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# INTELLIGIBILITY OF SOUND REINFORCEMENT IN LARGE PUBLIC SPACES


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ABSTRACT

Ten questions are posed and answered. 1. What is a large public space? 2. Are currently installed systems intelligible? 3. Why are multiple location loudspeakers not intelligible? 4. Are twin columns intelligible? 5. Can electrical delay devices help? 6. Can electrical equalization of frequency response improve intelligibility? 7. Can speech reinforcement be intelligible in a concert hall? 8. Can speech reinforcement be intelligible in a sporting arena? 9. Can public address systems be intelligible in airports? 10. Can sound reinforcement be intelligible in a church?

The answers to questions 2, 4, 5, and 6 are negative. Questions 7, 8, and 10 can have positive answers.


## I. WHAT IS A LARGE PUBLIC SPACE?

Many indoor and outdoor structures are now large enough that a single human voice cannot produce the acoutic power to cover the audience and overcome a usually significant background noise level. As examples, churches which will seat more than 500 people, sporting event arenas of any size, transportation terminals (airports, train stations, etc.), and large exhibition halls used for contemporary music performances require electronic amplifiers and loudspeaker systems for communicating information or entertainment in a high background noise environment.

The systems used for these sound reinforcement tasks have evolved over the past 50 years. Little design emphasis has been put into intelligibility factors; the usual claims for success are based on loudness and gain before feedback. I contend that ignoring psychoacoustic factors has led to poor intelligibility in the majority of installations; thus, this report is one with more negative than positive results. We must diagnose the causes for poor intelligibility before devising cures.

## II. ARE CURRENTLY INSTALLED SYSTEMS INTELLIGIBLE?

Recordings made in typical churches and airports will be played via a 4-channel demonstration system to illustrate my contention that many currently installed public address systems are electroacoustic disasters. If you are reading this after the convention presentation, recall the times you have struggled to understand an announcement over an airport P.A. system or fought to stay awake during a sermon in church. You have undoubtedly heard amplified sound at a football game--could you understand any of it? For the most part, my experience has been that there has been sufficient acoustic power (as measured with a single microphone, averaging meter SPL indicator) to overcome background noise. The problem is not power, but being bombarded with a number of coherent sounds at confusing delay times. I can explain the psychoacoustic problems with this by answering the question

## III. WHY ARE MULTIPLE LOCATION LOUDSPEAKERS NOT INTELLIGIBLE?

One of the more common kinds of public address systems found in churches has four to eight simple cone type loudspeakers in baffles chosen to match the visual decor rather than for acoustic properties. The actual loudspeaker is marginally adequate for male voice, poor for female voice, and a disaster for any kind of instrumental music. These inexpensive loudspeakers are usually mounted from the ceiling or perhaps along a side wall with typical spacing on the order of 10 meters between loudspeakers. I suspect that they were designed by visualizing the sound pattern as being similar to a floodlight beam with the objective being uniform illumination of the floor under the loudspeakers.

The fallacy of this design philosophy

is the visualized directivity pattern of the loudspeakers. The typical piston radius of 8 to 12 cm (8 inch to 12 inch frame diameter) leads to a very omnidirectional radiation pattern up to at least 1 kHz. Thus, most of the people in the audience hear all of these loudspeakers. The one person located equidistant from four of these loudspeakers (probably standing in a center aisle) will hear sounds from all four arriving at the same time. Those not in this favored location will hear sound from all of the loudspeakers arriving at different times. If, as usual, the height to the ceiling is about the same or even greater than the loudspeaker spacing, a person in the area just below one loudspeaker will hear sounds from 3 to 6 other loudspeakers which are within a few dB of each other and delayed by 10 to 30 ms. This gives the ear and brain a 1-2-3-4 punch and makes intelligibility poor. Add in some echos from flat walls in the church and the fact that the sound is coming from behind while the eyes tell the brain that the talker is in front and you can understand why these systems simply cannot be understood.

