

## SUPPLEMENT 2

# Emergency Communications Systems Design and Application Challenges

Wayne D. Moore, P.E., FSFPE

**Editor's Note:** Chapter 24 of the 2010 edition of the *National Fire Alarm and Signaling Code* is a new chapter that covers the requirements for the installation and performance of emergency communications systems for in-building fire emergency voice/alarm communications systems and other communications systems. This supplement focuses on those systems where the design includes the use of speakers. These systems often present the most design challenges and include in-building fire EVACS, in-building MNS, wide-area MNS, distributed recipient MNS, two-way emergency services ECS, area of refuge ECS, and elevator ECS.

Almost 30 years ago, NFPA began work on NFPA 72F, the first installation *Standard for the Installation, Maintenance and Use of Emergency Voice/Alarm Communication Systems*.<sup>1</sup> Finally published in 1985, the document contained approximately two pages of requirements, including additional pages of Appendix (Annex) material for “Voice/Alarm Signaling Service” and “Two-Way Telephone Communication Service.”

In contrast, the 2010 edition of the *National Fire Alarm and Signaling Code*, Chapter 24, provides the requirements for *Emergency Communications Systems* with a total of 23 pages, including the Annex material. The major difference: the fact that this chapter of the *National Fire Alarm and Signaling Code* now covers more than just in-building fire emergency voice/alarm communications systems (EVACS). It also requires much more in terms of system arrangement and performance.

Chapter 24 is structured to include many types of emergency communications systems (ECSs). These have been divided into two basic categories, one-way and two-way. The one-way emergency communications systems include in-building systems as well as wide-area and

distributed recipient mass notification systems. The two-way emergency communications systems provide requirements for both wired and radio emergency services systems, area of refuge systems, and elevator communication systems.

Chapter 24 includes a section that pertains to information, command, and control. This is for the communications methods and equipment used to receive and transmit information between premises sources or premises systems and the central control station(s). These may include wired or wireless networks for one- or two-way communications and/or control between a building or area and a central control station and could include an emergency services organization or public alarm reporting system. In a very basic configuration, a system and the receiving facility could be a supervising station system. However, there can be more complex systems that allow control of building systems and communication to building occupants from a remote location, including a municipal or other public alarm reporting command center or possibly even from a mobile command vehicle using secure communications.

Although prescriptive-based, mass notification systems will be required to serve very specific yet very varied needs. As such, mass notification systems design will require significant reliance on the risk analysis. Section 24.7 provides a performance-based design approach.

Each of these sections addresses requirements for pathway survivability. The arrangement of the sections containing the requirements for the different emergency communications systems presented is shown in *NFPA 72*<sup>®</sup> Figure A.24.3.6, which is reproduced here as Exhibit S2.1.

In recent years, the use of communications systems, both inside buildings and outside, has become more common for many different reasons. With the advent of terrorist activities, shootings on college campuses and high schools, and extreme weather issues, the public increasingly demands actionable information in real time. As a result of that demand, mass notification systems (MNSs) have become the norm in all Department of Defense buildings and sites. These systems have begun to make their way into other government and commercial buildings, college campuses, and outside environments. Many, if not most of the MNS designs, have combined or integrated these systems with the in-building fire EVACS.

During the 25-year history of EVACS, the Code did not allow for the sharing of the fire alarm textual audible notification appliances (speakers) or control equipment by any other system. The Code did not allow the use of the EVACS for anything other than fire alarm signaling, except under very strict control and approval by the authority having jurisdiction. However, for the first time in the history of the Code, the requirements permit the combining or

integrating in-building fire emergency voice/alarm communications systems with other communications systems, such as mass notification systems, public address, and paging systems. In addition, again for the first time in the history of the Code, certain mass notification messages may take precedence over a fire alarm signal.

The technology has become available to ensure that fire alarm or priority mass notification messages — as determined by a careful and thorough risk analysis — can take precedence over any other announcements from non-emergency systems, including paging from a telephone system or other public address system. Speaker system designs have become available that incorporate volume controls and components that allow occupants to lower or turn off the speakers in their area or office, but switch the speakers back on to operate at their required power output when the fire alarm system or MNS actuates. This is one of the safeguards now available to meet the requirements of the Code and allow integration of in-building fire emergency voice/alarm communications systems with other communications systems.

No one would question that using one speaker system to serve multiple functions offers financial benefits to the owner of the facility. Using one system reduces the costs of design, installation, and maintenance throughout the life cycle of the system. In addition, regular use of the system for normal paging functions provides an end-to-end test of the audible notification components and circuits. As occupants become familiar with use of the system for normal paging, they will also more likely become comfortable and proficient with use of the system during an emergency.

