Voice Evacuation Systems

SYSTEM SENSOR®

Voice Evacuation Systems

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Section 1:

Introduction

The purpose of this guide is to provide information about voice alarm systems used in conjunction with fire alarm and emergency communication systems. Voice communications are extensively used to provide building occupant notification during emergencies. These messages contain vital safety information that must be clearly understood by the building occupants.

While the information in this guide is based on years of industry experience, it is intended to be used only as a guide. The requirements of applicable codes and standards, as well as directives of the authority having jurisdiction (AHJ) should be followed. In particular, the most current version of NFPA 72®, National Fire Alarm and Signaling Code®, now requires that emergency voice/alarm communications systems be intelligible and discusses methods for verifying intelligibility.

This guide provides general information on the concepts of intelligibility and the design of emergency voice/alarm communications systems. It is intended to provide a better understanding of the factors affecting the intelligibility of these systems in public spaces, in order to improve design of systems that meet the requirements for speech audibility and intelligibility in a cost-effective manner.

What is the driving factor for voice evacuation systems?

Intelligibility for mass notification systems had its inception with the Department of Defense Unified Facilities Criteria (UFC) document 4-021-01, the Design and O&M: Mass Notification Systems.

Voice evacuation systems are growing in popularity and, required in more areas. The events of September 11, 2001, were a main driver because they highlighted the need to communicate to a large group of individuals outside of a fire event. That is especially critical for buildings where you have to manage the evacuation of complex layouts, such as high-rise buildings or large areas of assembly.

Prior to these emergency events, voice systems would only be used periodically during fire drills. Due to the need for constant communication, design importance and voice message intelligibility are critical.

Although it's necessary to communicate with occupants regarding a multitude of emergencies, such as weather threats or toxic gases, a traditional evacuation tone may not be an ideal signal for non-fire events where seeking shelter is preferred to evacuation.

States are also moving to the latest editions of the National Fire Alarm Signaling Code and building codes, which require voice systems in certain occupancies.

Basic components should be reviewed in order to understand voice systems.

Section 2:

Basics of Sound

What is sound?

Sound is created by mechanical vibrations that displace air molecules to create repetitive changes in air pressure. The ear detects these changes in air pressure and perceives the magnitude as loudness and the frequency as pitch.

The standard ear can hear from a wide range of 20 Hz through 20,000 Hz.

Table 1.

Young children	up to 25Khz
13 years and up	up to 20KHz
Adults	up to 16KHz
Elderly adults	depends on lifetime noise exposure

Speech frequencies range from 500Hz to 4,000 Hz

How does sound travel?

The air molecules themselves don't move very far. They simply transfer pressure changes into sound waves. Sound waves move away from the sound source, such as a speaker, at a speed determined by the sound source. The more power the source emits, the wider the sound waves spread. In addition, the further out the sound waves travel from the source, the less intense they become.

Sound waves are regularly intercepted by other sound waves. Imagine two children jumping into the water at the same time: their waves overlap. Similarly, when a sound wave is intercepted by an outside force, a portion is reflected into a different direction. As a result, before installing a voice evacuation system, it's imperative to understand sound output and the way sound waves reflect and interact.

Section 3:

Measuring Sound Output

Sound Pressure Level (SPL)

SPL is the difference between the pressure produced by a sound wave and the ambient pressure at some point in space. Sometimes SPL is confused with loudness of sound, but in reality SPL is a contributing factor of loudness but not loudness itself. The SPL range for the human ear is from 0 to 120 decibels. Going louder, the human threshold of pain is 130 decibels. Eardrums rupture at 190 decibels.

Decibel

Audio levels are commonly used by engineers using “Decibels” (dB) to express ratios between levels, such as power, Volts, Amps, and Sound Pressure Levels (SPL). The decibel is not an absolute measure like Volts and Amps; rather, it is used to make comparisons between two numbers. The decibel is defined as the logarithm of two power levels, shown below in the equation as P1 and P0:

$$\text{Decibel} = 10 \log \frac{P1}{P0}$$

P0 is the reference power ($P0=1pW=10^{-12}W$) and P1 is the power level used for comparison. The logarithm is used in the decibel in order to make comparisons of power over a very wide range. This is very useful in audio applications as the ear responds logarithmically to changes in SPL.

When the decibel is used to express SPL, the reference sound pressure is 20×10^{-6} Newtons/m^2 which is the approximate hearing threshold for a normal listener. When using a dB meter to measure sound, the meter is performing the calculation between the received SPL and the reference SPL:

$$dB_{spl} = 20\log \frac{SPL}{20 \times 10^{-6}}$$

A-Weighted Scale

An A-weighting filter is sometimes used when measuring SPL with frequencies around 600- 7,000 Hz. Because speech frequencies range from 500 to 4,000 Hz, the filter ensures that the measured dB corresponds with perceived loudness. In other words, the filter desensitizes the sound level meter to the extreme high and low frequencies. These sound levels are still measured in decibels, but are symbolized by dBA.

B-Weighted Scale

A B-weighting scale is sometimes used when measuring SPL with frequencies around 300- 4,000 Hz.

C-Weighted Scale

An C-weighting filter is sometimes used when measuring SPL with frequencies around 70Hz-4,000 Hz.

A-weighted scale is referenced in most test and building standards but the C-weighted scale is useful for measuring the peaks of the noise levels.

