“What we‘ve got here……
is failure to communicate”.

A Discussion on the Intelligibility of Fire Alarm/Emergency Voice Communication Systems.

For those that thought this would be a dissertation on the film Cool Hand Luke - sorry.

In this article, we want to eliminate any “failure to communicate” and we want our Emergency Voice Communication System to provide intelligible audio output when required.

We’re hopefully going to provide enough information that when completed, you should have a greater knowledge of intelligibility and possibly be able to incorporate some of this knowledge into the systems you are working on.

By one definition: *“Intelligibility is the ability to communicate a message so that the message is understood*”; but to get the message understood, there is math, science and physics at work. We may touch on some of the science but this will not be a detailed documentary of what sound is.

This discussion is regarding Intelligibility. So, what is Intelligibility? Some of the industry’s definitions of Intelligibility are:

- *“a measure of the degree to which we understand spoken language”*
- *“a measure of effectiveness of understanding speech”*
- *“audible voice information that is distinguishable and understandable”*
- *“when a human being can clearly distinguish and understand human speech reproduced by a communication system”*
- *“Intelligibility is a measureable aspect of electronic voice transmission systems that indicates the degree that human listeners will be able to understand the voice messages transmitted through them”*
- *“Intelligibility – The capability of being understood or comprehended.”*

The one I like the best is*: "Intelligibility is a measureable aspect of electronic voice transmission systems that indicates the degree that human listeners will be able to understand the voice messages transmitted through them"* - no room for error here.

These are all excellent definitions, and all contain one common component: We need to make the listener <u>UNDERSTAND</u> the speaker. Essentially, we want to make sure that what is spoken or broadcast is clear, understood and cannot be misinterpreted.

But, before we discuss just exactly what Intelligibility is and how to possibly achieve it, let's have a brief history of how we got to be discussing Intelligibility for Fire Alarm Systems/EVCS.

The main goal of Fire Alarm Systems has been to notify the occupants of a building that there is imminent danger. Technology has advanced the rudimentary audible devices to the point where a critical message can be communicated to the people that may be in danger.

Remember when Fire Alarms alerted the population via bells? Most buildings just had bells and most people understood that if the bells went off it indicated a fire and they had to get out. Over the years, technology and people got smarter. Bells, although still acceptable, gave way to electronic horns with electronic tones and the like.

Eventually, voice systems improved in quality, and became more cost effective and were an option when upgrading or where systems were to be retrofit. Tones became messages, digitized recordings that are stored on chips are now standard practice and more and more messages can be stored in a smaller space.

Incidentally, do you think anyone has ever ignored the Fire Alarm bells saying "ah, it's probably a false alarm" or "they're just testing"? Verbal instructions are not always ignored so readily and a change in the critical instructions can be communicated to the occupants in real time.

It is because these systems can allow communication to the masses that we need to ensure that these messages are not only heard but can be understood. It's no longer acceptable to just have audibility and a sufficient db rating, we need to get the message delivered and have the message comprehended.

Emergency Voice Communications Systems (EVCS) are put in place to not only notify the occupants of imminent danger, but to also supply instructions on how to escape or avoid this danger.

The language and terms of intelligibility are not difficult, but there are definitions that are unique and there are always acronyms. Some of the common definitions we will require:

