By Helen Gao
STAFF WRITER

San Diego Union Tribune

April 7, 2004

The county's regional emergency communications system needs $22.9 million in upgrades to avoid the multitude of busy signals that hampered firefighting during the October fires, sheriff's and fire officials said yesterday.

Darrell Jobes, chief of the East County Fire Protection District, who chairs the regional communications system board, and Curt Munro, communications system manager with the Sheriff's Department, made the remarks at the county Board of Supervisors meeting.

Supervisors Dianne Jacob and Pam Slater-Price had asked for a report on how to improve the radio system following the Cedar, Paradise and Otay fires. The three fires combined destroyed more than 376,000 acres and more than 2,400 homes.

Jobes and Munro said the system badly needs computer software and other upgrades to handle a higher volume of transmissions because there are more users than anticipated. Without the upgrades, they warned, an overloaded system would greatly harm emergency response.

"We believe it's imperative to start the improvements without delay," Munro said.

Supervisors directed county officials to return with proposals on how to pay for the upgrades. They said looming state budget cuts would make it difficult to find the money, but they are committed to fixing the problems.

"We have a job to do. Yes, we are in tight budget times, but this is of crisis proportion," said Jacob, whose East County district was hit by the Cedar fire and a string of other wildfires in recent years.

"If this latest fire didn't point out the importance of funding the system, I don't know what will."

East County needs 10 simulcast sites installed to increase the number of radio channels available so emergency workers can carry on multiple conversations at the same time, Jobes said. The region, which now lacks simulcast capabilities, is served by an inadequate number of channels.

South and North County, which are covered by simulcast sites, also need enhancements to increase the number of channels and coverage in dead spots. The upgrades would quadruple the number of channels.

Supervisor Greg Cox suggested that the San Diego region pool federal money it receives for homeland security for the upgrades.

"I think it's the best money we can spend on homeland security," said Cox, because a regional communications system is the backbone to any type of emergency response, whether its terrorist attacks or wildfires.

San Diego County's communications system, which is linked with Imperial County's, serves 207 agencies covering 9,000 square miles in two counties. It typically handles 3 million radio transmissions a month.

Initially, the system was expected to have 12,000 users in 2012. It now has 16,000 users, with the increase causing busy signals.

A report by the regional communications system board showed that during the fires, there were more than 99,000 busy signals on the south and east loops of the system. Normally, there are a few hundred or thousand in a given month.

But busy signals were not the only problem. Jobes and Munro said agencies from outside the county that had come to help with the fires had radios that were incompatible with the county's.

They urged supervisors to seek state legislation to help standardize and pay for communications equipment.

The upgrades would not solve the compatibility problems, however, Munro said.

Fire and sheriff's officials are now looking to switch to another system that surrounding counties are also planning to buy.

The new system is estimated to cost $100 million. Up to 60 percent of the equipment from the current system would be converted into use in the new system.

Attachment 7

"The 9-11 Commission Report"

National Commission on Terrorist Attacks Upon the United States

Recommendation: Emergency response agencies nationwide should adopt the Incident Command System (ICS). When multiple agencies or multiple jurisdictions are involved, they should adopt a unified command. Both are proven frameworks for emergency response. We strongly support the decision that federal homeland security funding will be contingent, as of October 1, 2004, upon the adoption and regular use of ICS and unified command procedures. In the future, the Department of Homeland Security should consider making funding contingent on aggressive and realistic training in accordance with ICS and unified command procedures.

The attacks of September 11, 2001 overwhelmed the response capacity of most of the local jurisdictions where the hijacked airliners crashed. While many jurisdictions have established mutual aid compacts, a serious obstacle to multi-jurisdictional response has been the lack of indemnification for mutual-aid responders in areas such as the National Capital Region.

Public safety organizations, chief administrative officers, state emergency management agencies, and the Department of Homeland Security should develop a regional focus within the emergency responder community and promote multi-jurisdictional mutual assistance compacts. Where such compacts already exist, training in accordance with their terms should be required. Congress should pass legislation to remedy the long-standing indemnification and liability impediments to the provision of public safety mutual aid in the National Capital Region and where applicable throughout the nation.

The inability to communicate was a critical element at the World Trade Center, Pentagon, and Somerset County, Pennsylvania, crash sites, where multiple agencies and multiple jurisdictions responded. The occurrence of this problem at three very different sites is strong evidence that compatible and adequate communications among public safety organizations at the local, state, and federal levels remains an important problem.

Recommendation: Congress should support pending legislation which provides for the expedited and increased assignment of radio spectrum for public safety purposes. Furthermore, high-risk urban areas such as New York City and Washington, D.C., should establish signal corps units to ensure communications connectivity between and among civilian authorities, local first responders, and the National Guard. Federal funding of such units should be given high priority by Congress.

Private-Sector Preparedness

The mandate of the Department of Homeland Security does not end with government; the department is also responsible for working with the private

Attachment 8

McKinsey and Company

“Increasing FDNY’s Preparedness”

2.1.2) Improve communication capabilities in high-rises There are approximately 2,000 high-rise buildings[34] in New York City today. Field experience suggests that FDNY personnel can communicate reliably in just a fraction of these buildings.[35] To address this shortcoming, the FDNY should immediately evaluate, acquire and deploy equipment, together with the associated procedures and personnel training.

High-rise communications gaps can be addressed with the deployment of repeating infrastructure that receives, amplifies and retransmits radio communication signals to improve coverage. Repeaters that are portable, mobile (e.g., truck-mounted), or air-based (e.g., on a deployable balloon) may help mitigate in-building communications difficulties, but do not provide full coverage for high-rises. Stationary repeating infrastructure can support reliable communications in most cases if it is designed, installed and maintained properly. This kind of infrastructure can be installed inside or outside a building. We propose the Department pursue all of these options, but do it along two parallel and complementary paths.

¶ **Test and deploy portable, mobile and air-based repeaters.** FDNY should complete rigorous tests with portable, mobile, and air-based repeaters to develop and document guidelines for optimal use of this equipment (e.g., where to place the equipment for best coverage, which combinations of equipment types are most effective). FDNY should also develop an understanding of the limitations of this equipment. Once guidelines for optimal use of it are established, the Department should acquire appropriate equipment, train personnel to use it, and deploy it. We believe that deployment of portable or mobile repeaters by FDNY would cost approximately $1 million to $2 million[36] and could be completed within six months.

¶ **Pursue stationary communications infrastructure.** In addition to accelerating deployment of portable, mobile and/or air-based repeaters,

[34] High-rise buildings are defined here as all buildings seven stories and higher. Our recommendations for high-rise buildings should also be applied to other types of buildings such as large malls, hospitals, and jails. Shorter buildings with substantial underground areas should be treated similarly to high rises since FDNY communications in underground environments are also inadequate.

[35] Reliable in-building communications means clear point-to-point communications in nearly 100 percent of the building, even in the case of building power loss, fire, or partial destruction. The Department does not have a comprehensive view of how its radios perform in different kinds of buildings and, hence, does not have an exact estimate of the number of buildings where its personnel can communicate reliably. There is some anecdotal evidence suggesting that firefighters and officers would not be able to communicate effectively and reliably in most high-rises in the city.

[36] Estimate based on this formula: three repeaters (two portable and one mobile) for each of the Department's nine divisions

Attachment 9

Testimony of
The Former Commissioner of the New York City Fire Department
Thomas Von Essen

The National Commission on Terrorist Attacks Upon The United States

May 18, 2004

their brothers. This, of course, is not to say that the firefighters who were able to evacuate were in any way less courageous or dedicated. It means simply that, as it has always been with firefighters in the New York City Fire Department, when faced with critical decisions, firefighters do what they believe the immediate situation requires of them. For many firefighters, an evacuation order means "get the civilians out, get all my guys out, and then I go." One team on their way out may have stopped to help some injured civilians, another team may have just cleared a floor and escorted the civilians down. We will never know what decisions many of our firefighters made that day. But I do know that firefighters do not abandon civilians in distress to save themselves.

Without question I wish so many more had evacuated. The emptiness from the losses that day has never left me, not for a moment.

