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4aAAb2. Optimizing the signal to noise ratio in speech rooms using passive acoustics

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Adults with normal hearing require roughly a 0 dB signal-to-noise ratio for good speech intelligibility. However, significantly higher values may be needed to compensate for neurological immaturity, sensorineural and conductive hearing losses, language proficiency and excessive reverberation. ANSI 12.60 addresses ways to lower the noise interference due to background levels and reverberation time. However, it is also possible to increase the signal, by reflecting or diffusing early reflections. Speech intelligibility is delivered in the consonants, which occur in the 2-6 kHz frequency range. Therefore, intelligibility can be enhanced by incorporating scattering surfaces, rather than solely surfaces that absorb sound in the 2-6 kHz region, on the front wall, lower side walls and central ceiling areas, to increase the speech signal by temporal fusion. The decay time can be controlled with broadband absorption on the perimeter of the ceiling and upper wall surfaces. Since ceiling diffusion is an important design ingredient and the ceiling plane is coveted by many trades, including lighting, HVAC, speakers, sprinklers, etc., we will describe a 24 VDC combined LED lighting and sound diffusor, with a 24 VDC emergency lighting central battery system, dynamic lighting capability and the ability to incorporate sonic actuators for announcements.

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I CAN HEAR YOU, BUT I CAN’T UNDERSTAND YOU

The key metric in speech intelligibility is the signal-to-noise ratio. Adults typically require 0 dB signal-to-noise ratios for high speech intelligibility when listening to simple and familiar speech material for short periods of time. An additional 2 dB is needed to compensate for neurological immaturity; an additional 5 dB is required to compensate for sensorineural and conductive hearing losses; an additional 5 dB is required for limited English proficiency and language disorders and an additional 3 dB is required to compensate for the effects of excessive reverberation. These additional requirements for any room in which speech intelligibility is required, such as classrooms, distance learning rooms, meeting rooms, conference rooms, offices, etc. total 15 dB over that of normal adults, or a signal-to-noise ratio of +15 dB. In addition to controlling the noise, which includes reverberation, outside noise intrusion, occupant noise and HVAC noise, we can use the early reflections from the passive acoustics of the architecture to increase the signal and provide some of this needed gain. A class room example can be seen in Figure 1. It has been shown, that our auditory system has the ability to fuse early reflections with the direct sound to

FIGURE 1. The signal-to-noise can be improved by increasing the early reflection from the passive acoustical design and lowering the sources of noise in a room.

FIGURE 2. Early reflections with a similar spectral content, appropriate arrival time (delay) and relative loudness compared to the direct sound, can increase apparent loudness, spaciousness, timbre and add body and fullness to the perceived sound.

increase the apparent signal loudness, spaciousness, timbral richness and give body and fullness to the perceived sound. The early reflections should also have a similar spectral response to the direct sound and arrive within roughly 40 ms for speech. The effect of early reflections on a speech signal has been shown by Toole1.
The problem with current acoustical design of speech and learning environments is that existing acoustical designs have not evolved to incorporate the current state-of-the-art and the results are failing to meet their intended goals. Existing acoustical designs are limited to conventional acoustical materials, like thin fabric wrapped panels, acoustical ceiling tile and simple curved reflectors, which cannot address all of speech intelligibility and music appreciation challenges. There is also limited understanding of the importance of lighting in the learning process. Even with adequate budgets, there is a false sense of economy in short term goals, rather than factoring costs over the life of the project and the long term effects on students, teachers and other participants. The solution is to adopt modern absorbing, reflecting and diffusing products and designs utilizing early reflections and reverberation control for core and ancillary learning or listening spaces, adopt recommendations of ANSI 12.62 to control reverberation, background noise and noise intrusion, and implement appropriate lighting settings of illuminance and color that have been demonstrated to significantly improve attention span, concentration and behavior of pupils in a school.