- **AUDIBILITY:** The measurement of the sound intensity (SPL - Sound Pressure Level) of an audio source measured at the position of the listener. This output is measured in dB.
- **STI:** ***Speech Transmission Index* -** A measurement of a signal that replaces speech with a repeatable signal and evaluates 98 combinations of modulated noise, using 14 modulation frequencies and 7 octave bands, to provide a single number that represents the impulse response and signal-to-noise ratio for a given area, accounting for noise, reverberation, echoes, non-linear distortion, and band-pass limitations of the system and environment.(Speech Transmission Index for Public Address (STIPA) and RaSTI - Room Acoustics STI = a modified methods of STI)
- **CIS:** ***Common Intelligibility Scale* -** Developed to be able to correlate the subject based methods and the quantitative methods. (0.70 on this scale is usually considered acceptable intelligibility)
- **EVCS or ECS:** ***Emergency Voice Communications Systems*** are for the "protection of life by indicating the existence of an emergency situation and communicating information necessary to facilitate an appropriate response and action".
- **MNS:** ***Mass Notification System:*** An ECS that is used to provide information and instructions to people, in a building, area site, or other space. (e.g.: Individual Building System, Operating Consoles, Giant Voice System (Outdoors))
- **ADS:** ***Acoustically Distinguishable Space:*** An emergency communications system notification zone, or subdivision thereof, that might be an enclosed or otherwise physically defined space, or that might be distinguished from other spaces because of different acoustical, environmental, or use characteristics, such as reverberation time and ambient sound pressure.

The Speech Transmission Index - STI - and Common Intelligibility Scale - CIS - will come up a lot and you should already know about Audibility.

Definitions alone cannot educate you on the science and math behind intelligibility, so the following are excellent references and I'm sure there is a lot more information available from other sources.

- *CANADA: ULC, NBC, ABC standards. USA: NFPA, UFC standards*
- *"Intelligibility of Fire Alarm and Emergency Communication Systems", Fire Protection Research Foundation November 2008.*
- *NFPA 72 – 2010 edition Annex D Speech Intelligibility*
- *IEC 60268-16, "Sound system equipment — Part 16: Objective rating of speech intelligibility by speech transmission index"*
- *ISO 7240-19, "Fire Detection and Alarm Systems — Part 19: Design, Installation, Commissioning and Service of Sound Systems for Emergency Purposes*
- *NEMA Standards Publication SB 50-2008, "Emergency Communications Audio Intelligibility Applications Guide*
- *"Understanding Speech Intelligibility and the Fire Alarm Code" – Kenneth Jacob, Bose*

Our industry relies on standards to provide direction as to how and where and what to install to be acceptable to all involved. Standards improve over time; they use the science and technology available and determine the proper use of this science and technology in an application.

The industry is continuously attempting to put better codes and standards in place and even though some standards exist that already allow designers, technicians and end users to better understand the criteria of intelligibility, the codes are still changing. Currently, they may not be completely comprehensive, but efforts are being made to quantify and standardize the intelligibility parameters to ensure the systems installed will be understandable and adhere to a common reference.

Since technology has improved so much, why wouldn't it automatically provide the intelligibility we seek? Various factors affect the audible output generated by an EVCS such as: the audio systems inabilities or limitations, building construction, human factors, background noise, speaker layout, etc. Our goal is to overcome the challenges provided by these conditions.

Before we delve into these factors, we do need to know some science. Here are some definitions from the physics books:

SOUND

- Sound is a vibration. 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, with the magnitude of the pressure perceived as loudness and the frequency of the changes perceived as pitch.
- It moves from its source in the form of waves. Like waves in a pond, the propagation of sound waves performs similarly.
- Sound waves are all around us and interact with each other to produce what we hear. The strength of these sound waves along with their distance from the listener can have a profound effect on the message received.
- The speed of sound in air is 1125 feet/second (768 mph) @ 68 degrees F. This may sound fast but it can create challenges when dealing with sound in large spaces

SPEECH

- Speech travels in waves and frequency modulations
- Most speech falls between 125Hz and 8,000Hz
- Frequencies that contribute most to intelligibility fall between 500Hz and 4,000Hz
- Consonants generally have lower power but are very important to intelligible sound
- Vowels (AEIOU & Sometimes Y) carry the most power of the signal

The nature of speech and intelligibility is such that not all frequencies contained in speech contribute equally to intelligibility. While vowels, using the lower frequencies, make up the largest portion of the power of a speech signal, it is the consonants, utilizing the higher frequencies that contribute most to intelligibility.