I have been asked to comment on the FDNY radio situation before 9/11. When I became Commissioner in 1996 the Department had already been moving towards upgrading their radios to an interoperable, interagency system, and switching from analog to digital. Our analog radios had limited frequencies available, the upgrading process would allow us to acquire more channels and better technology for interagency coordination. In March 2001, we gave all the units the new digital versions of the radios. Although the radios appeared to be the same, the digitals performed differently from the analogs. There were some problems reported in the field and safety concerns were expressed by the firefighters and chiefs. I immediately recalled the digitals and had everyone go back to the radios they were using before. One of the reported problems with the digital radios was that messages transmitted simultaneously cancelled each other out – the transmissions were "stepping on each other." We planned to re-release the digital

Attachment 10

National Institute of Standards and Technology

Graphic of Data Collected During In-Building Testing

2004

A Calibrated Communications Receiver System for the Measurement of Weak Signals

Marc Rütschlin[1], Kate A. Remley[1], Robert T. Johnk[1], Dylan F. Williams[1], Galen Koepke[1], Andy MacFarlane[2]

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Abstract: We describe an inexpensive, reliable system for use in weak-signal detection by the public-safety community. The system, based on a standard communications receiver and personal computer sound card, provides reception of signals on the order of 30 dB lower than is possible with standard handset radios. We describe a calibration procedure used to convert signals measured with the communications receiver system to electric field values, which enables use of the system for system-independent propagation studies.

Introduction

A well-known problem facing first responders who rely on radio communications is the loss of signal in complex propagation environments such as large buildings, tunnels, basements, and collapsed structures. Reduced signal strength due to attenuation through building materials can mean the difference between life and death. In the case of a dire emergency such as a collapsed building, the ability to detect a radio signal from a survivor may enable searchers to focus their efforts and may let the survivor communicate his or her status.

Here we describe a method that can be used to improve detection of weak signals by several orders of magnitude. The technique, sometimes known as Joint Time-Frequency Analysis [refs], has been used for years by ham radio enthusiasts, as well as in deep-space and other sciences that rely on weak-signal detection. Here we adapt the method to the unique needs of the public safety community, where systems must be reliable, straightforward to implement, and easy to use in emergency scenarios. The system described here meets these objectives. Additionally it is inexpensive and does not preclude the use of existing systems. At present, the method is limited to the detection of narrowband signals, meaning that its primary use is to determine whether a radio signal is present and the strength of that signal, rather than for voice communications.

We have developed a calibration for the method that provides the absolute electric field strength of the received signal. This provides additional information on signal level for the operator, enables system-independent comparison of measurements, and makes it suitable for studying propagation in complex environments.

We will first describe the method in detail before explaining the calibration steps. Finally, a case study implementing the system in the measurement of signal transmissions in a building will be described.

The Measurement System

The measurement system is shown in block diagram form in Fig. 1. It is based on a standard communications receiver, which is used to downconvert a narrow band of radio frequencies, and a personal computer (PC) sound card, which is used to digitize this band of frequencies. The digitized frequency band is then amplified and/or graphically displayed, letting the operator know whether a radio signal is present and what the level of that signal is.

As shown in Fig. 1, the electric field corresponding to the signal is received by the handset and fed as P_{rec} to the RF input of a communications receiver (CR). The receiver is operated in its upper sideband (USB) mode at a frequency slightly below that of the transmitted signal (it is assumed that we have knowledge of that frequency).

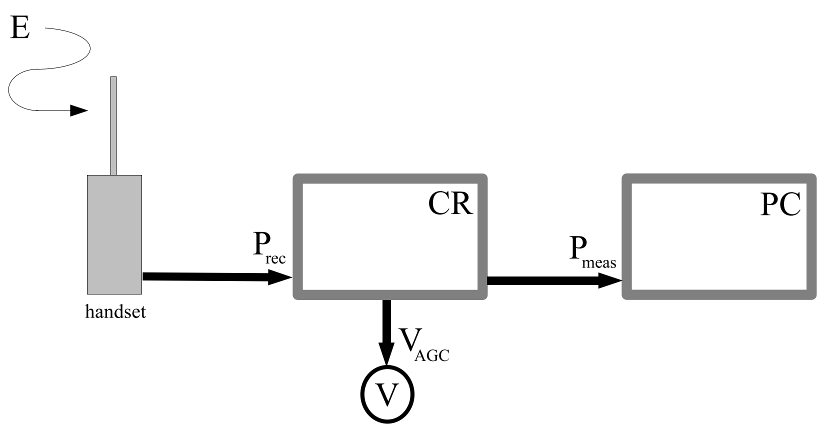

Figure 1: Block diagram of the measurement system. The electric field detected by the handset is related to the RMS voltage associated with the received power by an antenna factor: $E = AV_{rec}$, where $V_{rec} = (P_{rec}R)^{1/2}$; the power measured with the PC's sound-card input is related to P_{rec} by a V_{AGC} dependant power gain: $P_{meas} = G_pP_{rec}$, where $G_p = f(V_{AGC})$.

In this way, the receiver operates as a block frequency down-converter. By setting the receiver's frequency somewhat lower than the center frequency of the transmitted signal, the modulated received signal is converted in a block down to the audio band. We may observe the upper and lower sidebands of the down-converted signal by setting the receiver's center frequency to approximately the middle of the receiver's passband. For example, a 100 MHz signal may be measured by a receiver with a 3 kHz passband by tuning the receiver to 99.9985 MHz. In this case, the receiver will display the 100 MHz signal at 1.5 kHz.

The received signal may consist of the unmodulated FM carrier or a frequency modulated audio transmission. For public safety and other networked applications, the modulation may also correspond to a squelch tone. This sort of continuous tone is produced by a typical two-way radio handset when its 'push-to-talk' button is depressed.

The down-converted signal is sampled by a sound-card connected to a PC running audio recording software. The CR has an automatic gain control (AGC) which controls the receiver gain to produce a constant output signal regardless of the input power. In practice, the AGC is only active for signals within a certain power range, and does not modify weak signals (P_{rec} < -90 dBm). We monitor the level of feedback of the AGC – directly related to the input power – by measuring the voltage at the AGC jack on the back panel of the receiver at one second intervals using a digital multimeter with a recording feature.

For the purpose of developing a calibration for the signals measured by our system, we developed a handset simulator, shown in Fig. 2, whose electrical properties emulate a typical handheld transceiver but is easier to characterize. A description of its construction is aided by the photograph shown in Fig. 2: it consists of an antenna attached to a metal box, fed through the box by a coaxial cable. Magnetic ferrite 'chokes' are placed near the point where the coaxial feed attaches to the box, disrupting common mode current flow and allowing the box to act as the second element of an asymmetric dipole, as it would in an isolated radio handset. The success of these chokes in removing the effect of the feed cable, at least at relatively low frequencies, has been demonstrated previously [1] and confirmed in our own tests. At higher frequencies, a narrow-band sleeve balun of the type proposed by Icheln et al. may also be used [2].

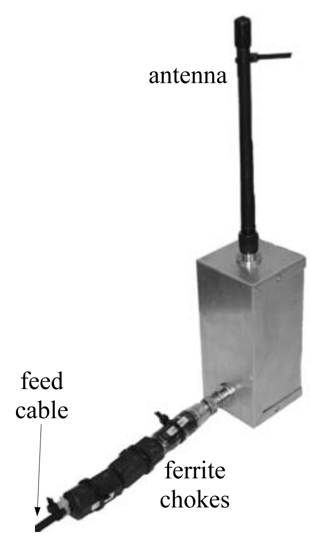

Figure 2: Photograph of the handset simulator used to develop the calibration. The antenna is of the helical type typically used with portable radio handsets. The effect of the feed cable is reduced through the use of ferrite chokes.

Calibration

Two steps are involved in the calibration procedure: first, we apply a gain factor to convert the perceived power measured by the PC sound-card to the actual power at the RF input of the communications receiver, and second, we use an antenna factor to convert this actual power to the electric field level present at the antenna.

The calibration is carried out as follows:

1. We record the sound-card input as a '.wav' file at the same time as the AGC voltage. The two measurements must be synchronized during post-processing. For long recordings like field mapping in buildings, we also record time stamps corresponding to important events. For example, one might record the time of departure from a certain room. A sequence of this sort of time stamp allows for easier deciphering of the final recording.

2. We convert the signal to the frequency domain using successive *N*-point Fast Fourier Transforms (FFTs). Each FFT is carried out on a segment of the signal centered on a time point that corresponds to when V_{AGC} was measured. The length of the FFT should be a power of two for greatest efficiency; a longer FFT will increase the frequency resolution of the results but will decrease the temporal resolution which may cause loss of detail in the case of a rapidly changing input.