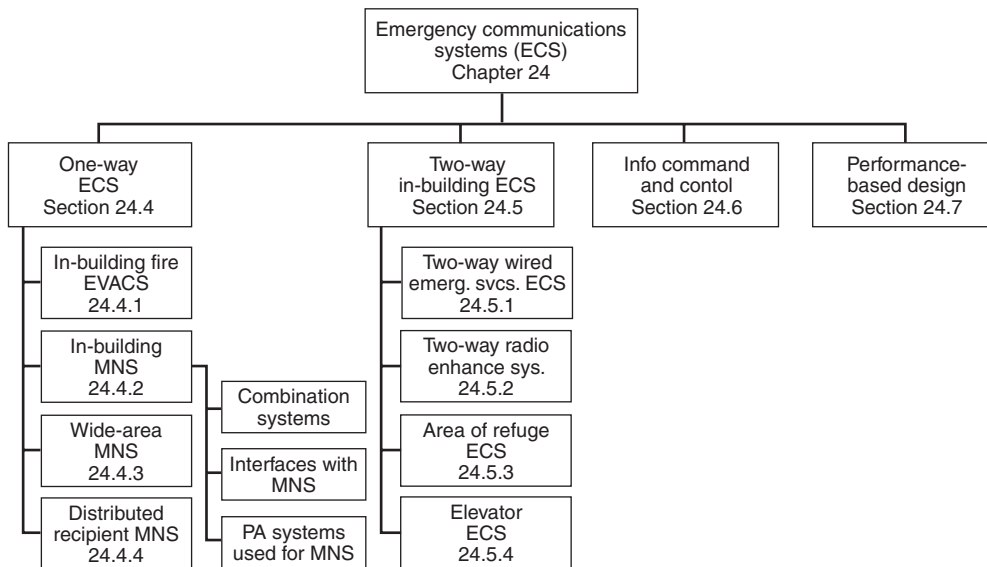


EXHIBIT S2.1 Emergency Communications Systems (ECS) Flowchart.

Since 1999, additions to the Code have required both audibility and intelligibility of voice communications. Prior to the introduction of intelligibility requirements, EVACS might have met the audibility requirements, but nothing ensured that occupants could comprehend and then react properly to the voice message. Typically, fire alarm system designers, installers, and authorities having jurisdiction had a limited background in the science of sound and communications. In previous editions, the Code offered only limited guidance on how to provide intelligible voice messages.

Users of the 2010 edition of the Code will find much improved design guidance for the layout of effective, audible, and intelligible communications systems. Of course, neither the Code itself nor this Supplement intends to serve as a complete design guide. See the References and bibliography at the end of this Supplement for additional design information.

Table S2.1 provides a list of emergency communications systems with their specific requirements. Integration of each of these systems can provide emergency information to the building occupants and meet the communications needs required by the owner.

**TABLE S2.1** *Emergency Communications Systems*

<i>One-Way ECS</i>	<i>Two-Way In-Building ECS</i>
In-building fire EVACS ECS	Two-way wired emergency services (ECS)
In-building MNS ECS	Two-way radio emergency services (ECS)
Wide-area MNS	Area of refuge ECS
Distributed recipient MNS	Elevator ECS

According to Wikipedia, communication is the process to impart information from a sender to a receiver with the use of a medium. The first step in any design process is to determine what ECS the owner or occupants of a building or area require or desire. In most situations, a voice communication system will need to include a combination system providing in-building fire EVACS, in-building MNS, and paging to meet the operational goals and cost savings objectives of the owner.

The next step is to evaluate the expected or measured ambient noise conditions of the building. Exhibit S2.2 shows typical levels of ambient noise.

As stated previously, one of the major operational goals is to ensure the messages distributed by the ECS are intelligible. The 2010 Code defines intelligible as “capable of being understood; comprehensible; clear” and defines intelligibility as “the quality or condition of being intelli-

dB SPL Operating Levels						
Listening level		Ear level range	Comments	High level music	Med. level music	Low level music
dB SPL	dB SPL Pk					
133	145	[Blue bar]	Pain threshold	[Blue bar]	[Blue bar]	[Blue bar]
130	142					
127	139		Non-linear region			
124	136					
121	133					
118	130					
115	127					
112	124		High level music			
109	121					
106	118					
103	115		Medium level music			
100	112					
97	109					
94	106	Low level music				
91	103					
88	100					
85	97					
82	94					
79	91	Speech @ 0.5 meter				
76	88					
73	85					
70	82					
67	79					
64	76					
61	73		Speech @ 1 meter			
58	70					
55	67					
52	64	Noisy HVAC				
49	61					
46	58					
43	55	Typical HVAC				
40	52					
37	49					
34	46	Quiet room				
31	43					
28	40					
25	37	VERY quiet room				
22	34					
19	31					
16	28					
13	25					
10	22	Recording Studio				
7	19					
4	16					
1	13	Dream on!				
-2	10					
-5	7					
-8	4					
-11	1					
		Brownian motion				
		Noise floor of air and ear				