Adding SPL from two speakers

If there is an application with two speakers in close proximity, the sound from the speakers is additive. However, the dB levels cannot simply be added together to determine the sound level. Instead, the SPLs have to be converted back to their actual powers and then added them to recalculate the level in dB. For example, one 80 dB speaker plus a second 80 dB speaker doesn’t equal 160 dB.

$$SP_1 = 80dB$$

$$SP_2 = 80dB$$

$$\text{Reference } P0=1pW=10^{-12}W$$

$$dB=10\log(P/P0)$$

$$80=10\log(P/10^{-12})$$

$$8=\log(P/10^{-12})$$

$$10\hat{}8=(P/10^{-12})$$

$$P=(10^{8})(10^{-12})=(10^{-4})=.0001W$$

$$2P=2*.0001W=.0002W$$

$$dB=10\log((.0002/10^{-12}))=83$$

Online tools for SPL addition can simplify this process. If the two dB levels are identical, then simply add 3 dB to either one. If the SPL from one speaker is more than 10 dB higher than the other, then simply use the higher SPL value.

dB Rules of Thumb

Sound pressure levels drop approximately 6 dB for every doubling of distance and increase by 3 dB for every doubling of power. For example, take a one watt speaker that provides 85 dBA at 10 feet. At two watts, the speaker will provide 88 dBA at 10 feet and 82 dBA at 20 feet. This rule of thumb is important to remember when determining whether you need fewer high powered centralized speakers or more low-powered dispersed speakers.

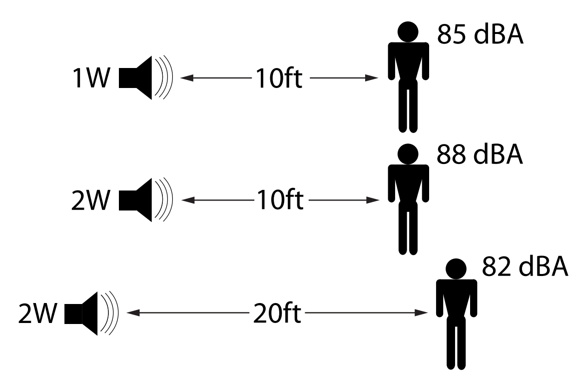

Figure 1. dB Rules of Thumb

Section 4:
Basics of Speaker Operation

Cone Materials

The cone, the part of the speaker that physically moves the air molecules, comes in a variety of materials, including paper, polypropylene, and carbon fiber.

Paper is the conventional material for speaker cones because it is easy to form into a variety of shapes. However, the paper must be chemically coated to adjust to changes in humidity and temperature. As humidity increases, the percentage of moisture within the paper increases. This leads to changes in cone mass and other parameters. Despite this, a well engineered paper cone can still deliver frequency response as smooth as any high technology material.

High Impedance (70.7 Volt/25 Volt) Distributed Line Systems

Impedance, expressed in ohms, is the the mechanism that impedes current flow.

In order to make large sound systems cost effective and easy to design, constant-voltage systems were developed. Direct drive, low voltage speaker systems would simply not be practical over long wire distances because of the voltage drop. As a result, a system was developed that produced near constant voltage to all of the speakers in the system.

Constant voltage fire alarm voice evacuation speaker systems in the United States require 70.7 volt or 25 volt, also known as 70 volt and 25 volt systems. These systems not only provide a safe, efficient way to connect many loudspeakers to one amplifier and make impedance-matching less complex, but they also ensure optimum volume, eliminate wasted power or stress to the amplifier and speakers, and help with uneven sound distributions.

In the past, 70V systems were very popular and more commonly used because they allowed longer wire runs. With electrical licensing changes, the 70V systems fell under high-voltage certifications and many low voltage fire alarm contractors switched to 25 volt systems.

25 volt systems provide other advantages. They don't require conduit or tubes for electrical wires and they are exempt from many local safety codes. Due to this additional safety, almost all educational facilities require the 25 volt systems as a standard. It's important to note that local codes may take precedence and require conduit tubing above and beyond the National Fire Alarm Code.

Most fire alarm speakers support both voltages, so whether the install is 70 volt or 25 volt system, make sure the speakers have dual voltage transformers with primary power taps. This will allow you to stock and use one product for both applications.

Section 5:
Basics of Voice Evacuation System Amplifiers

Voice evacuation system amplifiers, also known as voice evacuation panels, are a key component of fire alarm/emergency communications systems because they play previously recorded or live messages for emergency communications. To ensure they are operational, standard amplifier features include indicator messages for power, system trouble, message generator trouble, microphone trouble, record/playback, status of speaker zones, battery trouble, speaker circuit trouble, and other features.

Other standard amplifier features are field-adjustable voltage (25 or 70.7 volts); built-in alert tone generators with steady, 520 Hz square wave, slow whoop, high/low or chime capabilities; field-selectable tones; speaker zone control; independently field-programmable input circuits; power-limited outputs; auxiliary power outputs that provide local power for addressable control modules; and compatibility with fire alarm control panels.

Newer digital voice systems provide the ability to create custom prerecorded tones or messages. They can also distribute messages across multiple-channels.