3. We calculate the average power, P_{rec}, in the time period chosen for the FFT by squaring and summing the magnitude of the frequency components over the frequency band of interest, as

$$P_{rec} = \frac{1}{G_p R} \sum_{i=\omega_1}^{\omega_2} \left| V_i(\omega) \right|^2 \tag{1}$$

   where $V_i(\omega)$ is the root mean square (RMS) voltage of the *i*th spectral component, ω_1 and ω_2 are the lower and upper band limiting frequencies and R is the characteristic impedance of the system. The power gain, G_p, is the calibration coefficient whose value may determined according to the method described below. It is equal to the square of the voltage gain:

$$G_p = P_{meas} / P_{rec} = G_v^2 \tag{2}$$

$$G_v = V_{meas} / V_{rec} \tag{3}$$

   where each voltage is an RMS quantity associated with the relevant average power,

$$V_{rec} = (P_{rec} R)^{1/2}, \quad V_{meas} = (P_{meas} R)^{1/2} \tag{4}$$

The band is chosen to incorporate as many transmitted signal components as possible, but will be limited by the communications receiver's IF filter bandwidth.

4. We obtain the electric field by multiplying V_{rec} by the antenna factor:

$$E = AV_{rec} \tag{5}$$

where A, the antenna factor, is described below by (7). Upon expansion using (7) and (3), the electric field can be written simply as

$$E = \frac{E_{cal} G_{v,cal}}{V_{meas,cal}} \frac{V_{meas}}{G_v} \tag{6}$$

5. where V_{meas} is the voltage measured at the PC soundcard port. The characterization of the antenna in a TEM cell with a characteristic impedance of 50 Ω is described below; the field is thus equivalent to that TEM cell field which would have caused V_{rec} to be measured at the antenna's output.

Gain Determination

The relation between the power measured with the sound-card, P_{meas}, and that entering the communications receiver must be determined for a calibration to be conducted. The setup of Fig. 1 is used, with the handset replaced by a signal generator which supplies a known signal. The V_{AGC}-dependent gain may be determined as follows:

1. We use a vector signal generator (VSG) to excite single-frequency signals over a desired range of power levels. This range is representative of the signal levels likely to be encountered in transmission scenarios where the set-up will be used. The minimum power level of the signal generator may be decreased by the use of attenuators.

2. The communications receiver output, operated as described above, provides the input to the sound-card. After the signal generator output has been allowed to stabilize, the signal is measured. Its spectrum and average power, P_{meas}, are determined, while at the same time the AGC voltage is monitored and recorded.

3. The ratio of measured to input voltage, G_{v}, is plotted versus V_{AGC} to obtain a gain curve.

During a field measurement, the actual gain may be extracted by interpolating the curve based on the measured AGC voltage. We show an example of gain curves at three frequencies in Fig. 3. Note how the gain increases fairly linearly with rising V_{AGC}, only to flatten off when the voltage approaches its maximum of about 2.42 V. This maximum voltage is reached when the AGC is no longer active due to an insufficient input signal strength.

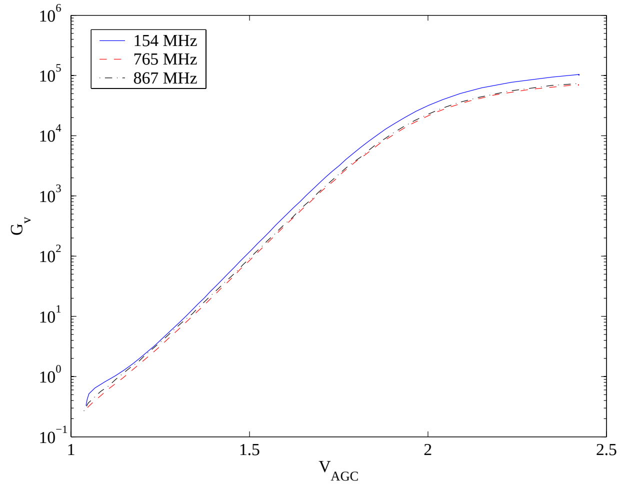

Figure 3: V_{AGC}-dependent voltage gain curves at three

Antenna Characterization

A relatively simple way of characterizing the antenna is to determine its response to a known electric field. Such a field may be created to a good degree of accuracy – locally for physically small antennas such as ours – in a transverse electromagnetic (TEM) cell [3]. We used a broadband flared gigahertz TEM (GTEM) cell with a 50 Ω characteristic impedance. In similar cells, measurements of small antennas' gain factors have previously compared favorably to anechoic chamber measurements (see e.g. [4]).

It is a simple matter to establish a specific potential difference between the conductors. Placing the antenna at the position where the plate spacing is x meters results in its exposure to an x V/m electric field. The configuration we used is sketched in Fig. 4. A vector signal analyzer (or spectrum analyzer) is used to measure the received signal as V_{VSA}, the RMS voltage corresponding to the measured power (equivalent to P_{rec} in Fig. 1). Alternatively, the CR measurement system described earlier may be used for the characterization. In this case the measured voltage V_{VSA} would be replaced by a voltage of the form given in (3) as:

$$A = \frac{E_{cal}}{V_{VSA}} \frac{E_{cal} G_{v,cal}}{V_{meas,cal}} \tag{7}$$

where $V_{\mathrm{meas,cal}}$ is the RMS equivalent of the power measured at the PC port, and $G_{\mathrm{v,cal}}$ is the voltage gain corresponding to the recorded AGC voltage.

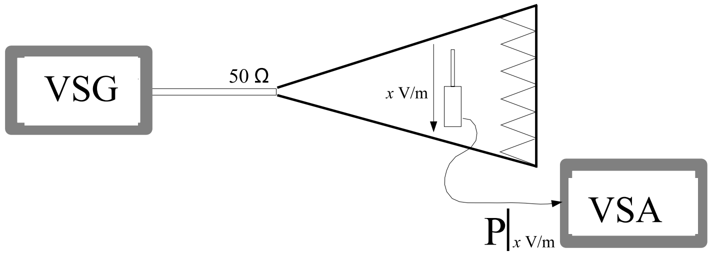

Figure 4: A block diagram view of the TEM cell antenna calibration. The TEM cell's input is supplied by the ESG. The antenna, positioned such that it is exposed to an *x* V/m field, has its output measured by a vector signal analyzer or similar.

Certain precautions are necessary when placing the antenna in the TEM cell so as to minimize impact on the field distribution in the immediate vicinity on the antenna. For example, we attach the feed cable to the antenna from 'behind', i.e. from the direction opposite to the TEM cell feed point, effectively 'hiding' it by attaching it to the lower conducting plate with adhesive conducting tape.

A Case Study

Our calibrated, receiver-based measurement technique described above was utilized in conjunction with an independent study conducted by the Phoenix Fire Department [5]. Their aim was to compare the voice quality of radio transmissions at different frequencies and with different modulation schemes (e.g. analog, digital) in various typical building environments. The result is a subjective evaluation of the different schemes: individual communications between positions at which fire fighters would typically be positioned are rated according to the criteria shown in Table 1. Our goal is to assign absolute field strength values to these subjective ratings.

Rating	Definition
0	No speech heard.
1	Unusable, speech present but unreadable.
2	Understandable with considerable effort. Frequent repetition due to noise or distortion.
3	Speech understandable with slight effort. Occasional repetition required due to noise or distortion.
4	Speech easily understood. Occasional noise or distortion.
5	Speech easily understood.

Table 1: The criteria for the subjective evaluation of voice signal quality used by the Phoenix Fire Department in its study (after [5]).

Our aim was to attempt to match electric field strengths to the ratings (1-5) given in Table 1. The difficulty in comparing an objective quantity (the field strength) to a subjective rating will require additional study involving the firefighters who carried out the ratings. However as a first cut, we can denote levels three, four, and five as "acceptable" communications, while levels zero, one and two will result in “unacceptable” communications. This division is borne out by the data shown in Fig. 5. This data, collected over a number of months by the Phoenix Fire Department, describes the perceived quality of voice transmissions over a wide spectrum of building types, at different frequencies and for different modulation schemes. There is a clear division between the ratings of 3-5, where a significant number of evaluations were made, and the ratings of 0-2, where very few were made.

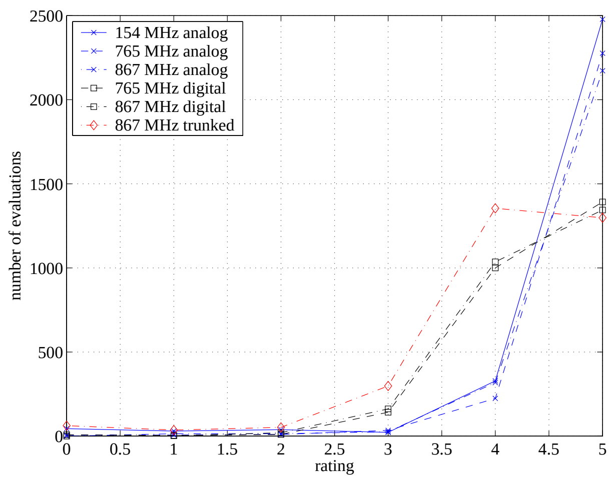

Figure 5: Sum of evaluations of radio transmission quality based on the rating descriptions in Table 1, reported for measurements of different modulation schemes at various frequencies in a wide range of buildings undertaken by the Phoenix Fire Department (after [5]).