The human hearing audible spectrum occupies a wide range of frequencies from about 100 Hz to 10 kHz, which can be represented by the seven octaves whose center frequencies range from 125 Hz to 8 kHz. Science lesson complete.

Now we know more about sound and speech, what can we do to make systems more intelligible? First, let's identify the factors that can affect the intelligibility of Emergency Voice Communication Systems. Most, if not all, can be overcome by pre-planning and forethought. I'm pretty sure we are familiar with some of the following; we'll look at them in detail and provide some possible solutions.

Speaker location – Loud versus understandable – do not assume that if the voice message is audible, it will be understood. Rather than create an audible system based solely upon the footprint of a building or floor plan, consider this:

Invariably, systems are designed from a set of plans where speaker layout is determined prior to the area being constructed. However, the end use of an area <u>has</u> to be considered, as do the potential background noise or ambient noise. The construction and materials used in the area will also come into play.

Designing for the specific area involved (ADS) allows the system's acoustics to be configured to provide the best intelligibility – in essence: consider the factors previously mentioned when designing the speaker layout.

Possible solutions to environmental factors may include more speakers at lower wattage taps which allows more efficient use of amplifier capacity, reduced distortion and therefore increased intelligibility. And as a general rule, spacing shouldn't exceed 30' from listener.

What type of environment will we be broadcasting into? If every building was constructed with the same design and materials, the intelligibility of the EVCS would be a given. But every building and environment is unique and sounds react differently within varied environments. Drawings don't always show what will be in the finished area; marble is beautiful, but sounds reverberate off marble extremely well and carpets and cloth materials absorb sound energy. Large marble atriums are, acoustically, considerably different than small carpeted corridors or offices.

In some cases, even with all our best efforts, intelligibility in some ADS may be difficult or impossible to achieve throughout the entire space.

Reverberation – It is one of the biggest factors in reduced intelligibility. Defined as *"the effect of sound being reflected off of surfaces from many different directions; unlike echoes, which are a distinct reflection of the sound, reverberation is essentially the effect of many small echoes."* Consider speaker placement and even a different type of speaker; this may help overcome this obstacle. You may be adding more speakers than you have in the past to meet intelligibility requirements.

Signal Absorption - Open office environments and cubicles are now more common than ever. The furnishings or construction of the areas around cubicles is usually designed to provide a quiet office environment with noise dampening materials. Also, sound/noise masking equipment, or white noise generators, have become common in cubicle designed office spaces to help eliminate distracting noises during a business day. The same sound masking equipment can have a profound effect on the audibility and intelligibility of an EVCS. These systems may effectively "mask" the EVCS message. Ensure you are aware of these systems and make provisions to interrupt them in the event of an emergency. The solution to signal absorption has been mentioned before…you may need more speakers to ensure audibility/intelligibility in all areas of the ADS. Also remember that low audibility may be as unintelligible as a loud, distorted output.

Microphone Technique - As important as the quality of the sound system is the clarity of message that is given. Microphone technique is something that is not always taught to people who are called upon to broadcast emergency messages. If called upon to speak over an EVCS, here are some tips and tricks that you, or emergency response personnel, might find useful: Take a deep breath *before* you key the microphone. Know what you are going to say; do not "wing it" – this will avoid getting yourself tongue tied. Keep the microphone close but not too close - check the manufacturer's instructions- usually 6 to 8 inches. Be aware of any extraneous noises in the room: people speaking, phones, printers, or beeping panels, etc, that could go out over the speakers. Watch or listen for feedback. And make sure you know how to operate the EVCS properly. Movement and distance of the microphone, tone and speaker volume can greatly affect the intelligibility of the final message so training response personnel and having preplanned, scripted messages can help in an emergency.   But if the designated people aren't trained on the system and how to speak into a microphone, then it doesn't matter what efforts have been put into the design and the technology.

To remove the human factor, consider pre-recorded messages. Pre-recorded messages have been incorporated into some systems and have proved successful in enhancing intelligibility. Usually, the content of the Fire Alarm 1st stage and 2nd Stage messages are provided and approved. Should the end user require special pre-recorded messages, they, too, should be approved. AHJ and Engineer input should always be considered crucial.