Section 6:
Laws, Codes and Standards Relevant to Voice Evacuation Systems

Accessibility Guidelines

The Americans with Disabilities Act Accessibility Guidelines (ADAAG) lists the technical requirements for accessibility to buildings and facilities by individuals with disabilities. While ADAAG does not go into specifics about voice evacuation systems, they do provide guidance for audible alarms that pertains to the voice systems. The principle standards relating to alarms can be found within the appendix A4.28.2 Accessible Elements and Spaces: Scope and Technical Requirements.

It is important to note that the 2010 edition of ADA standards has been harmonized with the 2002 edition of NFPA 72.

Anechoic vs. Reverberant Chamber

While UL and ULC product standards have many similarities, they also have some important differences. One of the differences is the kind of sound room used when measuring sound outputs of audible devices. UL uses a reverberant room for their SPL measurements while ULC uses an anechoic room. UL will use an anechoic room for frequency response and harmonic testing. The rooms used by each facility are different, but both are effective in the sound output testing of audible devices.

UL's reverberant chamber is designed so that radiated sound is reflected in all directions to a point where it is equal throughout the space. This results in an averaged sound pressure readings.

ULC's anechoic chamber is designed to completely absorb reflections of sound. In this room, the placement and distance of measuring the device is important. Measurements per this method are taken directly in front of the unit where typically the peak sound output occurs.

In the real world, rooms are somewhere between anechoic and reverberant chambers depending on materials and furnishings within the environment. Refer to Section 7 for how these ratings are used for designing a voice system.

International Building Code & International Fire Code

The International Building Code (IBC) and International Fire Code (IFC) were created by the International Code Council (ICC) with the goal of prompting all areas of the US to comply with one set of standards. The purpose of the IBC and IFC in terms of fire safety is to protect life and property from fire and other hazards attributed to the built environment and to provide safety to fire fighters and emergency responders during emergency operations.

The IBC and IFC are the most adopted and enforced model codes in the United States. The IBC and IFC mandate the installation of in-building fire alarm EVAC systems in the following occupancies.
- Assembly occupancies with an occupant load greater than 1,000
- K-12 schools having an occupant load greater than 100
- Special amusement buildings
- High-rise buildings
- Covered mall buildings greater than 50,000 square feet in area and open mall buildings greater than 50,000 square feet within the established perimeter line

NFPA 1, Fire Code is published by the National Fire Protection Association (NFPA). The purpose of the Code is to establish a reasonable level of fire and life safety and property protection from the hazards created by fire, explosion, and dangerous conditions. NFPA 1 mandates the installation of in-building fire alarm EVAC systems in the following occupancies.
- Assembly occupancies with an occupant load greater than 300
- High-rise buildings
- K-12 schools having an occupant load great than 100

NFPA 101, Life Safety Code is published by the National Fire Protection Association (NFPA). The purpose of the Code specifies the minimum design, operation, and maintenance requirements of buildings to ensure safety to occupants from fires and similar emergencies.
NFPA 101 mandates the installation of in-building fire alarm EVAC systems in the following occupancies.
- Assembly occupancies with an occupant load greater than 300
- High-rise buildings
- K-12 schools having an occupant load great than 100

NFPA 72®, The National Fire Alarm and Signaling Code
NFPA 72 first addressed emergency voice/alarm communication in 1996, but it didn't introduce the term "voice intelligibility" until the 1999 edition when they included it in the Annex material.

In the 2010 edition, and subsequent editions, of NFPA 72, Chapter 18 under general requirements states that audible notification appliances used for ALERT or evacuation signal tones need to meet the audibility requirements referenced in 18.4.4 (Public Mode), 18.4.5 (Private Mode), 18.4.6 (Sleeping Areas) or 18.4.7 (Narrow Band Tone Signaling for Exceeding Masked Thresholds) as applicable.

Voice messages shall NOT be required to meet the audibility requirements of 18.4.4 (Public Mode), 18.4.5 (Private Mode), 18.4.6 (Sleeping Areas) or 18.4.7 (Narrow Band Tone Signaling for Exceeding Masked Thresholds) but shall meet the intelligibility requirements of 18.4.11 where voice intelligibility is required.

Audibility Requirements Per NFPA 72

Public mode:
Audible public mode signals must have a sound level of at least 15 dB above the average ambient sound level or 5 dB above the maximum sound level, having duration of at least 60 seconds, whichever is greater. Measurements must be taken with an A-weighted scale (dBA) at 5 feet above the floor in the area required to be served by the system using the A-weighted scale (dBA) See 18.4.4.1.

Private mode:
Audible private mode signals must have a sound level of at least 10 dB above the average ambient sound level or 5 dB above the maximum sound level for at least 60 seconds, whichever is greater. Measurements must be taken with an A-weighted scale (dBA) at 5 feet above the floor in occupied areas.

Sleeping areas:
Audible signals must have a sound level of at least 15 dB above the average ambient sound level, or 5 dB above the maximum sound level for at least 60 seconds, or a sound level of at least 75 dB, whichever is greater. Measurements must be taken with an A-weighted scale (dBA) at pillow level in occupied areas.

If any barrier, such as a door, curtain, or retractable partition, is located between the notification appliance and the pillow, then the sound pressure level shall be measured with the barrier placed between the appliance and the pillow.

The introduction of the low frequency tone was new to the 2010 and subsequent editions of NFPA 72, for the sleeping area audibility requirements.

