Speech Intelligibility

A 3M White Paper

Is Your Emergency Communication Systems (ECS) Effective?

Introduction

Clearly understanding a live or a recorded emergency communication system (or a mass notification system) during a fire or a threatening situation is essential for the safety of a facility's occupants.

What if you were in a 20-floor high-rise building and the ECS announced a chemical spill in the building? The communication system specifically advised the contaminated area was on the southside of the 7th floor and advised to evacuate the building by using the north stairwell. If this was not intelligible, or clearly communicated, then lives could be lost. Ensuring safety of individuals is a number one concern for building owners.

This white paper is intended as a primer to understand how speech intelligibility is measured and addresses the following: basic principles of sound and speech path, factors influencing the test, how and what to test when deploying Speech Transmission Index - Public Address (STI-PA) testing, measurement scales and results to consider, what the standards recommend, and plausible solutions to low test results.

Common terms

This paper addresses some commonly used industry terms and testing procedures as specified by the ISO 60268-16 (2011), ISO 7240-19 (2007), ANSI S3.5 (R2007), NFPA-72 code (2010), and the UFC 4-021-01; changed 2010.

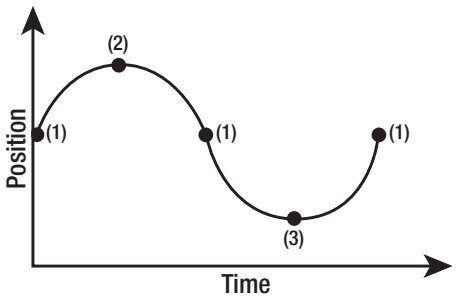

Figure 1: Sound Pressure Wave

This compression and rarefaction causes sound. The diagram above shows one sound wave cycle.

Sound waves

Understanding Sound: External background noise (or overall sound pressure level) can distract one's attention and interfere with verbal communication. Ultimately, background noise can mask (or hide) speech. Understanding what sound is and the range of sound the human ear detects is an important component of how speech intelligibility is measured.

When sound is transmitted through the air, it creates alternating positive and negative pressures (compressions/rarefactions). Imagine playing a chord on a guitar. As it is plucked, the string will move over time. As the string moves to position 2, it compresses the air molecules (see Figure 1). As it moves to the last position, it rarifies the air molecules.

Range of Speech: The human ear is capable of responding to frequencies ranging from approximately 20 Hz to 20 kHz. This range is also generally considered the range of speech.

Critical Elements of Speech: Speech encompasses two elements (or spectra). The first spectrum (or element of speech) are the sounds we hear, which is referred to as the sound path. This spectrum covers a wide range and detects the lower mid frequency ranges instead of the higher frequencies. The range is represented by seven octaves that have center bands ranging from 125 Hz to 8 kHz. The second element of speech is referred to as the modulation spectrum. The sound we hear in speech is not only composed of the sound path over the octave bands but, it is also composed of words. These words can be broken into syllables and phonemes. These phonemes are at a low modulating frequency and are called the modulation spectrum.

Speech Comprehension: Imagine sitting in a large, outdoor band shelter with the hum of car engines, distortion from the speakers, and ambient noise from the audience shouting and clapping around you. An announcement is broadcasted over the public announcement (PA)

system/emergency communication system and you strain to catch the intent of the message. The listener's speech comprehension is diminished by the ambient noise and the distortion of the system. So, how does one ensure that a message is clear and intelligible in all situations? The industry standard methodology is to measure the "intelligibility" of the system using a qualitative approach.

Speech Intelligibility (SI)

SI Testing: In essence, any noise which masks the talker-to-listener path is evaluated and a recommended measurement is computed at the end of an intelligibility test. Speech intelligibility testing is a method used to determine if an emergency communication system (ECS) (also called mass notification system, MNS) is clear, precise, and audible or intelligible. One type of quantitative test used to measure speech intelligibility is called Speech Transmission Index - Public Address (STI-PA).

National Fire Protection Assoication: NFPA-72

According to the NFPA-72 code (2010; sections 3.3.125, 3.3.126), Intelligible is identified as " The quality or condition of being intelligible. It is capable of being understood; comprehensible; clear, as stated by NFPA-72 code (2010)."

Factors Influencing Speech Intelligibility

Determine intelligibility of an ECS: People interpret and decipher speech even over background noise, also referred to as "signal-to-noise" ratio.