**EXHIBIT S2.2** *Typical Operational Level Over the Dynamic Range of the Ear. (Source: Bob McCarthy, Sound Systems: Design and Optimization, Elsevier, Ltd., 2008, Figure 1.14, page 15)<sup>2</sup>*

gible.” Although the Code does not yet require a system to meet a specific level of intelligibility, it does provide a new Annex D, entitled Speech Intelligibility, that treats the subject of measuring intelligibility levels in detail. In most designs of typical sound and communications systems, stakeholders measure intelligibility by whether or not the designers, installers, authorities having jurisdiction, and occupants can understand the messages. The stakeholders do not expect anyone to actually quantify intelligibility through measurements or tests.

The issue in design becomes how to ensure that the system “delivers” intelligible messages through an installation of cabling and equipment consisting of amplifiers and speakers. See Exhibit S2.3.

The “source” shown in Exhibit S2.3 could consist of a person orally giving emergency instructions via the microphone. Or, the source could consist of a prerecorded message. Once either of these signal sources are present, the next step occurs in the signal processing and amplifier equipment.

The NEMA *Emergency Communications Audio Intelligibility Applications Guide*<sup>3</sup> provides a description of factors that affect intelligibility:

There are many factors that affect the intelligibility of messages presented over public address systems in public and private spaces. Some major intelligibility factors include:

- Background noise.
- The configuration of the space being addressed.
- The acoustical properties of the materials on the walls, floors, and ceilings.
- The distortion and bandwidth of the sound equipment.
- The characteristics of the person speaking (male/female, accent, microphone technique, etc.)

The ECS system designer cannot control all of these factors, but he or she must design the system to compensate for those factors not under his or her control. The designer must address background noise or “ambient noise levels” as part of the design. In order for the system to meet the intelligibility goals, the system must have an adequate signal-to-noise ratio. If the system provides a speech signal at least 15 dB higher than the ambient noise level, this will minimize the intelligibility loss from the ambient noise levels.

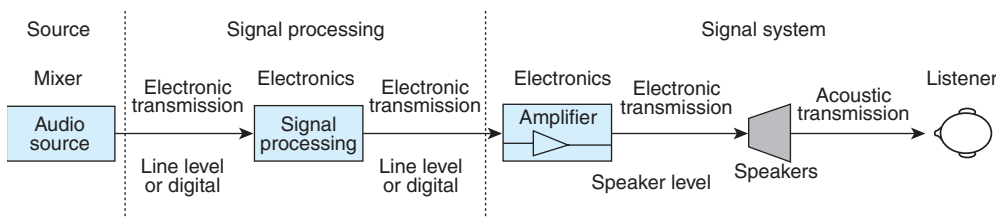
However, if the ambient noise levels reach exceedingly high levels — greater than 90 dB — then attempting to present a signal with sufficient level to overcome the ambient noise level will likely decrease the intelligibility of the message. Using the example of an ambient noise level of 90 dB, such as in a noisy manufacturing area, the

speaker must deliver 105 dB at the listener to overcome the noise. Such a level from the speaker could exceed 120 dB nearer the speaker, depending on the location of the listener in relationship to the placement of the speaker. The Code permits a maximum sound pressure level (SPL) of 110 dB. The SPL of 120 dB could result in hearing damage. The Code requires the use of visible notification appliances (strobes) in locations with such high ambient noise levels; see 18.4.1.2. In addition, the occupants of areas with such a high ambient noise level would need training to respond to the visible notification appliances and relocate to an area where they could hear the message from the speakers.

The Code also recognizes that some ambient noise signals are made up of different frequencies and states “in areas where the background noise is generated by machinery and is fairly constant, a frequency analysis can be warranted.” See A.18.4.3.1.

One must understand that proper microphone technique presents one of the uncontrollable factors in any design. The installer of an ECS system must provide the operators of the system with proper training in the use of a microphone, as well as for the other operation use of the system. In many cases, designers may prefer to use prerecorded messages or digitally compiled phrases rather than let untrained users operate the microphone. Recorded messages provide a consistent sound level output and a controlled speech pattern generally performed by recording professionals. Such output will provide a more intelligible message than a nonprofessional who makes an unpracticed announcement using a microphone.

Designers must consider other intelligibility issues, including possible distortion introduced by the amplifier and signal processing equipment. It should come as no surprise that equipment quality plays an important part in the delivery of an intelligible message to the listener. Although the Code requires the use of products listed by an organization acceptable to the authority having jurisdiction, such listings do not guarantee the equipment’s quality to reproduce clear, understandable messages. Assuming that the control and amplifier equipment meets the quality goal and



**EXHIBIT S2.3** Transition Flow from the Signal Source to the Listener. (Source: Bob McCarthy, *Sound Systems: Design and Optimization*, Elsevier, Ltd., 2008, Figure 1.1, page 3)<sup>2</sup>

operational needs of the design, the next important consideration must include an analysis of the effect of the environment on the speakers and the speaker placement throughout the facility.