Effective January 1, 2014, audible appliances provided for the sleeping areas to awaken occupants shall produce a low frequency alarm signal that complies with the following:

(1) The alarm signal shall be a square wave or provide equivalent awakening ability.
(2) The wave shall have a fundamental frequency of 520 Hz ± 10 percent.

For more information, refer to the Low Frequency Application guide.

Narrow band signaling
Narrow band signaling is an acceptable alternative method allowed by NFPA 72 for ensuring the audibility of voice evacuation systems. It is primarily used in applications that have a high ambient noise level, such as large factories where meeting the 15 dB requirement in the code is not practical. Narrow band signaling is based on the principle that for a signal to be audible, it need only exceed the background noise in a small frequency band. The 15 dB above ambient requirement in the code sometimes results in systems that are over designed (louder than necessary).

The narrow band signaling method is implemented by first performing an analysis of the ambient noise in the area that will be covered by the voice evacuation system. The amplitude of the noise across the audible spectrum needs to be determined. Once the amplitude is known, a system designer can select a frequency for an alarm tone that exceeds the noise only in a particular one or 1/3 octave band.

While this method is sound from an engineering standpoint, it requires much greater knowledge on the part of system designers and is not yet widely used because few fire alarm systems support this type of design.

ANSI/UL 1480 and CAN/ULC-S541

Speakers for fire alarm use are listed to the Underwriters Laboratories product standards. Testing of the speaker by the regulatory agencies ensures the product meets design and performance requirements of these standards. The UL product standard for speakers is ANSI/UL 1480 and the ULC product standard is CAN/ULC-S541.

Performance is typically evaluated over the frequency range of 400-4000 Hz. While speakers will operate beyond these limits, the test standards review only the performance of the speaker within this bandwidth. Manufacturers can request testing be conducted over a wider frequency range; however, this may result in lower sound ratings.

It should be noted that the testing labs measure performance using a band limited pink noise signal. This signal produces equal amounts of power to each octave. When conducting measurements in the field as part of a system performance check, the signal used may produce different results due to many factors.

Section 7:
Designing for Intelligibility

Definition
In the context of fire alarm voice evacuation systems, the only definition of intelligibility that matters is the one in NFPA 72. Intelligible is defined as being capable of being understood; comprehensible; clear. It defines intelligibility as a voice communication of having quality or condition of being understood comprehensible and clear. In general the message should be distinguishable and understandable.

The Department of Defense, UFC 4-021-01 also refers to the definition of intelligibility based on NFPA 72, National Fire Alarm and Signaling Code.

How to Layout Voice System

Acoustically Distinguishable Space (ADS)
An important term added to NFPA 72: 2010 edition was Acoustically Distinguishable Space (ADS) now in 18.4.11. The term represents notification zones, or subdivision thereof, that might be enclosed or otherwise physically defined within a given space, or that may be distinguished from other spaces because of different acoustical, environmental, or use characteristics such as reverberation time and ambient sound pressure level.

When designing emergency communication systems that will be required to comply with intelligibility requirements, it is important to the ADSs (Acoustically Distinguishable Spaces) be agreed upon at the beginning of the project.

Chapter 18 of NFPA 72 covers all types of notification appliances that are connected to a protected premises fire alarm control unit. Chapter 18 is where voice intelligibly requirements are first referenced.

- Section 18.4.11 specifies that voice intelligibility is ONLY required in ADSs that are required to produce intelligible voice messages.

- Section 18.4.11.1 requires the system designer to identify all the ADS during the planning of an ECS.

- Section 18.4.11.2 requires the system designer to determine which spaces, if any, will require intelligible voice communications.

In addition, an agreement should be made whether intelligibility will be measured and how. Audibility requirements must be met in all situations.

Factors that are controllable by a voice evacuation system designer

Signal-to-noise ratio
Signal-to-noise ratios determine how much louder a voice message has to be than the normal ambient noise levels in a space. The higher the ratio the greater the intelligibility. Factors that can affect the signal-to-noise ratio are the type of speakers being used, the spacing between the speakers, the tap setting of the speakers (how loud), as well as the ambient noise levels.

Speaker frequency response
As stated earlier, the frequency range of the human ear is approximately 20 Hz to 20,000 Hz (see Basics of Sound). A speaker's frequency response indicates how much of that range a speaker can reproduce voice message. The closer the speaker can match the original recording, the more intelligible and natural the output will sound.

Ideally, voice evacuation speakers should have a wide frequency response. The wider the frequency response of a speaker the better it is at reproducing the signal introduced to the system, which provides a better opportunity to ensure the message is understood. The frequency response should be as flat as possible; that is, the response should not vary considerably at the low and high ends in order to reproduce the most intelligible sound.

The frequency response range required by UL and ULC for fire alarm systems is 400 – 4 KHz. UL will allow for wider frequencies but this has been a standard requirement.

Total harmonic distortion
Total harmonic distortion (THD) is a contributing key factor in intelligibility. Audio signals suffer some distortion as they pass through electronic circuits. This distortion can be introduced by various components in the voice evacuation system and the effect is cumulative. Systems designed with low harmonic distortion tend to provide voice messages that are more intelligible than those that do not. The key is to minimize the % THD so that the output more closely matches the source signal.