With the speech transmission index testing methodology there are a handful of factors that are accounted for during a study including:

- **"Signal-to noise ratio"** is the comparison (or ratio) of the intended sound level generated from a speaker to the background noise (or ambient noise) in the room. "The values of the signal-to noise ratio are limited to the range between +/- 15 dB," according to the ISO 60268-16 (2011) and ANSI S3.5 (2003-05) standards. For achieving Speech Intelligibility, the sound system should be between 10 to 15 dB over the ambient noise, as recommended by the NFPA-72 code (2010).
- **"Reverberation"** is the distribution of sound after the initial sound is removed or decayed with reflections and echoes from the walls, ceilings, hard surfaces to name just a few. These reflections may interfere with the understanding of the message and are a main concern when ensuring an emergency communication system is intelligible.
- **"Distortion"** is any unwanted sound due to an alteration in the signal. If there is a significant source of distortion, such as distortion from an amplifier or speakers, this will diminish the clarity of speech/message.

Measuring STI-PA

A test signal is played through an emergency communication system. The test signal is made up of seven octave band signals which encompass a combination of vowels and syllables from common speech. There are 14 modulating frequency tones that emulate your speech pattern. This is referred as the modulating transfer function (MTF) and is noted on the modulation screen of the 3M™ SoundPro/3M™ Verifier sound level meter.

With the STI-PA test signal enabled, the instrument computes the signal to noise ratio based on the impact of background noise, reverberation and distortion. A weighted average of the signal to noise ratio for each modulation frequency is calculated and adjusted for auditory masking and the threshold of hearing. This result is a value between zero and one, representing the estimated intelligibility of the system.

What Does the MTF Represent?: MTF values may indicate the impact of background noise, reverberation and distortion in that region of the spectrum. A high MTF value may indicate the listeners received the message with no distortions or interference. A low MTF may represent a considerable reduction of intelligibility from a combination of reverberation and/or masked noise.

Causes of STI-PA Reduction: From MTF values, you may assess the cause of reduction of an intelligibility test. If the study reveals constant MTF values, this may signify that the interference is primarily due to background noise. Decreasing MTF values may indicate that the primary cause is reverberation (such as an echo).

Setting Up A STI-PA Test

There are a couple key factors to consider when setting up a speech intelligibility test.

Figure 2: MNS

A look inside testing a Mass Notification System (MNS) and factors influencing a typical testing environment.

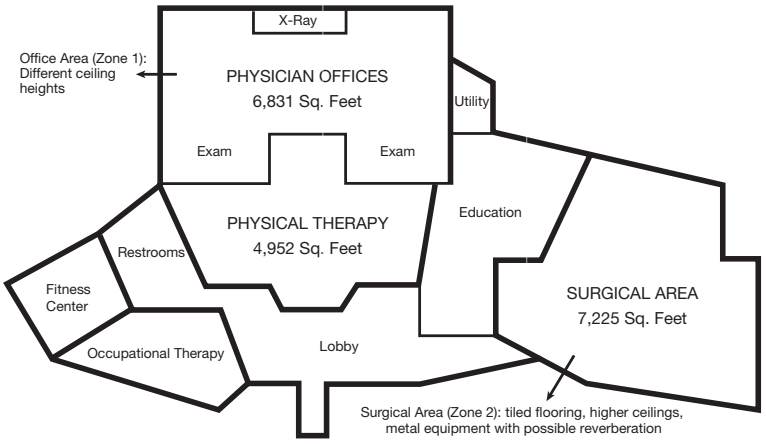

Figure 3: Acoustically distinguishable spaces
Generally, a building map is designed identifying the ADS to ensure intelligibility of the emergency communication system.

1st Factor: Room/Spaces

The first factor is to consider, "where do I measure speech intelligibility?" A university building or a commercial building can be broken into rooms or "acoustically distinguishable spaces (ADS)" as noted by the NFPA-72 (2010) code, with one or more alarm/communication points. The spaces are distinguished "from other spaces because of different acoustical, environmental, or acoustical characteristics, such as reverberation time and ambient SPL", as referenced from ISO 60268-16 (2011) and NFPA-72 code (2010, 2.3.1.1). In some situations, one room may have more than one alarm point or may have a change in ceiling height , according to NFPA-72 code (2010, D.2.3.1.7). In those instances, each section would be considered an ADS and each section would be tested.