The designer must understand the acoustics of the space. In addition, the designer must understand and address the acoustic performance properties of the proposed speakers. These considerations help ensure that he or she chooses the right speaker, its output, and placement. The analysis may disclose that the only way to achieve a proper design for the ECS is to include the modification of some architectural design features of the space.

As stated in Annex D of the 2010 edition of the Code, D.1.5, “The designer and the authority having jurisdiction should both be aware that the acoustic performance parameters of the chosen loudspeakers, as well as their placement in the structure, play a major role in determining how many appliances are necessary for adequate intelligibility. The numerical count of appliances for a given design and protected space cannot, by itself, be used to determine the adequacy of the design. Sometimes, the acoustic problems of certain placement constraints can be satisfactorily overcome through the careful selection of loudspeakers with the requisite performance characteristics, rather than by increasing their number.”

Chapter 18 of the Code requires designers to specify “acoustically distinguishable spaces” (ADSs) when designing an ECS. Annex D states that an ADS may be a physically defined notification zone or part of a notification zone. An ADS is a space “distinguished from other spaces because of different acoustical, environmental or use characteristics such as reverberation time and ambient sound pressure level.” The Code allows the designer to define an ADS as a space that “might have acoustical design features that are conducive for voice intelligibility, or it might be a space where voice intelligibility could be difficult or impossible to achieve.” In essence all parts of a building are a part of an ADS. There can be many different ADSs in a building. Some ADSs might require intelligible voice and others may be designated by the designer as requiring only tone signaling, or no occupant notification at all. See Exhibit 18.13, which is a decision tree that can be used for determining the requirements or needs for each ADS. Annex D encourages designers to review all of the information it provides regarding acoustically distinguishable spaces.

Reverberation time — also known as RT60 time — is defined as the amount of time it takes for a sound to diminish 60 dB below the original level. Sound reflecting off hard surfaces such as wood or tiled floors, concrete walls, ceilings, or other hard surfaces produces reverberation. Reverberation can seriously contribute to reduced intelligibil-

ity. When a speaker broadcasts a message, the listener hears direct sound from the speaker and somewhat delayed sound from reverberation. The degree of intelligibility of the sound will depend on the listener’s physical location in relation to the location of the speaker.

Reverberation in a room or space depends on the nature of that space: dimension of the space, construction materials used in the space, whether or not the space includes occupants, and furnishings in the space. The amount of reverberation in a room diminishes when the room or space includes construction features, people, or furnishings that absorb sound. The amount of reverberation varies from space to space, depending on the absorption characteristics of the materials in a particular space. Hard surfaces reflect sound rather than absorb it. Soft surfaces, such as drapes and carpeting, tend to absorb sound. The more reflection in a space, the greater the reverberation that space will have. The more absorbency in a space, the less reverberation that space will have. To help reduce reverberation in a room, designers should locate speakers away from hard surfaces, such as walls, and point the speakers towards soft, absorbent surfaces.

Increasing the power (wattage) of the speaker often distorts the message content from a speaker. Generally, a more efficient design locates the speakers in occupied areas of the space and uses more speakers at reduced power for each speaker. Both of these design considerations help reduce the effects of reverberation, provide a better direct signal to the listener, and increase the intelligibility of the messages. This guidance applies best where the ceiling heights do not exceed 10 to 12 ft (3.0 to 3.7 m). In rooms or spaces with high ceilings, the designer should use a more “focused” or directional speaker than a standard ceiling- or wall-mounted speaker.

UL Standard 1480, *Standard for Speakers for Fire Alarm, Emergency, and Commercial and Professional Use*<sup>4</sup>, requires a reverberant chamber test and an anechoic rating as defined by CAN/ULC-S541-07, *Speakers for Fire Alarm Systems, Including Accessories*<sup>5</sup>. The reverberant chamber test measures the total sound power output of a speaker in a chamber specifically designed to reflect a certain amount of the sound. Yet, it has proven difficult to correlate a speaker’s reverberant chamber sensitivity rating with real-world acoustics. Typically, the anechoic rating at 1 kHz is more representative of real world performance.<sup>3</sup> A designer should consult a manufacturer’s product information sheets to determine the speaker characteristics available. Because speakers are “point source” appliances, ideally the sound radiates outward in a near spherical pattern. As the sound moves away from the speaker, the inverse square law relates a drop of 6 dB of sound pressure level every time the distance is doubled from the speaker.