Among other factors, distortion can be caused by damaged speakers, overloaded amplifiers vs. available power, speaker installation, incorrect wire size, and message generators or recordings

The following information is needed to meet NFPA requirements:

- The average ambient background noise level of the area

- Room characteristics, e.g., length, width, and height of the ceiling and reflectivity of the surfaces in the room

- The coverage angle or polar plot of the speaker

In order to determine the average noise level in an area, it must be measured using a sound pressure level meter using the A-weighted scale. When the measurement is taken, the technician should replicate the conditions that will likely be in place when the space is occupied. For example, air handling units must be turned on, and ambient noise levels should be replicated. If the conditions cannot be replicated, then a measurement should be taken in a similar building that is occupied. Within the Annex of NFPA 72, there is reference information on average ambient sound levels per given location. See Table 2 as a reference.

Table 2- Average Ambient Sound Levels

Location	Average Ambient Sound Level (dBA)
Business Occupancies	54
Educational Occupancies	45
Industrial Occupancies	88
Institutional Occupancies	50
Mercantile Occupancies	40
Mechanical Rooms	91
Piers and Water Surrounded Structures	40
Places of Assembly	60
Residential Occupancies	35
Storage Occupancies	30
Thoroughfares, High-Density Urban	70
Thoroughfares, Medium-Density Urban	55
Thoroughfares, Rural and Suburban	40
Tower Occupancies	35
Underground Structures and Windowless Buildings	40
Vehicles and Vessels	50

The system designer will also need information on the area that will require speakers. Ceiling height and the type of wall and floor coverings are key factors in determining density of coverage. Hard surfaces will be more reflective, and more speakers at lower tap settings will be required in order to minimize reverberation and increase intelligibility.

It may also be important that the designer work with the architect or interior designer to determine the best placement of devices and to understand what may be mounted on the wall or ceiling.

Speaker Placement
Sound system designers are often heard saying, “put the sound where people are and do not put sound where people are not.” This usually implies locating speakers toward the center of the room, away from walls and other hard surfaces. When possible, aim speakers toward soft surfaces such as rugs or upholstered furniture. These soft surfaces absorb direct sound coming from the speaker, preventing the sound from scattering throughout the room.

The coverage angle of the speaker is perhaps the most important element of designing a system with good intelligibility. The coverage angle is defined as the angle at which the sound pressure level from a speaker drops to 6 dB below its on axis reading (for a given frequency).

For any given center-to-center speaker spacing, the coverage angle will determine the amount of variation in the sound level throughout an area. A polar plot is simply another way of representing very similar information. Typically, the coverage angle or polar plot is most useful for voice intelligibility purposes when measured at 2 kHz, although other frequencies are sometimes provided.

In a voice evacuation system, the most cost-effective method for spacing speakers will likely be using a coverage pattern known as edge-to-edge. This pattern spaces speakers so that the point at which the SPL of one speaker drops to 6 dB below its on-axis reading is the same point as the 6 dB down point on the next speaker. That is, there is effectively no overlap in the coverage of the various speakers in the system except at very low levels.

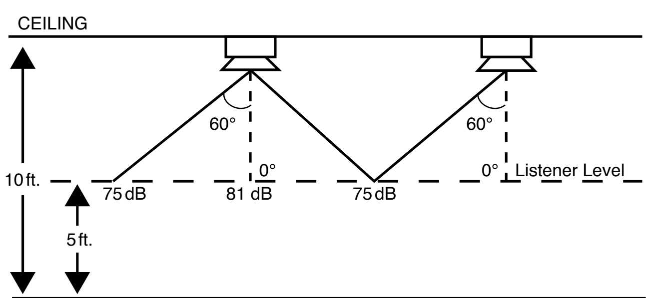

Figure 2.

Polar plots show where the speaker sound pressure level drops by 6 dB in all directions from the speaker. What is needed for a design, however, is the projection of that coverage onto a flat plane 5 feet above the floor (where NFPA 72 requires the sound to be measured). Tables are available in sound engineering handbooks that will assist the system designer in converting polar coverage angle to listening plane coverage angle. There are also software design programs that include the speaker manufacturer polar plots that help design systems for intelligibility.

Voltage drop on speaker circuits
In a voice evacuation system, the tap setting of a speaker generally equates to the sound pressure level that speaker will produce. If the voltage at the speaker is lowered due to the impedance of the speaker wires, the system will not be as loud. How much of a factor the wire in a system becomes is a function of the size (gauge) and length of the wire. The length of the wire is much less a factor in high impedance systems, like the 70.7 or 25 V RMS amplifiers used in fire alarm voice evacuation.

The first step in determining wire length for a particular amplifier is to decide how much loss can be tolerated. High end audio systems will typically specify less than a 0.5 dB power loss due to the speaker cables. In fire alarm systems, where the frequency response requirements are less stringent, a 1.5 dB power loss is often acceptable. This is a determination that the system designer will need to make based on the overall project objectives.

Since the distance from the amplifier to the speakers is fixed, the only variable that can be changed is the gauge of the wire. A lower gauge means the wire diameter is larger and the resistance is lower. This means that a longer distance can be traversed from the amplifier to the speaker.
The maximum allowed wire length is the farthest distance that a pair of wires can extend from the amplifier to the last speaker on the notification appliance circuit without losing more than the allowable dB of the signal.

The following information will be needed:
- The resistance/1000 ft of wire (refer to NFPA 70, NEC, Chapter 9, Table 8)
- Allowable wattage of amplifier
- Amount of speakers and tap settings of each device

With this available information you can utilize many free online tools to determine maximum wire length of voice system.