In churches where the background noise is not too great and the system is operated at moderate level, most of the audience members will say that the "pa system is good". This is based on not having a lot of howlback and distortion rather than intelligibility. I have personally observed that the result is listening fatigue in the audience. I have seen the same talker put an audience to sleep in 5 minutes in a church with four horrible honkers mounted on the ceiling and hold an audience spellbound for over 40 minutes in a different room using an intelligently designed sound system (or, using no reinforcement.) When you consider that listening fatigue sets in within 5 minutes no matter who is talking via the horrible honkers, one must conclude that the pa system is at fault. Indeed, on the few occasions this electroacoustic disaster has been broken, audience attention span has been much better. Sad to say, no-one will heed my advice to turn the machine off and leave it off.

Typical airports suffer from the same psychoacoutic troubles. Each member of the crowd in the typical size ticketing or baggage claim area hears several loudspeakers with some 50 ms delay between. Add some distortion caused by the announcer eating the microphone in an attempt to be understood and then you know why visual communication is more reliable. (In the boarding gate areas, multiple loudspeaker systems are more understandable. This is because of the lower ceilings, carpets, and acoustic tile ceilings.)

If multiple loudspeakers cannot be understood in a church then we ask

## IV. ARE TWIN COLUMNS INTELLIGIBLE?

I have observed that the typical history of the public address system of a church starts with an architect working with a very limited budget. He cannot hire (even if he could find one) a competent electroacoustic engineer to help with first the acoustic design of his building and then with the design of electronic equipment. Thus, either no sound system is installed (by far the best option) or a very low price system with distributed loudspeakers is specified. Within just a year or so, everyone becomes dissatisfied with the pa system; yet, the building is not paid for and there certainly isn't money to spend for professional help. Usually, a member of the congregation comes forward to solve the problem. He will tinker with microphone placement, possibly change amplifiers, and even install loudspeakers with larger magnets in an attempt to improve the system. Often, he will achieve greater loudness and his work will be received with enthusiasm because he is doing something about an annoying problem. Yet, with the distributed loudspeakers, it is impossible to attain good intelligibility.

About the time the building is paid for or when there is a change of pastor or when the sound "expert" leaves the congregation, there will be enough disgust with the pa system to bring forth a decision to spend enough money to straighten out the mess. A sound contractor will be engaged to install a completely new system. Obviously, he cannot install more or different distributed loudspeakers and have the system really look new and different. His usual installation consists of two column loudspeaker systems, (typically 1 to 1½ meters long) installed one on each side near the front of the church. The new amplifier will operate with balanced-line low-impedance microphones so the hum will be gone and the cable connector problems will be alleviated. Indeed, the new system will sound different.

Most of the difference can usually be explained by the difference in frequency response of the new loudspeakers. The typical commercially available pa column loudspeaker has very low compliance drivers with 5 to 6 cm cone radius (4 to 6 inch frame diameter.) The low frequency response is such a disaster that it cuts off the bottom octave of male speech worse than the old loudspeakers. However, one psychological problem has been solved;

now the eyes and the ears agree that the talker is in front of the audience.

I haven't answered the important question--is this system intellegible? Usually, the answer is no. If the church floor plan is not rectangular, or if the twin columns are installed as high as possible and aimed at the floor near the rear, the answer could be yes. I have seen only one church where these conditions are met and the twin columns were intelligible. However, the acoustic design of this church was superb and the pastor had the good sense to leave the pa system switched off and the intelligibility was excellent.