The sensitivity of a speaker is defined as the amount of sound a speaker can produce with a known signal frequency, power level, and distance from the speaker. For fire alarm speakers listed under UL Standard 1480, the sensitivity is rated at 1 Watt of power measured 10 ft (3.0 m) from the speaker.

Speaker sensitivity may prove useful for comparing different models and manufacturers of speakers. However, a designer may find a polar distribution plot for a speaker more useful when choosing a speaker for a particular design. This is because speakers in the direct line of the listener actually produce the loudest sound. As the listener moves away from that centerline, speakers produce less loud sounds. This directionality information is useful when determining the coverage area of a speaker. The “coverage angle” is defined as the angle where the SPL drops 6 dB from the on-axis SPL. As stated in the *NEMA Guide*,<sup>3</sup>

Speakers used for emergency voice/alarm communication system are wired as ‘Constant Voltage’ systems, where the maximum power output of the amplifier is obtained at a certain speaker voltage, such as 25 V or 70.7 V. The power output of a speaker, and thus the resulting SPL is controlled by wattage taps on the speakers themselves. The minimum wattage tap for a UL Standard 1480 listed speaker is  $\frac{1}{4}$  W. Typical 4-inch speakers have wattage taps in 3 dB increments:  $\frac{1}{4}$  W,  $\frac{1}{2}$  W, 1 W, and 2 W. Each wattage tap doubles the power delivered by the speaker, and so increases the SPL output by 3 dB for each increasing tap. An increase of 3 dB is considered a just noticeable increase in SPL, changing the wattage tap from  $\frac{1}{4}$  W to 2 W increases the perceived loudness by slightly less than double.

A designer may choose one of many speaker layout options. The layout will obviously depend on the room or space geometry. See Tables S2.2 and S2.3 and Exhibit S2.4 for some recommendations for ceiling-mounted speakers. As stated in the *NEMA Guide*, in general low ceilings require more ceiling-mounted speakers per square foot of area than high ceilings.

Designers have also used wall-mounted speakers in many applications, especially in corridors and other narrow spaces. The *NEMA Guide* lists some of the advantages and disadvantages of wall-mounted speakers, which are extracted below:

Advantages

- For narrow areas such as hallways, fewer speakers and less amplifier power may be needed to cover the same size area. This is because all of the speaker’s sound contributes to useable audibility.
- Mounting can be on more than one wall. This further improves the distribution of direct sound to the listener.

**TABLE S2.2** Examples of Typical 4-in. Speaker Coverage for Varying Ceiling Heights

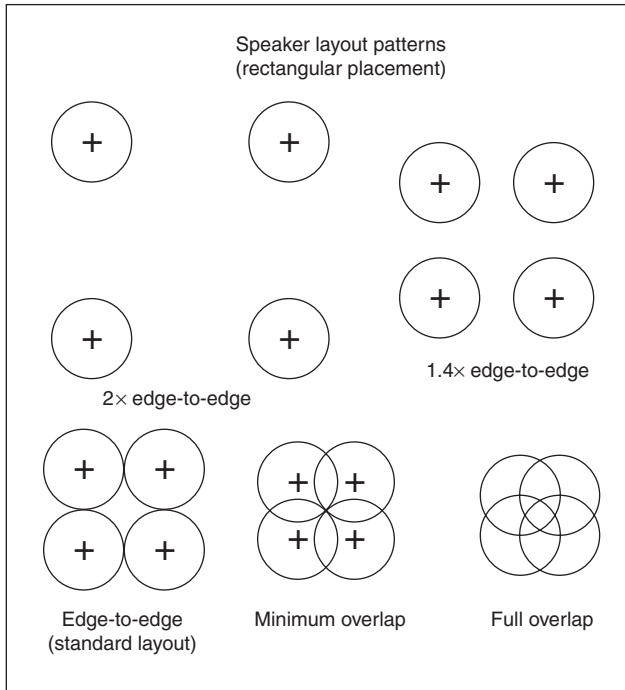
Listener Height = 5 ft		
Ceiling Height	Coverage Diameter	Coverage Area
8 ft	7.7 ft	46 ft <sup>2</sup>
10 ft	12.8 ft	129 ft <sup>2</sup>
12 ft	17.9 ft	252 ft <sup>2</sup>
14 ft	23.0 ft	417 ft <sup>2</sup>
16 ft	28.2 ft	623 ft <sup>2</sup>
18 ft	33.3 ft	870 ft <sup>2</sup>
20 ft	38.4 ft	1158 ft <sup>2</sup>
Listener Height = 1.5 m		
2.5 m	2.6 m	5.1 m <sup>2</sup>
3 m	3.8 m	11.6 m <sup>2</sup>
3.5 m	5.1 m	20.6 m <sup>2</sup>
4 m	6.4 m	32.2 m <sup>2</sup>
4.5 m	7.7 m	46.3 m <sup>2</sup>
5 m	9.0 m	63.0 m <sup>2</sup>
5.5 m	10.2 m	82.3 m <sup>2</sup>
6 m	11.5 m	104.2 m <sup>2</sup>