Factors that are not controllable by a system designer

- Furnishings and decorations
- Building occupant activities
- Talker ability - accents, dialects, diction, frequency of voice, etc.
- Listener ability - sensitivity of listener’s hearing

Room acoustics

Reverberation is one of the most important contributors to reduced intelligibility, and is the result of sound being reflected off floors, walls, ceilings, and other surfaces. When a message is broadcast over a speaker system, the listener hears a combination of the direct sound from the speaker plus the reflected or delayed sound from the reverberation. Reverberation should not be confused with echoes, which is a series of sounds caused by reflections of sound waves off surfaces back to the listener.

The reverberation of a room is dependent on its dimension, construction, and materials and objects within the room, including the occupant load. People and furnishings are good absorbers.

Typically, excessive reverberation in the range of 500 to 4,000 Hz will have a negative effect on the STI measurement.

Very hard surfaces, such as glass or marble, have a low absorption coefficient. This indicates that most of the energy is being reflected back into the space.

Another concern is having speakers on two separate lines that may be in the same notification zone. If the speakers are not at the same settings or same timing, they can introduce reverberation that will impact the intelligibility of the area.

Countering the effects of reverberation

Reverberation usually gets worse if the speakers are louder than necessary. It is recommended to use more speakers at lower tap settings. Depending on the room design, the addition of drapes, wall hangings, carpeting, or specifically designed diffusers can absorb sound and reduce the amount of reverberation.

Section 8

Testing for Intelligibility

Measurement Methods

Voice intelligibility is inherently a subjective system characteristic. A message that may be clear to one person may not be clear to another. In the past, intelligibility was measured using specially trained groups of listeners. With the addition of voice intelligibility into the National Fire Alarm and Signaling Code, there has been greater emphasis on devising an objective and reliable method for measuring intelligibility.

There are some rules of thumb that may be helpful in achieving audibility and intelligibility. In apartment buildings and hotels, there should be no more than one door between an occupant and a speaker. The average attenuation of a door is roughly 25 dB. As a general rule, a speaker must be placed in every bedroom (to assure 70 or 75 dB at the head of the bed) and on every level to assure 10 dB above ambient in residential occupancies. Reference books are available with further information on the sound attenuation provided by various materials.

Intelligibility Measurement Methods:

1) Subject Based- Use of human subjects to assess how speech will be understood and simulate what it may sound like during a real event.
2) Quantitative- Use of an instrument or tool that will provide speech intelligibility score.

Subject-based test methods can gauge how much of the spoken information is correctly understood by a person or a group of individuals. Results of speech intelligibility are usually described as predictions but documented as measurements.

Quantitive Method Tips and Tricks

Scales

Speech Transmission Index (STI) and Speech Transmission Index for Public Address (STIPA), which is a modified version of STI, is special audio signal played over the emergency communications systems being tested and is the most commonly used.

Instruments used to measure STI or STIPA use a special protocol consisting of signals in seven octave bands.

These signals have been standardized in IEC 60268. Unfortunately there has not been standardization for signal testing so it is best to follow the recommended practices by the measurement equipment.

Although the STIPA signals sound similar, the speed or gain can be adjusted depending on the test equipment instrument.

Talk Box

This is an instrument that is sometimes specified in intelligibility test requirements. It is an acoustical signal generator. It performs the complete end to end evaluation of the speech intelligibility, STIPA, from the talker(s) microphone to the listener's ear.

Testing Methods: When and Where

Intelligibility is important everywhere but is not always achievable in every location.

Some locations with extremely high ambient levels -- such as a factory with ambient noise levels over 90dB -- will prevent any voice message from being heard.

In situations like this, alternative notification appliances (such as strobes) should be used. It's also an option to use a system that would turn off the equipment and bring ambient noise levels to a reasonable level during an event.

There are also areas in the building where the probability of occupants is limited. Examples are janitor closets or storage closets, where people are not intended to be for long periods of time.

It is important to assess every area and discuss with your AHJ which areas will or will not be required to meet intelligibility.

Use of Intelligibility Meters

Test Methods

Annex D in the 2010 and subsequent edition of NFPA 72 provides recommendations for testing of intelligibility of voice systems.

An agreement should be made whether intelligibility testing will be conducted using a microphone with a live message or a pre-recorded message.

Testing a system that includes a microphone

Microphones used in voice alarm systems may not have studio-grade fidelity, but they are nearly all 100% intelligible and have passed testing to ensure product performance by nationally recognized testing labs.

Occasionally, microphones may be cause for concern in intelligibility testing because users are unfamiliar with their use. If the talker is too far away, the intelligibility may be diminished because the signal drops below the ambient noise within the given space. If the microphone user shouts at a very close level, the microphone element or some other part of the sound system may become distorted.

If the microphone is part of the test, then an apparatus is needed to simulate the talker. This apparatus consists of a loudspeaker whose on-axis response, when excited by the standard artificial speech signal, matches that of an average talker. These levels are referenced in IEC 60268-16 and ISO 9921-1. With this apparatus, a wide range of talker conditions can be simulated, including different voice types and different user distances from the microphone.

The recommended method is using a pre-recorded message played through the speaker system via the panel or amplifier.

The intelligibility measurements should be taken where a person would typically be,and the measurement should be taken where they do their normal activities. For example, in an office environment the measurement should be taken by the desk area. If it is a sleeping room, then the test measurement should be taken near the pillow.