2nd Factor: Building Map

After determining the ADS in your building, it is recommended to design a map of the key spaces to determine the intelligibility. In some instances, the use of additional speakers and system components may be needed to achieve intelligibility if the frequency and level of ambient SPL is different from one space to the next as suggested by the ISO 7240-19 (2007) and the NFPA-72 code (2010, D.2.3.1.8).

When to conduct a STI-PA Study?

Scenario 1

You are at a facility that will not be disrupted by playing the test signal through the ECS (or PA system) during the peak time or "normal" time of the day/night. In this scenario, you would set the instrument to STI-PA and select either STI - Speech Transmission Index scale or CIS - Common Intelligibility
Scale scale and run your study at your zone areas.

Scenario 2

In other situations, running a test tone through an ECS/PA system during business hours could be distracting and not feasible for your environment. In this situation, you would:

- **STEP 1:** Take sample background noise measurements during business hours using the 3M Quest Verifier or SoundPro instruments in the designated ADS. The instrument will save up to four "captured curves" and will store them in the "post processing" field of the STI-PA menu.
- **STEP 2:** Using the instrument select the appropriate captured curve you wish to apply while testing during non-business hours.
- **Note:** Since you selected a curve in step two, it will automatically factor in the results of the STI-PA results. If you wish to change the curve in different ADS (spaces), see step 2 and then proceed to step 3.
- **STEP 3:** Enable the test signal and run your speech intelligibility tests in the applicable ADS .

STI Scale or CIS Scale?

Both Speech Transmission Index Scale (STI) and Common Intelligibility Scale (CIS) are measurement testing methods that provide highly time efficient 15 second runtime results. According to the ISO 60268-16 (2011) and the NFPA-72 code (2010), these are both highly accurate, quantitative methodologies that may be used to test speech intelligibility.

STI: The STI-value is a weighted average of the response to the fluctuating modulation frequencies. The results are illustrated in Figure 4 below. STI is a measurement scale that indicates single value results in which **zero** correlates with **complete unintelligibility** and **one** equates to **perfect intelligibility.** Figure 4 is a guideline to understand the STI rating scale.

STI	0.00 - 0.30	0.30 - 0.45	0.45 - 0.60	0.60 - 0.75	0.75 - 1.00
Scale	Unacceptable	Poor	Fair	Good	Excellent

Figure 4: STI Scale, cited by ISO 60268-16 (2007)

CIS: Another method to report intelligibility results is to use the Common Intelligibility Scale (CIS). It was created to map all methods (i.e.,STI, percentage of articulation loss of consonants, word lists) to the same scale so that results could be compared.

CIS	0.00 - 0.48	0.48 - 0.65	0.65 - 0.78	0.78 - 0.88	0.88 - 1.00
Scale	Bad	Poor	Fair	Good	Excellent

Figure 5: CIS Scale,cited by Barnett, 1995, 1999.

Figure 6: 3M Quest's STI-PA Instrument with STI scale results display

Verifier or SoundPro SE/DL series with STI-PA option

Instrument displays "Excellent" rating on a STI scale with an 0.80 value. As indicated above on the graphical display, any STI value under 0.50 rating is considered "Poor"and not an acceptable intelligibility value; with a CIS scale, a reading of 0.70 or above is acceptable, according to NFPA 72 code (2010).

What do the codes say?

Currently in the international markets and the United States, there are four codes/standards that define speech intelligibility and also provide recommendations and methodologies to accurately test an emergency communication system. The following standards may reference each other for specific terms and/or calculation measurements.

ISO Standard: The International Organization for Standardization ISO 60268-16 (2011) recognizes and defines four methods to rate the quality of speech intelligibility, which include: RASTI, STI, STITEL, and STI-PA. These methods are used to rate the quality of speech when using a test signal "simulating the speech characteristics of a real talker, when sounded in a room or through a communication system," cited by ISO 60268-16 (2011, part 4.1).

NFPA 72 code: Of these four methods presented in the ISO 60268-16 (2011, Annex A and Annex B), the NFPA 72 code recommends using the STI method with the STI scale or the CIS scale to determine the intelligibility of an emergency communication system.

ANSI Standard: With the American National Standards Institute ANSI S.3.5 -1997 standard, Speech Intelligibility Index (SII) may be used to measure speech intelligibility by implementing the calculations, theory, and instructions with this alternative assessment.