Source: NEMA Standards Publication SB 50-2008, *Emergency Communications Audio Intelligibility Applications Guide*, Table 2-1.<sup>3</sup>

**TABLE S2.3** Layout Pattern Selection Guide

Layout	Description
2× Edge-to-edge	Not recommended except for tone only signaling or small rooms with low noise or low reverberation.
1.4× Edge-to-edge	Uses fewer speakers than edge-to-edge pattern. Only appropriate for rooms with low noise and low reverberation.
Edge-to-edge	Preferred layout pattern for most areas.
Minimum overlap	Use with areas of high reverberation and/or high ceilings.
Full overlap	For the worst areas, generally provides excellent intelligibility for even difficult areas. Use with caution. This type of pattern can result in lower than expected intelligibility due to multiple speaker interaction. Modeling is recommended for areas that would need this layout pattern.

Source: NEMA Standards Publication SB 50-2008, *Emergency Communications Audio Intelligibility Applications Guide*, Table 2-2.<sup>3</sup>



**EXHIBIT S2.4** Speaker Layout Patterns. (Source: NEMA Standards Publication SB 50-2008, *Emergency Communications Audio Intelligibility Applications Guide*, Figure 2-7)<sup>3</sup>

- Wall mounted speakers put sound directly into the listener area. This can reduce the excitation of the reverberant field.
- Combination speaker strobe units permit voice and visual notification in a single appliance.

Disadvantages

- The sound field from wall mount speakers is more likely to encounter obstructions from furnishings such as cubicle walls in office environments or movable partitions in conference rooms. If the furnishings in a room are likely to change, a distributed overhead system or a combination wall mount and overhead design should be considered. This minimizes the variation of audibility and intelligibility.
- In rooms with low, hard ceilings the sound emitting from the top hemisphere of the coverage pattern is reflected off the ceiling and down to the listener. This can increase the reverberant field sound level and result in delayed arrival of sound. These factors both contribute to a reduction in intelligibility.

The principal difference between a wall-mounted speaker system and a ceiling-mounted speaker system is the influence speaker location has on the distance from the speaker to the listener’s location in the room.

The Code requires installers to locate wall-mounted

speakers at heights not less than 90 in. (2.29 m) above the floor. When provided with a visible notification appliance, the unit is required to be installed such that the entire lens is not less than 80 in. (2.03 m) and not greater than 96 in. (2.44 m) above finished floor. With wall-mounted speakers, designers must determine coverage for each speaker using the diameter of coverage rather than the coverage area used for ceiling-mounted speakers. The speaker spacing is then determined using the width of the wall coverage defined by the diameter of coverage. See Table S2.4.

**TABLE S2.4** Wall-Mounted Speaker Coverage Width vs. Room Depth

Wall-Mounted Speakers (in Feet)	
Room Width	Coverage Width 3 ft (1 m) from Wall Opposite Speaker
10 ft	18 ft
12 ft	23 ft
14 ft	28 ft
16 ft	33 ft
18 ft	38 ft
20 ft	44 ft

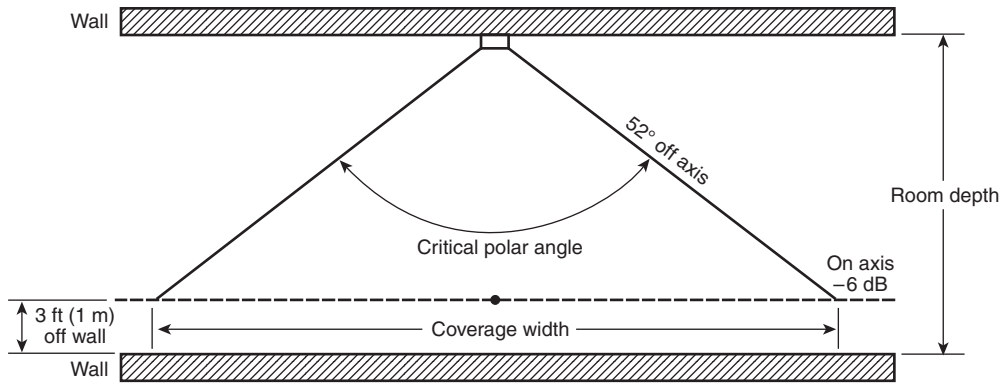
  

Wall-Mounted Speakers (in Meters)	
2.5 m	3.8 m
3.0 m	5.1 m
3.5 m	6.4 m
4.0 m	7.7 m
4.5 m	9.0 m
5.0 m	10.2 m
5.5 m	11.5 m
6.0 m	12.8 m