To investigate the link between these subjective ratings and absolute electric field strength, we first developed a map of signal strength in an eight-story building in Phoenix in which poor signal transmission quality had been observed in previous tests. A listening station – an implementation of the measurement set-up described in Fig. 1 – was placed on the fifth floor of this building. Hand-held radios were set to transmit continually while being carried on a circuitous path through the building. At the same time, the radio bearers were regularly in voice communication with the listening station, allowing the quality of transmission to be judged and compared to the ratings from Table 1. Separate walks were done for transmissions at about 154, 765 and 867 MHz. Detailed notes were kept of the whereabouts of the transmitter as well as the signal quality, allowing the analysis shown below.

Since all results displayed the same trends, only the 867 MHz case is discussed in detail here as a representative example. The calibrated electric field is shown in Fig. 6, plotted versus an ‘absolute time’ measured from the beginning of the walk. The vertical marker lines and comments are based on the notes taken during the walk. Of particular interest are the comments regarding degraded signal quality: all occur when the measured electric field is below about 1×10^{-4} V/m, shown in Fig. 6 by the horizontal marker line. We assign this level to the "unacceptable" (levels 0-3) given in Table 1. This choice is somewhat arbitrary, since it is based on limited observations.

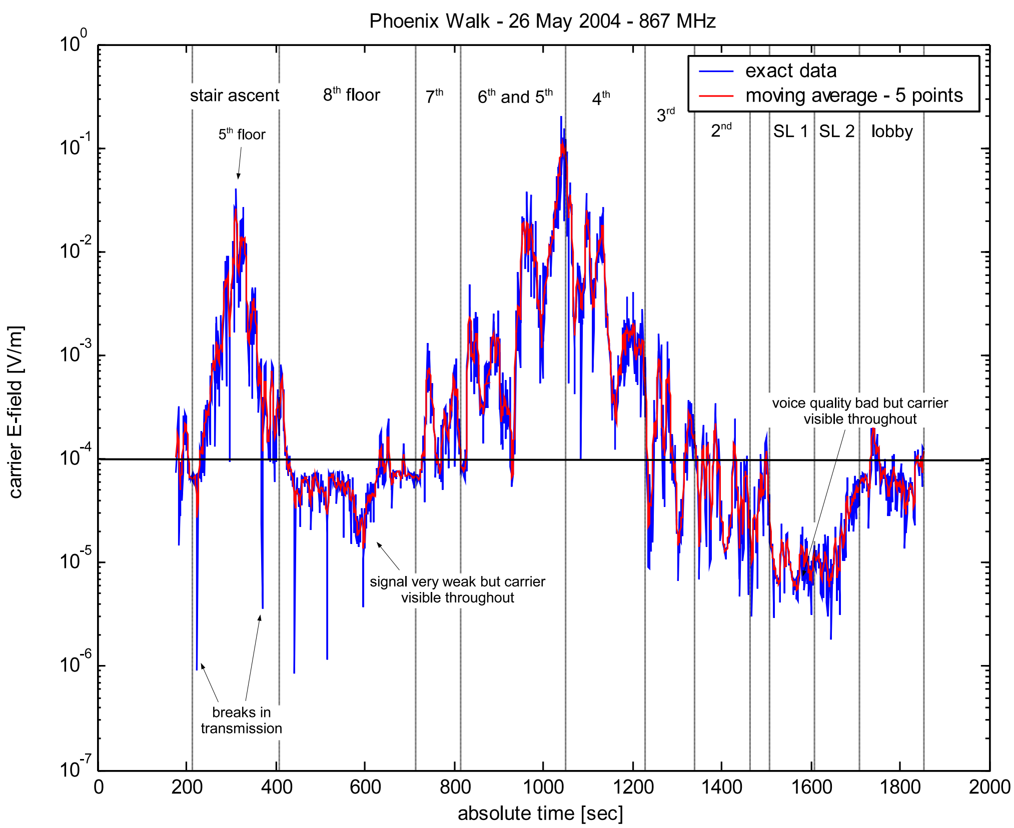

Figure 6: Electric field strengths measured during the 867 MHz building walk-through. The vertical marker lines represent boundaries in time between different sections of the walk. The horizontal marker at 1×10^{-4} V/m is the threshold below which poor signal quality, corresponding to ratings of 1 or 2 in Table 1, was observed. The red curve is a five-point moving average of the exact measured data shown by the blue plot.

The route of the walk is roughly described by the comments along the top of the graph, e.g. 'stair ascent' refers to the transmitter being carried from the ground floor past the receiver position on the fifth floor – note the correspondingly strong measured field just after the 300 second mark – to the roof. Access to the roof was not possible, so a brief circuit was walked on each floor before the sub-levels were visited. As shown by the comments in Fig. 6, the measured field strengths were lowest when the transmitter was in the roof access hatch just above the eighth floor (at about the 600 second mark), and when it was in the parking garage sublevels ('SL1' and 'SL2'). At these points the received audio quality was also worst, deserving ratings lower than two according to Table 1. A further aspect of the use of our receiver-based method for the detection of weak signals, also described by the comments, is that the carrier was visible even when the voice quality was very poor. This would appear to hold promise for alternative means of communication when voice transmission is difficult.

Conclusion

We have described a method, developed for the public safety sector, for detecting weak signals based on commercially available equipment. The method includes a calibration that enables display of the received signal in terms of absolute electric field strength. This allows system-independent comparison of measurements and makes the technique suitable for mapping signal propagation in complex environments. We applied the measurement technique to develop such a field-strength map in a large public building. Based on a general assessment of audio quality, we assigned a field strength value below which communications were considered "unacceptable."

References

[1] J. Demarinis, "The Antenna Cable as a Source of Error in EMI Measurements," in Proc. 1988 IEEE Symposium on EMC. IEEE, pp. 9–14, 1988.

[2] C. Icheln, J. Ollikainen, and P. Vainikainen, "Reducing the Influence of Feed Cables on Small Antenna Measurements," Electron. Lett., Vol. 35, No. 15, pp. 1212–1214, July 1999.

[3] M. L. Crawford, "Generation of Standard EM Fields Using TEM Transmission Cells," IEEE Trans. EMC, Vol. 16, No. 4, pp. 189–195, Nov. 1974.

[4] P. Hui, "Small Antenna measurements Using a GTEM Cell," in Antennas and Propagation Society International Symposium, 2003. IEEE, Vol. 4, pp. 715–718, June 2003.

[5] Andy MacFarlane, et al. 2004, Data compiled from Phoenix Fire Department voice quality evaluations.

Attachment 11

"Measurement of Building Penetration Into Medium Buildings at 900 and 1500 MHz"

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Measurement of Building Penetration Into Medium Buildings at 900 and 1500 MHz

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***Abstract*—The propagation loss into ten medium-sized buildings in Schaumburg, IL, has been measured. At 900 MHz, the mean penetration loss in the lower enclosed floors at or near ground level was found to be 10.8 dB with a standard deviation of 5.8 dB. At 1500 MHz, penetration loss was found to be 10.2 dB, and the standard deviation was 5.6 dB. Data was also taken up to 12 floors (with a higher concentration of data on the first five floors) to show higher elevation trends in the penetration loss. The measured building penetration loss was combined with data from other references, and the slope of a best fit curve as a function of frequency is found to be –7.9 dB per decade.**

I. Introduction

MANY PAPERS have been introduced to show building penetration loss for the 30-, 150-, 450-, and 900-MHz bands for various building types [1]–[4], [7]–[13], [16], [17], [19]–[24]. A paper was presented at the 1993 VTC Conference that measured four large buildings and made a comparison between building penetration for 880 MHz (the band where private, shared, and cellular systems now reside) and building penetration for 1800 MHz [the band where some personal communication systems (PCS's) are being investigated] [20]. This paper reports building penetration loss at 900 and 1500 MHz for ten medium buildings found in the Schaumburg, IL, area.

The particular interest in making these measurements was to determine whether there would be a significant difference between the 900-MHz building penetration loss values and the 1500-MHz building penetration loss values for the Japan Specialized Mobile Radio (JSMR) system. The spectrum at 900 MHz was being utilized, and the 1500-MHz spectrum was being proposed.