Here is a general rule of thumb: "All messages shall be clear, short, unambiguous and, as far as practicable, pre-planned." Digital recorders/players quality is increasing, but, as with proper microphone technique, the recorded voice has to be clear and enunciate words correctly; a trained professional might be considered to record your scripts.

High Background Noise - Broadcasting into an area with high background noise must be considered when designing emergency voice communications. This can decrease the signal to noise ratio thus making it difficult to understand the emergency message. The background noise may be loud machinery that starts and stops creating noise and quiet in the same area. Malls and heavily occupied areas may have general population noise that would not be considered loud, but may fluctuate depending on the crowd or event. For high background noise areas, consider decreasing the distance from the speaker to the listener. (A good rule of thumb is to maintain the distance from speaker to listener to 30' or less). And remember, no matter how hard you try, you may not be able to achieve respectable intelligibility in all areas.

Faced with the problems and factors mentioned, can we design and preplan to achieve our intelligibility goals? Yes. Providing solutions to intelligibility in tricky areas has never been easier, we can design some of the adverse factors out of the equation. With our knowledge of how sound reacts in different environments and what type of environment will be in the area, we can adjust our design to enable maximum intelligibility. Now, software is available to assist the designers in attempting to improve the intelligibility of the system. There is a particular software suite where the designer inputs all the room and audio system characteristics and the software allows the designer to see what effects the different types of speakers, locations of speakers or even different room furnishings will have on intelligibility. It may even supply an STI or CIS calculation to assist in predicting intelligibility. This allows the designer to try different scenarios to get the best solution; possibly different types of speakers or different locations with different wattage taps, etc.

But planners and designers can only control some aspects of the EVCS intelligibility. Some of the things that cannot be controlled are room geometry, background noise such as HVAC noise, or external noise such as traffic. We can adjust for these factors, but we can't change them. Would more speakers help, or possibly wall mount instead of ceiling?

So we've done our due diligence, thought about all the environmental situations, created speaker layouts suited for the specific ADS, chosen the appropriate speakers, trained our personnel, we're finished, right? Almost…one more thing – we need to test the system for proper intelligibility.

Like so many other components of a Fire Alarm system we measure (volts, amps, sensitivity, power, etc) we need to measure the intelligibility of our system. To test the effectiveness of the design and installation, two methods can be used.

#1 - Subjective assessment - This method is based on the use of talkers and listeners. This method uses personnel to listen to pre-determined broadcast words or sentences and record and grade what they hear. The level of intelligibility is determined by the graded number of recorded words or sentences. Results of this test, although they are subjective, may still be a good indication of how the system can perform and does provide some level of quantification.

This method uses Phonetically Balanced words that utilize trained listeners stationed within the coverage area to listen to the words spoken to determine the intelligibility of the message. Each listener scores the words and they are combined to determine the overall intelligibility.

First introduced in 1910 and utilized extensively in WWII this method of using human speakers and listeners was, and possibly could still be, considered the most accurate method available for determining intelligible speech.

Examples of words used include:						
Are	Cane	Dike	Folk	Is	Pile	Slip
Bad	Cleanse	Dish	Ford	No	Plush	Smile
Bar	Crash	End	Grove	Nook	Rag	Such
Bask	Creed	Feast	Hive	Pants	Ride	There
Box	Deed	Fern	Hunt	Pest	Rise	Use