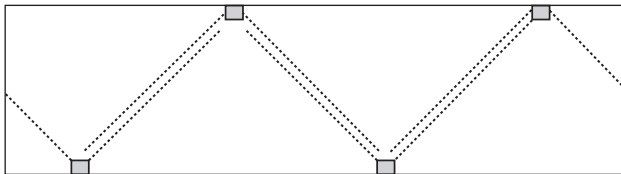
Source: NEMA Standards Publication SB 50-2008, *Emergency Communications Audio Intelligibility Applications Guide*, Table 2-4.<sup>3</sup>

Wall-mounted speakers generally consist of a single row on one side of a space. However, a designer must take care to not overextend the expected sound penetration into a room larger than 20 ft (6.1 m) wide. When the opposite wall is greater than 15 ft (4.6 m) away from the wall where the speakers are installed, a second group of speakers should be installed on the facing wall with full overlap of the speaker coverage. See Exhibits S2.5 and S2.6 for a typical wall-mount coverage layout.

For both ECS and MNS systems, intelligibility of the voice message is one of the most important aspects of a well-designed system. But equally important is the development of the messages to be used during an emergency. Additional information on planning, design, and testing for speech intelligibility can be found in Chapter 18, Annex D, and Supplement 3.



**EXHIBIT S2.5** Wall-Mount Speaker Coverage Pattern (Viewed from Ceiling). (Source: NEMA Standards Publication SB 50-2008, *Emergency Communications Audio Intelligibility Applications Guide*, Figure 2-8)<sup>3</sup>



**EXHIBIT S2.6** Typical Wall-Mount Speaker Coverage Layouts (Source: NEMA Standards Publication SB 50-2008, *Emergency Communications Audio Intelligibility Applications Guide*, Figure 2-9)<sup>3</sup>

Research shows that the message is one of the most important factors in determining the effectiveness of a warning system<sup>6</sup>. The warning style is also crucial and should be specific, consistent, certain, clear, and accurate. All emergency communications systems used to communicate emergency directions or messages should ensure the information provided meets the following general criteria:

- Must be real time — should not rely solely on prerecorded messages, although they might provide limited value in some scenarios.
- Must be rich in content — actionable information. An informed population will respond more efficiently. The message must provide the following content:
  - Information on the hazard and danger
  - Guidance on what people should do
  - Description of the location of the risk or hazard
  - An idea of when they need to act
  - The name of the source of the warning (who is giving it, i.e., the identity of the authority)
- Must be intelligible — audibility is not the same as intelligibility; the message must not just be loud, it must be understood.

- Must be zonable — able to allow addressing only those population groups affected by the situation.
- Must be intrusive — must gain and retain the population's attention. Warning style is also crucial; it must be specific, consistent, certain, clear, and accurate.

The design of an ECS should also allow informed emergency managers to provide live and correct information to the population as a situation develops. For example, consider an incident where a vehicle strikes the wing of a fueled aircraft resulting in a significant fuel spill at a terminal gate. Just sounding the fire alarm with no instructions would result in passengers exiting to the tarmac. In this example, live messages to the occupants near the incident could instruct them to move away from the gate waiting area to a safe location.

Another example to consider would occur when the MNS initiates amber strobes (labeled ALERT) in an airport terminal and all monitors in the terminal change to display information on the nature of the emergency and the action needed by passengers. Will the passengers and staff know what the amber strobes mean? Will they know to look at the monitors for instructions? Will all the passengers read English?

In addition to the information about message use and content stated above, it becomes very important to repeat the messages and provide timely updates to avoid incorrect actions by the building occupants. Empirical research of natural disasters, technological events, terrorism, and more has developed some general guidance. This information will provide direction on the following generic issues:

- Deciding to warn (how, when, who, where)
- Writing the warning message(s) — content matters



- Disseminating the message (channels, frequency)
- Monitoring real-time response and updating
- Testing the warning systems

Once stakeholders have made decisions on the basic information needed in a message, they should refine the message to accommodate specific needs. Such needs include addressing unique community demographics — elderly, disabled, non-English speaking — and any unique geographical feature of the location where the message will be delivered. In addition, the stakeholders must consider how sudden or protracted events, large or even concurrent disasters, will change the message.

In order to ensure the maximum effectiveness of the messages, the recipients of the messages must receive training and education. In the case of a mass notification system, the training and education of the public becomes critically important. They must understand the nature of the messages they may receive and how the technology will deliver those messages in an emergency.

The system and its components must remain secure. The design of speakers and control equipment — hardware and software — must render them tamper-proof and hacker-proof. The ECS must include interoperability, so that it can complement other local and regional emergency response systems. And finally, the system must be survivable. Chapters 12 and 24 of the Code have specific levels of survivability for various emergency communications systems. The system must be able to withstand attack based on the planned ECS use. Also, the stakeholders must determine the use of the system by a rigorous risk analysis, following guidance provided by the Code and other applicable codes and standards.