Measurements should not be made near the floor, ceiling, or corners of a room because it's unlikely a person would position themselves there.

Direct injection method for test signal

With this method, the STI or STIPA signal is driven directly into the control unit or amplifier. The system should be calibrated using this signal and a pre-recorded message should be used for testing.

Calibrating Signal Source

This will require the use of the STI or STIPA test signals played into the microphone using the talk box. The talk box should be calibrated per manufacturer's instructions before calibrating the signal source and be set up per the manufacturers' recommendation.

There are two methods for calibrating the STI or STIPA.

Method 1

The intent of this method is to set the volume of the input test signal to be the same as the pre-recorded message. Two people will be needed to perform this test setup. One person needs to be at the talk box and the second person needs to be taking the intelligibility meter measurements.

1. The analyzer needs to be set to measure the SPL using the A-weighted fast scale.

2. Activate the pre-recorded message from the Emergency Communication System.

3. Record the highest dB reading using the systems procedures.

4. Do not move the analyzer from the test location.

5. Turn off the pre-recorded voice message.

6. Place the microphone on the Emergency Communication System at a distance from the talk box as recommended by the microphone or ECS manufacturer.

7. Start the talk box STI or STIPA test signal

8. Adjust the talk box sound level until the field measurement of the test signal is ±3dB of the level generated when the pre-recorded voice message was played and measured. This setting should NOT change for the remainder of the testing.

Method 2

1. The analyzer needs to be set to measure the SPL using the A-weighted fast scale.

2. Start the talk box STI or STIPA test signal and hold the meter at a distance of 39.4 inches (1 m) on axis from the talk box or audio source.

3. Set the talk box volume so that the meter registers 65 dBA at a distance of 39.4 in (1m). This setting should not change for the remainder of the testing.

4. The distance from the microphone to the talk box should be documented so that future tests can be set up consistently.

5. Place the microphone of the ECS at a distance from the talk box as recommended by the microphone or ECS manufacturer. If a manufacturer does not reference a distance, a rule of thumb is 10".

The purpose of this test is once again to set a baseline capability of the system and its environment to support intelligible communications.

STI/STIPA Test Procedure

When testing is being performed, the test should be done as quietly as possible. Impulse sounds, such as tapping of the microphone or a door slamming, will be picked up by the meter and an error message may occur. It is best in these situations to start over and not include that reading into the average.

The system under test should be tested on secondary power for a minimum of 15 minutes and then on primary power the remainder of the testing.

An upfront agreement is also needed on whether the testing will be done in a fully occupied or unoccupied space.

Occupied Testing

Testing should be done during a period of time when the area is occupied and is reasonably close to having maximum background noise. It is highly recommended that the building owner inform the occupants that a test procedure is taking place.

1. Ensure the calibration of the signal source.

2. Take the STI predictions within each of the ADSs defined.

3. Record the results.

Unoccupied Testing

This is the preferred method because it does not disrupt building occupants or business operations. It also might be necessary if the emergency communication system needs to be commissioned before occupancy can be granted.

This test method requires three different measurements at each of the measurement points, typically made during two site visits. Measure the unoccupied ambient sound pressure level at each measurement point in each ADS.

1. Start the STI or STIPA test signal.

2. Take the STI predictions within each of the ADSs defined.

3. Record your results.

Acceptable Criteria

The intelligibility of emergency communication systems is considered acceptable if at least 90% of the test locations within the ADS have a predicted STI of no less than 0.45 and an average STI of no less than 0.50.

Speech intelligibility is not a physical quantity like distance, voltage, or current. It is a benchmark of the degree of acceptance of which speech can be understood, and is therefore a complex phenomenon affected by many variables.

If the value for one reading is less than 0.50 STI, additional readings could be taken at the same location. As with the SPL readings, intelligibility readings at any point will vary.

Some ADSs may require multiple test locations due to their large size. However, even in small ADSs where one location is permitted, a designer might intend that multiple readings be taken. When there are multiple locations, the pass requirement is that at least 90% of the test locations have value not less than 0.45 STI and that all locations average to 0.50 STI or greater.

Measuring Intelligibility (STI)

Acceptability Criteria

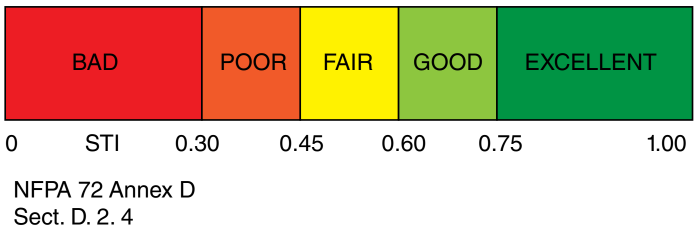

Figure 3.

Measurements should be made and recorded using two decimal places because the STIPA method for predicting the speech transmission index generally have a precision on the order of 0.02 to 0.03.

Averages can be calculated to three decimal points and rounded. The calculated average value should be rounded to the nearest .05 to reflect possible reading errors and the intent of the requirement.