To extend to other frequencies, other references were noted on building penetration [3], [4], [12], [20], [21]. A curve fit was then made of the data measured in this report and of the data in those references to determine a particular class of building penetration (in this case, medium to light buildings) relative to frequency.

II. Measurement Procedure

A. Single Building Penetration Loss

Using the methods developed by Walker [1] and Rice [3], it was noted that the building penetration loss for a system should be defined by taking a given number of local mean samples inside the building in the first enclosed floors. This was then followed by taking a given number of samples around the outside perimeter of the building at the ground level. Each local mean sample would consist of 500 instantaneous samples taken while traveling approximately 40 wavelengths using the method proposed by Lee [14], [15], [18] and similar to that suggested by Walker. Since room and hallway distances can be less than 40 linear wavelengths, an "S" or "U" pattern would be traveled to reduce the correlation of the signal. In most cases, three–five measurements were taken per floor inside each building, and three–five measurements were taken outside the building. The inside medians were determined for each of the three–five measurements and then converted to decibels as suggested by Walker. In addition, the corresponding outside measurements were also averaged and converted.

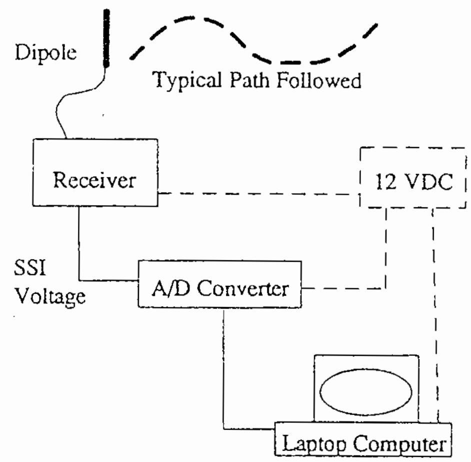

Fig. 1. Block diagram of measurement equipment.

The *median* value for each sample is used in this paper in order to alleviate any possibilities of anomalous data caused by radio signal-strength indicator (RSSI) saturation or "bottoming" by the measurement equipment. The difference between the averaged inside median and averaged outside median decibel measurements was then defined as the mean building penetration loss for that particular building.

B. Combined Building Penetration Loss

Continuing to follow the methods proposed by Walker and Rice, the individual building penetration losses were then combined to obtain a mean building loss for a particular class of building for a total area of concern. This was done by averaging the decibel penetration loss of all ten buildings

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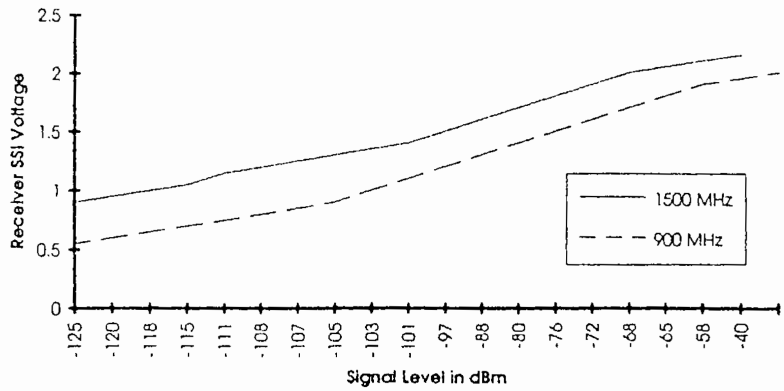


Fig. 2. 900- and 1500-MHz calibration curves.

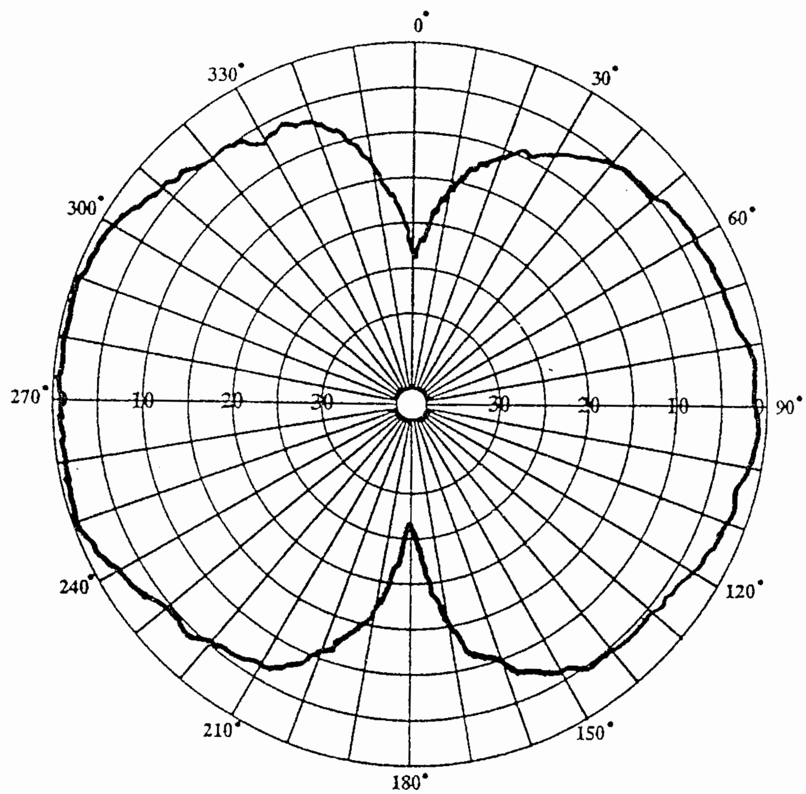


Fig. 3. Pattern of test dipole with two sleeves at 1.48 GHz.

measured in the Schaumburg area. The standard deviation of the decibel losses was also computed. The mean and standard deviation is, therefore, the result of a total of 64 250 measurements taken in the ten buildings for each frequency band.

III. Measurement Equipment

Fig. 1 shows a block diagram of the equipment used to perform the test. The equipment consisted of a laptop computer, a 900- and a 1500-MHz radio receiver with a 12.5-kHz bandwidth, an analog-to-digital (A/D) converter, and a dipole antenna mounted on a rolling "tea" cart.

Software was specifically written to measure the local mean as described in Section II for walking speeds. Each measurement was given a file name before the laptop computer requested the A/D to sample the radio receiver's signal strength indicator (SSI) at the appropriate velocity. At a typical walking speed of 3 mph, the software would direct the A/D converter to sample at approximately 55 samples per s. Each radio's SSI was calibrated periodically throughout the testing. Fig. 2 shows typical calibration curves of the 900- and 1500-MHz radios. Also, these curves indirectly show each radio's sensitivity and dynamic range.

Coaxial dipole antennas were specifically constructed for these tests. The design included two sleeves to decouple the coaxial cable feeding the antennas. The pattern in Fig. 3 for 1500 MHz indicates that the decoupling was adequate. The voltage standing wave ratio (VSWR) for both antennas was under 2:1 for the frequencies of interest. The tests were

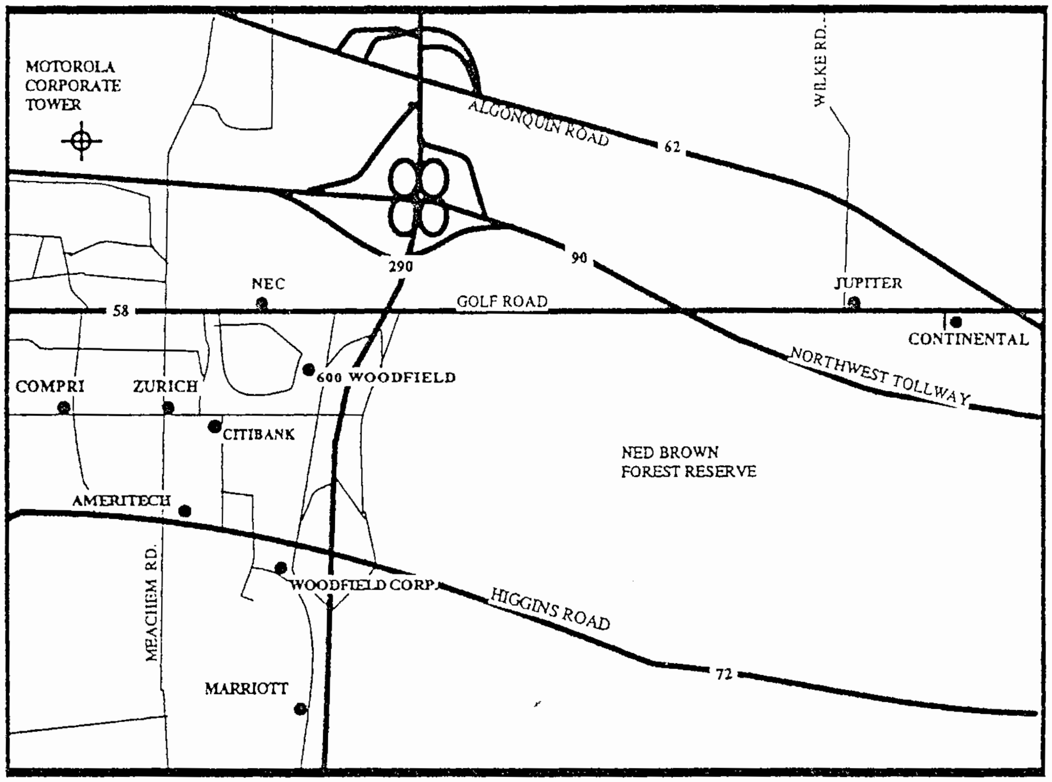


Fig. 4. Location of buildings with respect to the transmitter.