Emergency communications systems — whether they consist of stand-alone in-building EVACS or MNS or include some other form of integrated ECS — provide a critical emergency capability that can save lives and property. Designers must keep in mind that for any design of an ECS, intelligibility, security, survivability, and the proper use of messaging all represent important aspects of a complete design.

## REFERENCES

### References Cited

1. NFPA 72F, *Standard for the Installation, Maintenance and Use of Emergency Voice/Alarm Communication Systems*, 1985 edition, NFPA, Quincy, MA.
2. McCarthy, B., *Sound Systems: Design and Optimization*, Elsevier, Ltd., London, 2008.
3. NEMA Standards Publication SB 50, *Emergency Communications Audio Intelligibility Applications*

*Guide*, National Electrical Manufacturers Association, Rosslyn, VA, 2008.

4. UL 1480, *Standard for Speakers for Fire Alarm, Emergency, and Commercial and Professional Use*, Underwriters Laboratories Inc., Northbrook, IL, 2003.
5. CAN/ULC-S541, *Speakers for Fire Alarm Systems, Including Accessories*, Underwriters Laboratories of Canada, Toronto, ON, 2007.
6. Gray, R., “Taking it From the Experts When Crafting Your Messages,” *Campus Safety Magazine*, May/June 2008.

### Selected Technical Bibliography

- Beranek, L. L., *Music, Acoustics & Architecture*, Wiley, New York, 1962.
- Beranek, L. L., *Concert Halls and Opera Houses: Music, Acoustics, and Architecture*, 2nd ed., Springer, New York, 2004.
- Cantu, L., “Monaural Hearing and Sound Localization,” Austin State University, Nacogdoches, TX, 1999.
- Cavanaugh, W. J., and Wilkes, J. A., *Architectural Acoustics Principles and Practice*, Wiley, New York, 1999.
- Davis, D., and Davis, C., *Sound System Engineering*, 2nd ed., H. W. Sams, Indianapolis, IN, 1987.
- Duda, R. O., *Sound Localization Research*, San Jose State University, San Jose, CA, 1998.
- Eargle, J., *Electroacoustical Reference Data*, Van Nostrand Reinhold, New York, 1994.
- Everest, F. A., *The Master Handbook of Acoustics*, 3rd ed., TAB Books, Blue Ridge Summit, PA, 1994.
- Giddings, P., *Audio System: Design and Installation*, H. W. Sams, Indianapolis, IN, 1990.
- Herlufsen, H., *Dual Channel FFT Analysis (Part 1)*, Technical Review, Advanced Techniques in Acoustical, Electrical and Mechanical Measurement, No. 1, Bruel & Kjaer, 1984.
- Martin, K. D., “A Computational Model of Spatial Hearing,” Massachusetts Institute of Technology, Cambridge, MA, 1994. McCarthy, B., *Meyer Sound Design Reference for Sound Reinforcement*, Meyer Sound Laboratories, 1998.
- “Message Mapping: How to Communicate During the Six Stages of a Crisis,” White Paper, 3n Global, 2008.
- NEMA Standards Publication SB 40-2008, *Communications Systems for Life Safety in Schools*, National Electrical Manufacturers Association, Rosslyn, VA, 2008.
- Sound System Design Reference Manual*, JBL Professional, 1999.
- Tremaine, H., *Audio Cyclopedia*, H. W. Sams, Indianapolis, IN, 1979.

Various, *Sound Reinforcement*, an anthology of articles on sound reinforcement from the *Journal of the Audio Engineering Society*, volumes 1 through 26. (Available from the AES)

### Papers

- Boner, C. P., and Boner, R. E., "The Gain of a Sound System," *J. Audio Engineering Society*, 1969;17(2).
- Haas, H., "The Influence of a Single Echo on the Audibility of Speech," *J. Audio Engineering Society*, 1972; 20(2).
- Hopkins, H. F., and Stryker, N. R., "A Proposed Loudness-Efficiency Rating for Loudspeakers and the Determination of System Power Requirements for Enclosures," *Proceedings of the IRE*, March 1948.
- Molloy, C. T., "Calculation of the Directivity Index for Various Types of Radiators," *J. Acoustical Society of America*, 1948;20:387–405.
- Peutz, V. M. A., "Articulation Loss of Consonants as a Criterion for Speech Transmission in a Room," *J. Audio Engineering Society*, 1971;19(11).
- Peutz, V. M. A., "Quasi-steady-state and Decaying Sound Fields," *Ingenieursblad*, 1973;42(18) (in Dutch).
- Various, "Loudspeaker Arrays — Design and Performance," *J. Audio Engineering Society*, 1990;38(4).