Let’s discuss how a typical classroom can be improved using state-of-the-art acoustical materials, placement and lighting. A classroom goal would include a quiet room, free from distractions, appropriate reverberance for speech intelligibility and early, diffuse reflections for loudness, envelopment & speech intelligibility. Ideally the classroom would include massive walls (8” CMU or 6” insulated, double-layer GWB), no noise flanking paths (offset penetrations, ducts/conduits above corridor ceiling), solid core wood doors with gaskets, double layer, isolated, insulated GWB ceiling, diffusion over center of ceiling, reflective front part of room, diffi sorption (combination of high frequency diffusion with mid-low frequency absorption) along mid-third of side walls and rear, carpeted floors under student seating, maximum NC-25 background noise, HVAC in MERs, duct silencers, lined ductwork, ducted return, VAV/FPB above corridor, air velocities below 500 fpm within 25’ of classroom, and NC-20 air terminals.

With respect to surface treatment in speech rooms, there are three options for ceiling treatment shown in Figure 3. An absorptive ceiling simply attenuates the incident sound, a reflective ceiling redirects the incident sound and a diffusive ceiling uniformly scatters the incident sound. While an absorptive ceiling has the potentially beneficial effect of reducing the reverberation time and level, this paper suggests that absorption should not be used to cover the entire ceiling, rather it should be used around the perimeter of the ceiling, as is shown in Figure 4, to control the decay time. The ear / brain processor can fill in a substantial amount of missing information in music, but requires more detailed information for understanding speech. The speech power is delivered in the vowels (a, e, i, o, u and sometimes y) which are predominantly in the frequency range of 250Hz to 500Hz. The speech intelligibility is delivered in the consonants (b, c, d, f, g, h, j, k, l, m, n, p, q, r, s, t, v, w), which requires information in the 2,000Hz to 6,000 Hz frequency range. Therefore, in this author’s opinion, it seems inappropriate to use acoustical ceiling tile on the entire ceiling and thin fabric wrapped panels on walls of speech rooms, because these surfaces absorb useful high frequency reflections and prevent them from fusing with the direct sound to provide a louder more intelligible sound.
A reflective ceiling beneficially utilizes the early reflections, but a diffusive ceiling in the central portion is better at uniformly diffusing the incident sound. The directivity of the spoken word is roughly 120°, therefore it is suggested that the surfaces surrounding the speaker be reflective, so that the high frequency content of the speaker’s voice can be reflected back into the room when the speaker is facing away from the listeners. This is typically achieved in current classrooms, because this is where the black or white board is usually placed. However, absorbing acoustical ceiling tile should not be extended over the speaker preventing the direct sound from being reflected into the room. This acoustical support also reduces fatigue in the speaker. To provide beneficial reflections from the side and rear walls, it is suggested that conventional purely absorptive fabric wrapped panels be replaced with binary amplitude diffusors, which diffuse reflections above 1 kHz and absorb sound below. This suggestion helps to reduce mid to low frequency reverberation, while utilizing useful diffuse reflections above 1 kHz and maintaining ambiance. These panels can be positioned vertically so that they are effective with listener seated or standing. Treating the ceiling can be a difficult process, because many trades compete for use of the ceiling, as is shown in Figure 5. In this paper a new multi-purpose ceiling element, which fits conventional T-bar systems is described. This device is a 2-dimensional diffusing element that can optionally be illuminated with a 24 V DC, remotely controlled LED backing, provide 24 V DC emergency backup and provide music and emergency or paging announcements. When illuminated the device is called Lumaphon and when not illuminated it is called Harmonix, as illustrated in Figure 4.

The Lumaphon device can also provide dynamic lighting to programmatically adjust to desirable lighting conditions during the day. With this approach, dynamic lighting, emergency backup, music and announcements can be provided by a single T-bar ceiling element, thus simplifying ceiling design and allowing the acoustical elements to
be optimally located. A photo of an illuminated lay-in combined sound and LED lighting diffuser is shown in Figure 6.