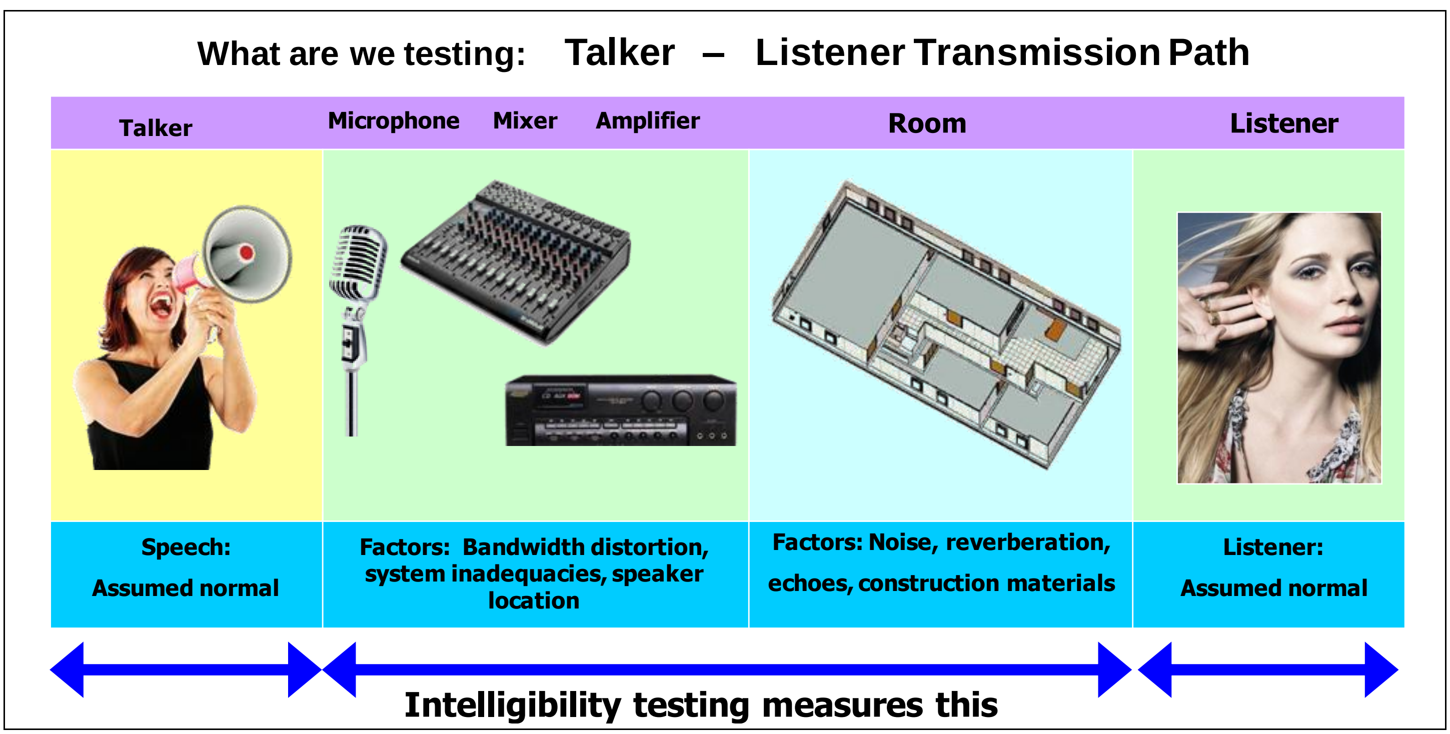
Here is an excerpt from one designer's specification:

In accordance with the ANSI S3.2- 1989 Standard, the test shall present phonetically balanced words embedded in a standard carrier sentence. In designing the test, at least 100 words shall be selected at random from the list of phonetically balanced words provided. Participants in the intelligibility tests shall include a minimum of three listeners and three announcers; and the test words shall be concealed from the listeners.

#2 - The second method is an **Objective Assessment** based on physical parameters of the transmission channel. It is a quantitative based method using hand held meters that is usually less open to interpretation or less subjective and the results are mostly repeatable. Basically, a signal is injected into the EVCS and the output measured at locations around the facility using portable meters. These devices try to compare the base STI or STIPA test signal to the measured signal in the space. The output of the testing determines the intelligibility in the STI or Common Intelligibility Scale (CIS).