TABLE I
APPROXIMATE RADIAL DISTANCE OF BUILDINGS FROM TRANSMITTER

Compri Hotel	1.3 miles
Ameritech Building	1.6 miles
Jupiter Building	2.5 miles
Continental Towers	2.7 miles
NEC Building	1.2 miles
600 Woodfield Building	1.5 miles
Citibank Building	1.5 miles
Marriott Hotel	2.4 miles
Zurich Towers	1.4 miles
Woodfield Corporate Center	2.0 miles

performed with the antennas vertically polarized. The measurement equipment and methods have been previously described by Hill and Olson [25].

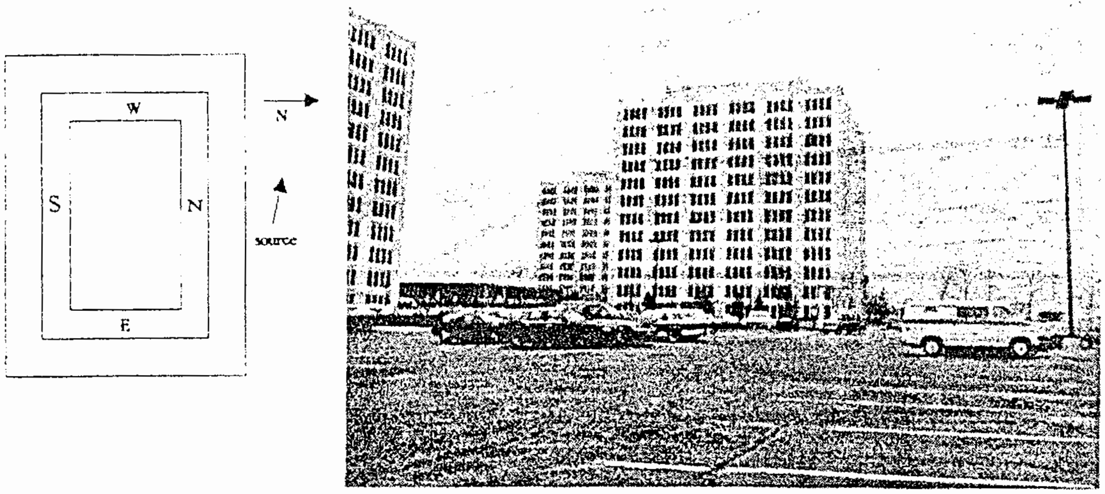
IV. Physical Description of Locale and Buildings

Fig. 4 shows a map of the buildings tested, which are indicated by the building "name" with a large "dot." Also shown is the Motorola Corporate Tower where the base transmitting antennas were located at a height of approximately 180 ft. The antennas had a beamwidth of 7–8°, and the only constraint on the choice of the medium-sized buildings tested was that they be within the vertical 3-dB beamwidth of the base antennas. This limited buildings to be tested to distances greater than 0.7 mi from the transmitter site. Table I shows the distance to each building, and the closest building measured was the NEC building 1.2 mi from the transmitter. This is only 1.6° down from the horizon, which was well within the half-power beamwidth of the antennas.

TABLE II
EXAMPLE MEDIAN SIGNAL STRENGTH MEASUREMENTS IN dBm FOR THE CONTINENTAL TOWERS (OUTSIDE): FLOOR NUMBERS AND COMPASS HEADING ARE NOTED

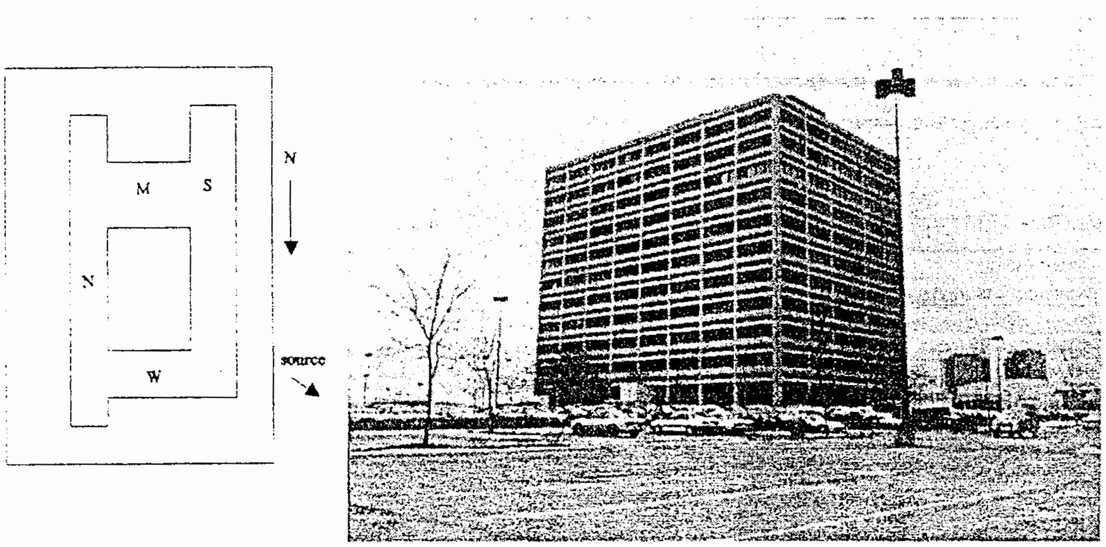
LOCATION	900 MHz	1500 MHz
OE	-67.4	-74.2
OS	-64.5	-71.3
ON	-58.9	-71.4
3S	-80.1	-84.9
3W	-72.5	-77.0
3N	-68.9	-74.5
3E	-77.2	-82.8
4S	-81.6	-94.3
4E	-65.1	-93.7
4N	-72.4	-81.1
4W	-82.1	-79.3
8S	-77.3	-79.8
8E	-60.0	-66.3
8N	-62.7	-73.0
8W	-80.7	-91.7

Photographs of two of the buildings tested are shown in Fig. 5. These buildings are typical of the measured buildings that were all located in a suburban environment. A large percentage of the building surface is glass, which is typical of the newer construction in the area. Also shown is the internal layout of hallways in the buildings with letters showing where the test measurements were made. The layout is for the lowest



CONTINENTAL TOWERS

(a)



600 WOODFIELD BUILDING

(b)

Fig. 5. Building layouts and photographs.

aboveground enclosed floor and shows that the measurements were not made near the outside walls (windows) of the building.

V. Analysis of Measurement Results

A. Received Power

Table II shows an example of individual median signal strength measurements in dB (1 mW) taken in the Continental Building for 900 and 1500 MHz. Under the location column, "O" denotes outside measurement files, and the numbers in the first column represent the building floor on which the measurement was taken. The general compass heading is denoted by North, South, East, West, or Middle. The data at 1500 MHz for the Jupiter Building and Woodfield Corporate Center was found to be miscalibrated and was eliminated from the 1500-MHz analysis, thus it is omitted from the results reported.

The received power taken outside the buildings was analyzed to determine if it could be shown that the received power on the side of the building away from the transmitter was lower than that on the other sides. Table III shows the data, and on the average, there is a 1-dB drop in the data for measurements taken on the side away from the transmitter.