DoD Code: The Department of Defense DoD Uniform Facilities Criteria (UFC 4-021-01; changed 2010) code is a detailed plan addressing compliance to the design, deployment, and annual testing of a mass notification system (MNS). The purpose of the MNS is to "provide real-time information and instructions to people in a building area or site" and is intended to protect the life of the occupants during an emergency situation with specific instructions for appropriate response and actions recommended by the UFC (4-021-01; changed 2010).

Obstacles: Low Test Results: If low scores are revealed after testing, what are some corrective actions that you can take to make your system intelligible?
A low STI or CIS value may indicate one of the following issues:

- Inordinate noise reverberation or echoes (see "A" below).
- Insufficient number of acoustical speakers or inadequate speaker coverage deployed uniformly in the building ADS (see "B" below).
- Insufficient speaker power (see "C" below).

(A). One solution for echoes and excessive reverberation is to add sound absorbing materials such as drapes, more furniture, or ceiling tiles. This will help deter the reverberation and perhaps lead you to better STI-PA results. Another solution is to move suspended speakers closer to the occupants (i.e., like in a stadium or a church) and then lower the volume on the speakers.

(B). Another possible solution to correct inadequate speaker coverage is to increase the number of speakers in the building's spaces or increase the power of the signal. Then, the results may either pass or fail depending on the situation. It is good to note that if there are changes in occupancy and ambient noise levels, a second test should be conducted in order to verify if the ECS/MNS is indeed intelligible and compliant.

(C). For insufficient speaker power, increasing the ECS/MNS audio power and ensuring the building has adequate speaker coverage in each space is a possible solution.

Figure 7: Up to code?

Emergency Evacuation
Ensuring your emergency communication system is intelligible.

Other Obstacles

Some new buildings or renovated buildings may be tested initially before the building is completed. A word of caution: one should realize that if all the furnishings and installation of the flooring (i.e., carpeting) is not completed prior to testing, the results may either pass or fail depending on the situation. When there are changes in occupancy and ambient noise levels, a second test should be conducted in order to verify if the ECS/MNS is indeed intelligible.

STI-PA testing guidelines

The following are the basic steps to perform a STI-PA test with the 3M Quest Verifier or the 3M SoundPro:

1. Calibrate the SoundPro or Verifier.
2. (Optional) Customize STI-PA setup options.
3. A level setup is conducted.
   - From a fixed-point, the technician measures the A-weighted SPL of ECS/MNS and adjusts the range as needed. The test signal volume should approximately match the ECS/MNS message volume. Adjust the test signal to match the LAS value as needed.
4. The test signal is played through the buildings voice system (PA system). (The test tone mp3 player is included with the STI-PA kit.)
5. The technician/sound tester positions himself/herself in the ADS (spaces/rooms).
   - It is recommended to design a map of the ADS to indicate where you will be taking your measurements.
   - Set measuring range appropriately.
6. STI-PA measurement is conducted. Press the Run/Pause key to start the study. After a 15 second countdown, either a STI or CIS level is displayed with a pass/fail message.
7. (Optional): To capture the background noise prior to STI-PA testing (typically when conducting the test after business hours), first "capture curves" (or background noise) and then apply this during the STI-PA measurement.
8. The technician/sound tester moves throughout the building and measures in all the ADS.
9. The tests are noted as pass/fail and are stored in the File System screen. These results are viewable in the 3M™ Detection Management Software DMS.