Testing a system, although time consuming, is not very difficult; essentially, it is data gathering. The analysis of that data should give a definitive answer as to the intelligibility of the system. If, after all our efforts, the results are not positive, the testing may indicate how to adjust or fix the system. Whichever method is used, the basic questions should still be asked – can everyone hear and understand the broadcast message.

Whatever test we choose, we are actually testing the "Talker to Listener Transmission path". We cannot test each individual that may talk, as we can't test each listener that may hear. So we have to assume that these two factors be considered "normal". We can test the Transmission path or the possible electronic and physical effects on the audio that will affect intelligibility.



Most manufacturers of test equipment usually incorporate a db meter in the test meters and they can provide output in STI or CIS. Per one manufacturer's manual:

> "The STI test signal contains known modulation rates and by measuring the difference in the sound heard from the known sound played, we can derive the STI number. STI evaluates 98 combinations of modulated noise, using 14 modulation frequencies and 7 octave bands, to provide a single number that represents the impulse response and signal-to-noise ratio for a given area, accounting for noise, reverberation, echoes, non-linear distortion, and band-pass limitations of the system and environment."

The Speech Transmission Index or STI is a quantitative method for predicting intelligibility. Regardless of which speech intelligibility measurement is used, subject-based or quantitative, there are times when it is valuable to relate the results obtained from one measurement to those that would be obtained from another. This scale comparison is shown here: (0.7 on the CIS scale is generally an acceptable level of intelligibility and in some cases is the minimum allowed.)

STI	1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.00
	EXCELLENT					**GOOD**			**FAIR**			**POOR**			**BAD**						
CIS	1.00	0.98	0.95	0.93	0.90	0.87	0.84	0.81	0.78	0.74	0.70	0.65	0.60	0.54	0.47	0.39	0.29	0.16	0.00	0.00	0.00

If the STI is not referenced, standards will refer to the Common Intelligibility Scale or CIS. The CIS is <u>not</u> a method of measuring intelligibility itself, but is a standardized scale to which a variety of measurement methods are correlated. It is a widely accepted standard used in the verification of audio sound systems.

So, let's review some of the knowledge we may have found today.

The understanding of the spoken word requires human hearing and human evaluation. What may be clear to many may also be garbled to just as many.

Pre- recorded messages provide repeatable, concise, pre-determined instructions. This takes the human factor out of the equation. Technology now has digital players that might be able to enhance the input into an audio system. When pre-recorded messages aren't a possibility, proper microphone technique must be demonstrated and promoted to all who might need to speak over the EVCS.

Knowledge and awareness of the areas function, area use, materials and even local noise factors need to be known ahead of time.

As mentioned, intelligibility may be enhanced by more speakers at a lower wattage. More, in this case, may be better. Audibility and intelligibility are equally important. You need to be heard – audibility - to be understood – intelligibility.

There may be cases where intelligibility is not going to be achieved or is not a concern and audibility is the only design criteria.

We will finish by saying a word about EVCS intelligibility and Mass Notification Systems. The Fire Alarm Voice Communication System may also be called upon to be part of a Mass Notification System or a hazardous response system where different messages than Fire Alarm messages may be broadcast. But, if the MNS system needs to be able to broadcast messages, all the rules for intelligibility apply. And all voice systems should allow the incident commander or on site personnel to be able to communicate directly inside or outside the facility.

The audio system used for Fire Alarm systems is designed to be robust, used sparingly and expected to function when required. This makes it a perfect candidate for use in an MNS and communicating instructions in a disaster or emergency that is not fire related. The ability to communicate intelligibly with the masses can save lives in <u>any</u> emergency. Some jurisdictions are allowing the MNS to use the Fire Alarm system and provide intelligible voice commands during Fire, natural or un-natural disasters.

The systems we work on today have essentially the same goal as their early cousins - notify the occupants of a building that there is imminent danger. With Emergency Communication Systems, we're just increasing the level of notification and allowing incident commanders to react to changing conditions and hopefully provide a safer environment.