The usual installation of twin columns in a church with a rectangular floor plan is to place the bottom of the column at about head height for the talkers. This placement is defeated by the poor acoustics of the basic building. Almost always there is a very flat, smooth wall at the rear which serves as an acoustic mirror. Those near the front of the church hear two sounds with differential delay of 0 to 25 ms (depending on their position from left to right) from the twin columns; then, they hear two sounds from that acoustic mirror in the rear which are very coherent and delayed by the transit time from front to rear and part way back --say 100 to 200 ms. This time delay of greater than 75 ms means the ear perceives this reflected sound as an echo and has to work hard to ignore it. Again, listening fatigue sets in and after the first enthusiam for the new, professionally done, sound system subsides, you will hear the acoustics of the church described as "barny". For most churches, turning off the twin columns is strongly advised.

## V. CAN ELECTRICAL DELAY DEVICES HELP?

This is a question of renewed importance in light of recent advances in moderately priced digital delay techniques. Delay with either endless loop tape recorders or long acoustic delay lines has been used in the past. Typically, these are taken out of the system because of reliability or noise or frequency resonse problems. For the moderate bandwidth required for pa systems, digital delay devices will not suffer these faults. Yet, I predict failure if digital delay devices are used in pa systems.

The rationale behind the idea of useing electrical delay devices starts with a visualization of a sound source radiating outward a spherical travelling wave. As the wave diminishes in amplitude, sound reinforcement must increase the amplitude with phase coherence; thus, electrical delay is added in proportion to the distance of the loudspeakers in the audience area.

The fallacy of this idea is the same as with any distributed loudspeaker pa system--the loudspeakers used are essentially omnidirectional. If properly done, the people to the rear of the auditorium will hear the reinforced sound with less than 10 ms differential delay. It is the people in the front of the audience who suffer. The sound radiated omnidirectionally from the loudspeakers behind them arrives with 50 to 75 ms differential delay after sound from the stage. This is perceived as an echo--call it big barn sound.

## VI. CAN ELECTRICAL EQUALIZATION OF FREQUENCY RESPONSE IMPROVE INTELLIGIBILITY?

No. Then why is it so widely promoted? If a sound system has been installed with a loudspeaker(s) which has bad humps in the frequency response (and this is true of practically all commercially available loudspeakers used for sound reinforcement), then using an equalizer can increase gain before feedback (and attainable SPL if the amplifier has the horsepower) by the height of the hump removed by equalization. Often this is 6 to 10 dB. Thus, the system can sound 6 to 10 dB louder. If the cause of intelligibility trouble was multiple loudspeakers separated by more than 10 m in the auditorium, the increase in loudness is not going to improve intelligibility.

## VII. CAN SPEECH REINFORCEMENT BE INTELLIGIBLE IN A CONCERT HALL?

Yes. It has been proved by example that speech reinforcement can be intelligible in a 2800 seat concert hall. The original design of the Concert Hall of the Sydney (Australia) Opera House called for sound reinforcement for making announcements, commentary from the stage, etc. The hall is large, with an eliptical floor plan and a stage off center about 1/4 of the way from one end. For a full house, perhaps 1/3 of the audience is to the side or rear of the stage.

This is a challenging problem and I am most pleased to say that the engineer who worked on the problem met the challenge and in doing so advanced the state-of-the-art in both loudspeaker and sound systems. Dr. J. Ernest Benson [1], working in the AWA Research Laboratories, quickly determined that one optimumly placed loudspeaker system was the answer to the psychoacoustic problem created by audience area behind the stage. The crucial requirement was control of the loudspeaker directivity pattern throughout the voice range. Commercially available horn loaded or column loudspeakers did not have the required constancy of directivity pattern through the 150 to 5000 Hz range required for natural sounding speech reinforcement. Thus, Dr. Benson first studied the control of directivity pattern and further developed the concept of electricially tapered column loudspeakers [1]. Exactly one of these columns was hung over the center of the stage in the Sydney Opera House with the main lobe of the directivity pattern carefully aimed (by adjusting the length of the support cable) at the center tier of seats. The result is superb--this is one of those rare sound reinforcement systems which must be turned off to make you realize that the voice was being reinforced.