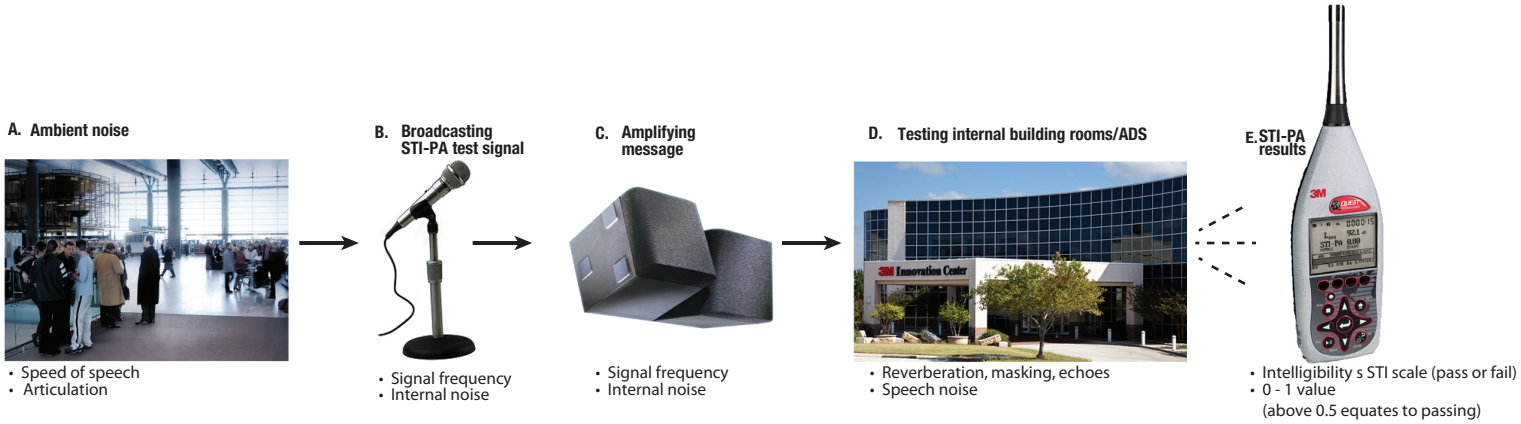

Figure 8: At a glance: Speech Path

The illustration above depicts obstacles that mask the quality of the speech path when conducting a STI-PA test. The first phase (A) addresses the presence of background noise in the building or ADS. The test signal is then broadcasted through the ECS (or PA system) via speakers (refer to B and C). Internal noise, such as HVAC systems, quality of speakers, or reverberation on concrete walls are factored in to determine the overall intelligibility of each space (refer to D and E).

Conclusion

The concept of the emergency communication systems (ECS) or mass notification system (MNS) was developed out of the inability to clearly communicate safety instructions to the occupants during the events of 9/11, which prompted the U.S. Department of Defense (DoD) and other regulatory agencies to create a set of criteria or codes which mandates the installation of an "intelligible" ECS/MNS systems worldwide. The intent of the white paper was to provide you with an overview of speech intelligibility testing and addressed the factors, obstacles, and standards/codes of speech intelligibility measurements. The next steps are to determine If STI-PA measurement is required, then selecting a method, a scale, and an acoustic instrument. In many situations, using an acoustic instrument is a practical method which may have the capability to store the data for further analysis and record keeping purposes.

PERTINENT WEBSITE LINKS

- Noise Pollution Clearing House http://www.nonoise.org
- Environmental Protection Agency http://www.epa.gov
- Occupational Safety & Health Administration http://www.osha.gov
- American National Conference of Government Industrial Hygienists http://acgih.org
- National Fire Protection Association http://www.nfpa.org
- International Electrotechnical Commission http://iec.ch
- International Association of Chiefs of Police http://www.theiacp.org
- The National Institute for Occupational Safety and Health (NIOSH) http://cdc.gov/niosh
- Mine Safety and Health Adminstration http:// msha.gov
- Department of Defense and UFC code http://www.wbdg.org/ccb/DOD/UFC/ufc_4_021_01.pdf

3M Quest Technologies

Products supporting: acoustics, dosimetry, and heat stress with 3M™ Detection Management Software for the detection instrumentation system solution.

Occupational Health & Environmental Safety Division
Quest Technologies, a 3M Company
1060 Corporate Center Drive
Oconomowoc, WI 53066
Customer Service: 1-262-567-9157
Toll Free: 1-800-245-0779
Fax: 1-262-567-4047
www.3M.com/detection
E-mail: 3Mdetectionmail@mmm.com

3M and SoundPro are trademarks of 3M Company, used under license in Canada.
Please recycle. Printed in USA.
© 2012 3M Company
All rights reserved.

70-0716-2512-6 Rev A 3/12

Quest Technologies, a 3M company, is a manufacturer of durable, reliable instrumentation and software systems that help monitor a variety of health and safety hazards, including noise, vibration, heat stress, indoor air quality and toxic/combustible gases. The 3M Quest brand of instrumentation is used by safety and industrial hygiene professionals to help comply with worker safety and environmental regulations and standards around the world. Quest Technologies, a 3M company, is part of the 3M Occupational Health & Environmental Safety Division, a global leader in respiratory, hearing, eye, head and fall protection, visibility and protective clothing, and detection products. To learn more, call us at 262-567-9157 or visit www.3M.com/detection.

If you have any questions concerning our technology, pricing, availability or would like to schedule a product demonstration, you may contact our customer service representatives at 800-245-0779 or e-mail us at 3mdetectionmail@mmm.com.