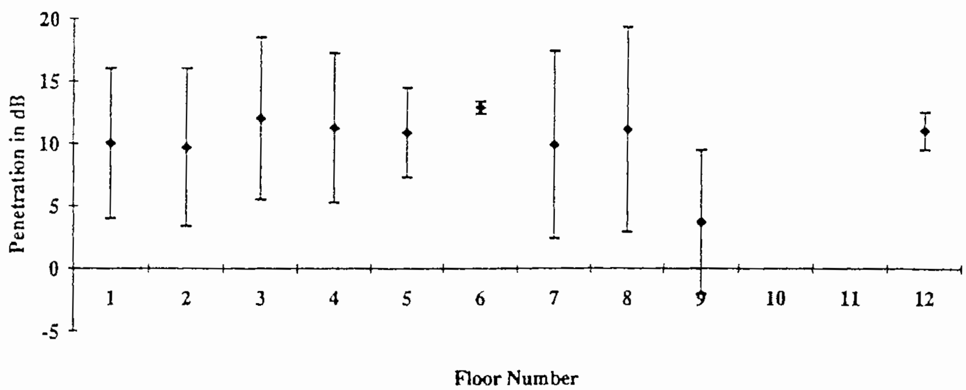


Fig. 6. Computed 900-MHz penetration mean and standard deviation for each floor using measured data from all buildings.

TABLE III
AVERAGE RECEIVED POWER OUTSIDE THE BUILDINGS WITH AND WITHOUT THE DATA ON THE SIDE OF THE BUILDING AWAY FROM THE TRANSMITTER

Building	Average Received Power in dBm			
	900 MHz		1500 MHz	
	All Data	Not Side Away	All Data	Not Side Away
Ameritech	-56.2	-56.5	-67.1	-67.1
Continental	-63.6	-61.7	-72.3	-71.3
Jupiter	-57.3	-56.2	*	*
Zurich	-52.6	-52.3	-62.2	-61.9
Compri	-52 4	-51.4	-64.0	-62.9
Citibank	-53.5	-53.3	-63.2	-62.5
Woodfield Corp.	-58.8	-58.2	*	*
Marriott	-71.3	-68.5	-80.3	-77.7
NEC	-53.3	-52.0	-64.2	-64.0
600 Woodfield	-55.5	-56.4	-67.3	-66.4
Average	-57.4	-56.4	-67.3	-66.4

Shadowing problems have also been shown to exist with data taken close in by Durante [8], causing those measurements to be discarded.

In this paper there were generally more inside data points taken on the sides of the building toward the transmitter than away. Therefore, since the intent of this paper is to show building penetration and not building shadowing, the average received power at each building, without using data from the side away from the transmitter, will be used to compute the building penetration loss.

B. Building Loss Analysis

Using the methods described in Sections II and III, each building was then analyzed by comparing the outside average to the inside average for the first few enclosed floors (up to the fifth floor), and the penetration loss was computed. This is consistent with the methods used by Walker, who noted that there were loss differences between open "lobby" floors and the first few enclosed floors. Table IV gives the penetration losses for each of the buildings.

These penetration losses were then combined for all buildings and plotted as a function of floor height in Figs. 6 and 7 for 900 and 1500 MHz, respectively. Table V shows the enclosed floors that were tested for each building. It is observed that there is little variation in the measured building loss on the sixth and twelfth floors. As shown in Table V, data was only taken in one building on these floors, and it appears that the clustering of the data may be the result of this small sampling size.

TABLE IV
MEDIUM BUILDING PENETRATION LOSS AND STANDARD DEVIATION AT 900 AND 1500 MHz

	900 MHz	1500 MHz
Ameritech	18.3	13.8
Continental	13.3	12.2
Jupiter	11.7	*
Zurich	11.9	10.8
Compri	6.7	7.9
Citibank	8.3	10.6
Woodfield Corp.	12.4	*
Marriott	13	15.7
NEC	8.1	6.1
600 Woodfield	3.9	3.6
Average	10.8	10.2
Standard Deviation	5.8 dB	5.6 dB

* Data eliminated or not available

There is a slight trend in the first five floors for the building loss to increase as the floor number increases as shown in Figs. 6 and 7. It was noted during the measurements that some of the ceiling heights on the first and second floors tended to be higher than those in upper floors of the office buildings. Floors just above these tended to become more cluttered with a reduced ceiling height. This may be the cause of the increase in loss seen at the third floor as shown in Figs. 6 and 7. This leads to the choice of averaging the first five enclosed floors of these buildings as opposed to only averaging the first one or two floors as done by Walker and Cox [2].

By observation of the data, it is seen that there is adequate data for the first five floors of the buildings tested, and that the building penetration data for these floors at both frequencies is nearly constant. The data for the first five floors was compiled into cumulative distribution functions (CDF's) for 900 and 1500 MHz. Fig. 8 shows the CDF for 1500 MHz. The mean

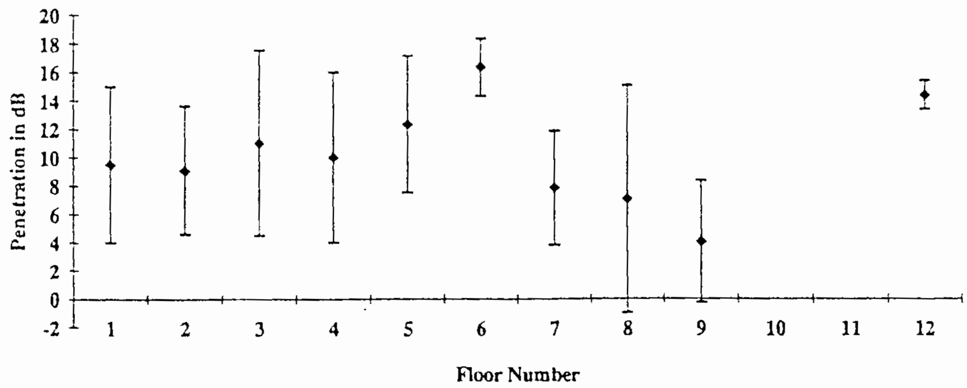


Fig. 7. Computed 1500-MHz penetration mean and standard deviation for each floor using measured data from all buildings.

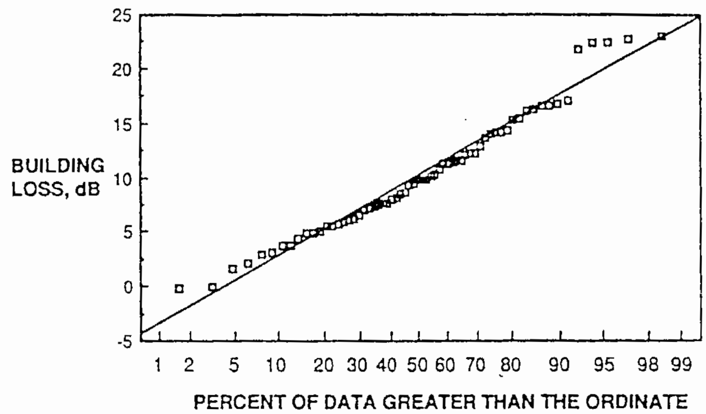


Fig. 8. Cumulative distribution function of the measured building loss at 1.5 GHz on the first five floors. The mean is 10.2 dB, and the standard deviation is 5.6 dB.

TABLE V
ENCLOSED FLOORS TESTED PER BUILDING

BUILDING FLOOR #	1	2	3	4	5	6	7	8	9	10	11	12
Ameritech	X		X	X								
Continental			X	X				X				
Jupiter	X			X				X				
Zurich	X		X	X			X					
Compri	X	X	X		X							
Citibank	X	X		X								
Woodfield Corp.		X	X	X								
Marriott					X	X						X
NEC	X	X		X								
600 Woodfield	X								X			

loss was found to be 10.2 dB at 1500 MHz and 10.8 dB at 900 MHz, and this will be taken as the basic ground level building loss for this class of buildings as determined by this measurement. The standard deviations were computed to be 5.6 and 5.8 dB for 1500 and 900 MHz, respectively. Table IV summarizes the building penetration loss and standard deviation for these frequencies.

Therefore, observing the measurements, it is concluded that the building penetration losses and standard deviations are essentially the same at 900 and 1500 MHz for this class of buildings.

Measurements were also taken later in the 800-MHz band for 20 medium-class buildings in Atlanta, GA, using the same standard procedures and equipment as outlined above. The average building penetration loss was calculated to be 12.6 dB with a standard deviation of 5.1 dB. This additional data fits well with that shown in Fig. 9.