Limitations of Test Methods

Control units, amplifiers, and speakers for fire alarm and emergency communication systems are designed to comply with UL 864, UL 1711, and UL 1480, accordingly and are only required to produce frequencies within the range of 400 to 4000 Hz.
Speech intelligibility using STI and STIPA includes octave band measurements that range from 125 Hz to 8000 Hz. STI results are highly dependent on the 500, 1K, 2K, and 4K octave bands, and to lesser extent to the 125 Hz, 250 Hz, and 8 KHz octave band. See Figure 4 Octave band contribution to Intelligibility.

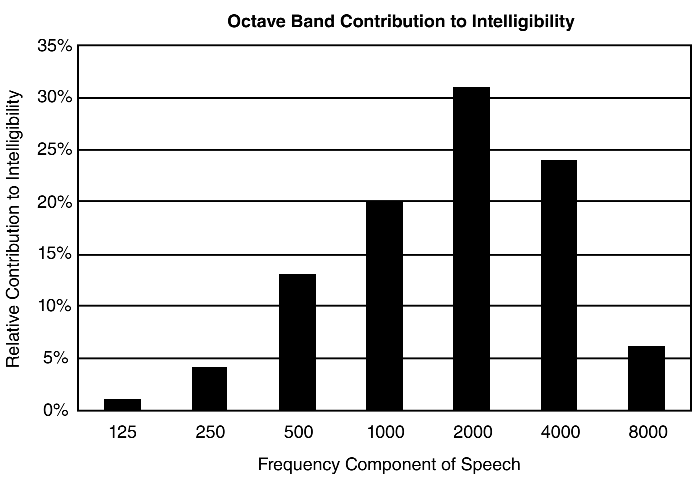

Figure 4.

While the wider frequencies will sound better and be more intelligible to a listener, it might not be necessary to meet the minimum intelligibility requirements.

Note: System Sensor does not approve, inspect, or certify any installations, procedure, equipment, or materials. In determining the acceptability of installations or procedures, equipment, or materials, the authority having jurisdiction may base acceptance on compliance with NFPA or other appropriate standards. The authority having jurisdiction may also refer to the listings or labeling practices of an organization concerned with product evaluations that is in a position to determine compliance with appropriate standards for current production of listed items. The information in this guide has been provided in an attempt to assist in making this decision and should in no way be constructed as a formal approval or certification.

Section 9

Glossary of Terms

Acoustically Distinguishable Space (ADS)- represents notification zones, or subdivision thereof, that might be an enclosed or otherwise physically defined within a given space, or that may be distinguished from other spaces because of different acoustical, environmental or use of characteristics such as reverberation time and ambient sound pressure level.

Americans with Disabilities Act Accessibility Guidelines (ADAAG) - lists the technical requirement for accessibility to buildings and facilities by individuals with disabilities.

Anechoic room - a room without reverberation.

Attenuation - Affects the propagation of sound waves in the air.

Cone (diaphragm) - part of speaker that physically moves the air molecules.

Current - flow of electricity through a circuit over a period of time; measured in amperes.

dBA - sound pressure level measurement with an A-weighted filter.

Decibels (dB) - logarithmic scale measuring the intensity of sounds (SPL).

Distributed line systems (70 volt or 25 volt) - provides a safe, efficient way to connect many loudspeakers to one amplifier; makes impedance-matching simpler; ensures optimum volume; eliminates wasted power, stress or damage to the amplifier and speakers; and reduces reverberant noise, distortion and uneven sound distribution.

Frequency - rate in which the sine wave completes one cycle.

Hertz (Hz) - unit of measurement for frequency

Impedance (Ohms) - the resistance to the flow of an electric current in a circuit measured in ohms.

Intelligibility - being capable of being understood.

International Building Code - code created by the ICC to protect life and property from fire and other hazards attributed to the built environment and to provide safety to fire fighters and emergency responders during emergency operations.

International Code Council Inc. (ICC) - produces a single set of model building and fire codes.

International Fire Code - code created by the ICC to protect life and property from fire and other hazards attributed to the built environment and to provide safety to fire fighters and emergency responders during emergency operations.

National Fire Protection Association (NFPA) - administers the development of and publishes codes, standards and other materials concerning all phases of fire safety.

NFPA 72 - defines requirements for signal initiation, transmission, notification, and annunciation, as well as the levels of performance and the reliability of various fire alarm systems.

Ohms - the unit of measurement of electrical resistance. The value of resistance through where a potential difference of one volt will maintain a current of one ampere.

Power (watts) - energy per unit time. For speakers, voltage in volts times current in amps.

Reverberant room - a room with echo used to measure the sound absorption of products.

Signal-to-noise ratio - compares how much louder a voice message is to the normal ambient noise levels in a given space.

Sound - changing air pressure over time.

Sound pressure level (SPL) - loudness of sound.

Sound waves - vibrations in the air.

Speech Transmission Index for Public Address(STIPA) - is the objective rating of speech intelligibility.

Talk box - an acoustical signal generator.

Total Harmonic Distortion (THD) - distortion suffered by audio signals as they pass through electronic circuits.

UL 1480 - standard for speakers for fire alarm and signaling systems, including accessories.

Voice evacuation system amplifiers (voice evacuation panels) - plays live or recorded messages for emergency communications.

Voice intelligibility - the clarity of a recorded voice message.

Volts - a unit of electrical pressure. One volt is the electrical pressure that will cause one ampere of current to flow through one ohm of resistance.

Watts - a unit of electrical power used to indicate the rate of energy produced or consumed by an electrical device. It is the current multiplied by voltage used by a device.

Secton 10

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