## VIII. CAN SPEECH REINFORCEMENT BE INTELLIGIBLE IN A SPORTING ARENA?

Notice that the first word of my question is "can", not "is". Examples abound to show that intelligibility is poor in most arenas--just try to understand half-time announcements over the pa system as you listen to your television.

Does this have to be so? The cause of the trouble is multiple loudspeakers distributed throughout the audience. The cure is the same as Dr. Benson's answer in Sydney, use exactly one carefully engineered loudspeaker system. I first saw this solution in 1940 in the Municipal Auditorium, Kansas City, Missouri.

When the president of Colorado State University complained that his commencement addresses could not be heard (he meant understood) in the Field House, I was called to Fort Collins to study the problem. I found a multitude of theatre type loudspeaker system located over perhaps 20% of the area of the ceiling. Enough power amplifiers were available to develop 2 electrical horsepower into resistors. The previous consultant had recommended a frequency equalization and performed the ritual of noise testing and knob twiddling. (This did increase SPL and more than 10 dB).

Just one sentence had to be spoken through this sound system to tell that the problem was the multitude of loudspeakers. We mounted one commercially available column loudspeaker on the "cherry picker" used for maintenance and powered it with one 200 W amplifier. The cherry picker was moved around on the floor and the elevation of the loudspeaker changed until reflections from far walls was minimized. (The third position tried was the final result.) With a microphone on the floor of the Field House, gain before feedback was 10 dB higher than with the equalized multiple loudspeaker system. This translated to 10 dB increased loudness in the audience area. Even more important, the single source of sound could be understood throughout the audience area. My final recommendation was some acoustic treatment of some flat side wall areas.

The political problems in this business are illustrated by a question from the University's sound engineer as we completed our work: "How can I explain to my boss that you got more sound out of one amplifier and loudspeaker than we were getting out of 6 amplifiers and 16 loudspeakers?"

## IX. CAN PUBLIC ADDRESS SYSTEMS BE INTELLIGIBLE IN AIRPORTS?

I don't know. In many of the airports serving cities of less than 1/2 million population, I think I have spotted a location for a single column loudspeaker which could be heard through the arrival and ticketing area. For terminals such as those at Chicago, Los Angeles, and Dallas, I have reservations about being able to improve the systems now in use. I would like to try my hand at a smaller air terminal but can you imagine the opposition to letting an egg headed professor try to improve the sound system?

## X. CAN SOUND REINFORCEMENT BE INTELLIGIBLE IN A CHURCH?

After opening this paper with descriptions of why most churches have lousy sound systems, I am going to surprise you by saying the answer can be yes. And to quote a Klipsch & Associates advertisement the cure is effected by "putting Heresy® in your church." The Heresy® is a 40 liter closed box loudspeaker system manufactured by Klipsch and the important part of their recommendation is to use just one loudspeaker located close to the ceiling and above the location of the talker. From this location, the sound from the loudspeaker will arrive within 20 ms of sound from the talker and the effect is that the sound appears to come only from the talker. Launching the amplified sound from the top of the church means reflections from that acoustic mirror in the rear will be splattered when it hits the congregation and furniture; herefore, the people in front do not hear the coherent echo which plagued the twin column design.

When Mr. W.J.J. Hoge became the local "expert" at the West End Church of Christ in Nashville, Tennessee, he asked me to bring my brief case (to qualify as an out-of-town expert) to Nashville and help him with the problem. We used the heretical Mr. Klipsch's location and installed a 1 m long column with 4 drivers using 5 cm cones. The system did not have enough directivity at low frequencies so a second identical column was added to make a system 2 m long. A 50 W amplifier and simple mixer provides more than adequate gain and acoustic power. We considered the installation successful when Mr. Hoge had to push the off button to convince Mr. A. Neville Thiele that sound reinforcement was being used.

## X. REFERENCE


[1] J. E. Benson, "Theory and Applications of Electrically Tapered Electro-Acoustic Arrays", Conference Record, 1976 IEEE ICASSP, April 19, 1976.