VI. CURVE FIT OF DATA INCLUDING OTHER REFERENCES

Fig. 9 shows a plot of the measured data as reported in Section V along with that reported from several other sources [3], [4], [12], [20], [21]. To be included, other references were required to have two or more measured frequencies with data taken and processed in a similar manner as described in Section V. The initial curve fit was first presented by Davidson and Marturano [5] in a different format and is

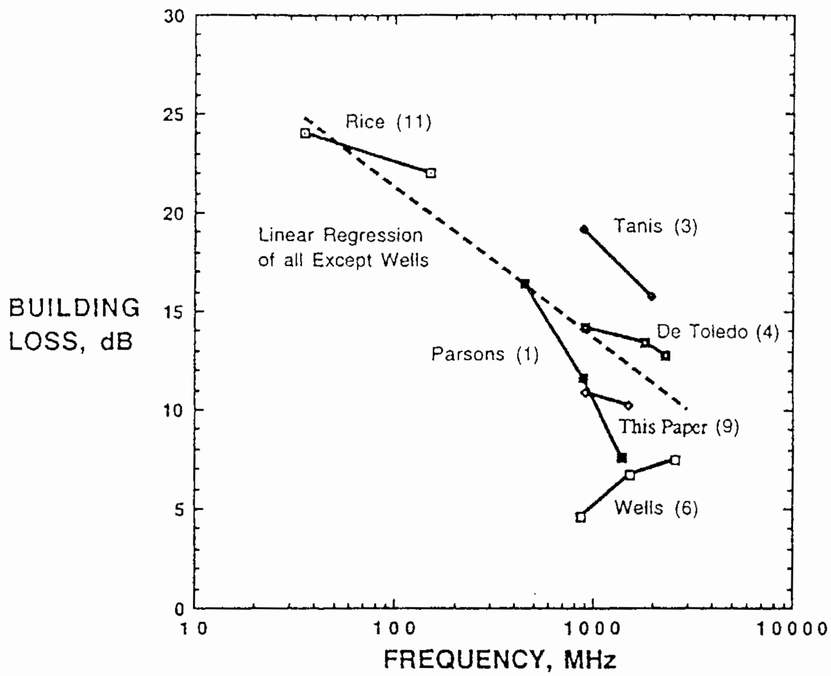


Fig. 9. Measured buildings' penetration loss versus frequency. Number of buildings measured shown in ( ).

formally presented here. The slope of this least squares best fit curve is –7.9 dB per decade and can be used to predict the loss starting from 24.8 dB at 35 MHz. Macario [6] referenced this curve in presenting an opposing analysis of building penetration versus frequency. However, many inconsistencies in measurement and data reduction methods were found to be inappropriately combined to form the curve fit, leading back to the conclusions as shown in Fig. 9 [26].

The standard deviation reported in Rice [3] is 14 and 12 dB at 35 and 150 MHz, respectively, while the standard deviation reported by others at the higher frequencies clusters between 4.1–8.1 dB. There is a trend of decreasing standard deviation versus frequency. However, the most noticeable trend is that the standard deviation reported in any one reference varies by 2 dB or less, and Tanis [20] shows the trend to be increasing. Therefore, no model will be given for the standard deviation as a function of frequency at this time.

It is interesting to note in Fig. 9 that the data from Wells [4] does not follow the trend of the curve fit [27]. In fact, the frequency trend of Wells goes against all other five sets of measurements. Though some measurements can bias the outside data with very close distances from the transmitter to the measurement [22], this was not found to be the case with Wells. However, in the nonmetallic single-family-type homes that Wells studied, the important materials are glass, brick and mortar, dry wall, plywood, wood, and cinder block. In these structures, the penetration is primarily through windows, walls, and the roof where the loss through the material is relatively low and goes up as the frequency increases as described by Wyss [22]. This is entirely consistent with the results of Wells.

The data reported herein, on the other hand, is for industrial or commercial buildings of reinforced concrete, steel, aluminum, and brick where the loss through the material is very high, and the dominant penetration is through slots (windows, cracks, etc.) where the loss decreases as the frequency increases. Therefore, both measurement results can be valid even when they differ in both magnitude and frequency trend. They are each merely constrained by the type of building and material measured.

VII. Conclusions

Building penetration measurements have been taken for ten medium size buildings at 900 and 1500 MHz. Standard methods were used to measure and reduce the data consistent with those used to measure buildings in other frequency bands. The penetration losses at these two frequencies were found to be nearly the same. The data was plotted along with measurements made by other authors, and a curve fit of penetration loss versus frequency has been presented. The data measured in this paper was found to follow the trend of decreasing building penetration loss as the frequency increases for the medium class of buildings.

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References

[1] E. H. Walker, "Penetration of radio signals into buildings in the cellular radio environment," *Bell Syst. Tech. J.*, vol. 62, pp. 2719–2734, Nov. 1983.

[2] D. C. Cox *et al.*, "Measurements of 800 MHz radio transmission into buildings with metallic walls," *Bell Syst. Tech. J.*, vol. 62, pp. 2695–2717, Nov. 1983.

[3] L. P. Rice, "Radio transmission into buildings at 35 and 150 mc," *Bell Syst. Tech. J.*, pp. 197–210, Jan. 1959.

[4] P. I. Wells, "The attenuation of UHF radio signals by houses," *IEEE Trans. Veh. Technol.*, vol. VT-26, Nov. 1977.
[5] A. Davidson and L. Marturano, "Impact of digital technologies on future land mobile spectrum requirements," *IEEE Veh. Technol. News*, vol. 40, pp. 14–30, May 1993.
[6] R. Macario, "How building penetration loss varies with frequency," *IEEE Veh. Technol. News*, vol. 40, pp. 26–27, Nov. 1993.
[7] S. T. Chia and A. Baran, "900 MHz attenuation and bit error ratio measurements inside a modern office building," in *IEEE Mobile Personal Comm. Conf. Proc.*, 1993, pp. 33–35.
[8] J. M. Durante, "Building penetration loss at 900 MHz," in *IEEE Veh. Technol. Conf. Proc.*, 1973, pp. 1–7.
[9] J. Shefer, "Propagation statistics of 900 and 450 MHz signals inside buildings," presented at the Microwave Radio Symp., Boulder, CO, 1973.
[10] V. Graziano, "Propagation models for 900 MHz cellular systems using portables and mobiles," in *IEEE Veh. Technol. Conf. Proc.*, 1982, pp. 4–6.
[11] S. J. Patsiokas *et al.*, "Propagation of radio signals inside buildings at 150, 450 and 850 MHz," in *IEEE Veh. Technol. Conf. Proc.*, 1986, pp. 66–71.
[12] A. F. deToledo and A. D. Turkmani, "Propagation into and within buildings at 900, 1800 and 2300 MHz," in *IEEE Veh. Technol. Conf. Proc.*, 1992, p. 633.
[13] J. Dietz *et al.*, "Examination of the feasibility of conventional land mobile operations at 950 MHz," FCC Office Research Div., Washington, D.C., Rep. R7102, 1971.
[14] W. C. Y. Lee, "Estimate of local average power of a mobile radio signal," *IEEE Trans. Veh. Technol.*, vol. VT-34, pp. 22–27, Feb. 1985.
[15] ——, *Mobile Communications Engineering.* New York: McGraw-Hill, 1982.
[16] P. I. Wells, "The attenuation of UHF radio signals by houses," *IEEE Trans. Veh. Technol.*, vol. VT-26, pp. 358–362, Nov. 1977.
[17] T. K. Sharpe, "Paging systems," in *Personal Mobile Radio Systems*, R. C. V. Macario, Ed. London: Peregrinus, 1991, pp. 161–162.
[18] "Coverage prediction for mobile radio systems operating in the 800/900 MHz frequency range," *IEEE Trans. Veh. Technol.*, vol. 37, p. 11, Feb. 1988.
[19] T. S. Rappaport, "The wireless revolution," *IEEE Trans. Commun.*, vol. 29, pp. 52–71, Nov. 1991.
[20] W. J. Tanis and G. J. Pilato, "Building penetration characteristics of 880 MHz and 1922 MHz radio waves," in *IEEE Veh. Technol. Conf. Proc.*, 1993, pp. 206–209.
[21] D. Parsons, *The Mobile Radio Propagation Channel.* New York: Wiley, 1992, pp. 190–194.
[22] J. C. Wyss *et al.*, "Building penetration project," NBS, Boulder, CO, Rep. NBSIR-84/3009, 1984.
[23] S. E. Alexander, "Radio propagation within buildings at 900 MHz," *Electron. Lett.*, vol. 18, no. 21, pp. 913–914, 1982.
[24] A. M. D. Turkmani *et al.*, "Measurement of building penetration loss on radio signals at 441, 900 and 1400 MHz," *IERE J.*, pp. 5169–5174, 1988.
[25] C. Hill and B. Olson, "A statistical analysis of radio system coverage acceptance testing," *IEEE. Veh. Technol. Soc. News*, vol. 41, pp. 4–13, Feb. 1994.
[26] A. Davidson and L. Marturano, private communication, Nov. 1993.
[27] ——, private communication, June 1993.

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