Diffusive ceilings increase the acoustic level and uniformity of coverage, as compared to absorptive ceilings, without corrupting the speech intelligibility. Increasing the acoustic level increases the learning process and intelligibility by extending the attention span and also addresses hearing acuity and hearing impairment. The speaker exerts less energy and experiences less fatigue by not speaking into an acoustic vacuum. Energy reaches the students or audience from many directions creating a sense of immersion in the learning experience (surround sound vs. mono) for a more intimate, attentive learning or listening experience. Diffusion also improves student-student and student-teacher communication (not only teacher to student communication).

As an alternative to absorptive ceiling tile, a translucent, LED illuminated, absorptive, micro-slit lay-in panel is also available for reverberation control. These can be used in health care facilities, operating rooms and MRI and other diagnostic rooms to provide illumination, graphics and control reverberation time.

These same principles can be applied to any environment in which speech intelligibility is important. Next we describe the acoustical design of meeting, training and conference rooms. In most current designs, an absorptive ceiling tile T-bar system is used and the floor is treated with carpeting. Both elements offering sound absorption weighted to the high frequencies, with the potential of making the room acoustically “dead” and lacking ambiance. In this design, sound traveling vertically and horizontally encounters a radically different environment, making for an unnatural sounding room, as shown in Figure 7. In addition, absorption on the ceiling and floor will accentuate any flutter echo between parallel reflective side walls. In some cases absorptive fabric wrapped panels are also added to side walls, reducing both the signal and the noise, creating an acoustically “dead” space.

**FIGURE 6.** A few views of the 2-dimensional illuminated sound/light diffusor are illustrated. Translucent, illuminated, absorptive micro-slit versions of the element are also available, with optional digitally printed graphics or signage.

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**FIGURE 7.** Left: Sound attenuation resulting from reflections from a parallel absorbent ceiling and floor result in roughly 28 dB. Right: During the same amount of time horizontal reflections from opposite reflective walls are barely attenuated at all.
While it is important to control the decay time in speech rooms, because reverberation can mask the speech signal, as shown in Figure 8, we also need to simultaneously enhance the direct sound with early reflections as has been described.

In Figure 9, we describe a typical lecture or training room. The room is designed with acoustical ceiling tile, a carpeted floor and reflective side walls (Single Plane Absorption Syndrome- SPAS). The problems encountered in this room include possible flutter echo and poor propagation of sound to the rear of the room. The acoustics can be improved by making the surfaces surrounding the speaker reflective, as outlined in blue, adding diffusive elements to the center of the T-bar ceiling, as outlined in red, and making the mid-third of the side and rear walls diffusorptive, i.e. diffusive above 1 kHz and absorptive below, as outlined in yellow.
Next, we describe a design for a large conference room using the ideas previously stated and explore the use of a ceiling soffit. Typically, ceiling soffits are used to cover HVAC ducts, with the hope of also attenuating noise. However, it should be stated that HVAC noise is more properly treated at the source and with lined ducts. In this paper, we suggest using absorptive soffits to control the mid to low frequency reverberation time in the room and use diffusive elements in the center of the ceiling, as we have been describing and diffusorptive side and rear wall treatment. This room can be improved by replacing the central area of acoustical ceiling tile, outlined in red, with an illuminated 2D sound diffusor, Lumaphon, as previously described, simultaneously providing diffuse light and sound. A few rows of acoustical ceiling tile surrounding the diffusors can be maintained to control reverberation. Replace the purely absorptive fabric wrapped panels on the mid-third of the walls, as outlined in yellow, with minimally 2” diffusorptive panels. The soffits can be made absorptive to reduce mid and low frequency reverberation.

In conclusion, we have described an approach to improve intelligibility in speech rooms for people of all ages, by increasing the signal to noise ratio. This is accomplished by supporting the sound source with surrounding reflective surfaces, utilizing diffusive early reflections from central ceiling areas and walls, minimizing external and internal noise sources with good noise control designs, and minimizing reverberation with absorptive surfaces on ceiling perimeter, soffits and diffusorptive wall treatment. A new 24 V DC low-voltage combined sound and light T-bar diffusor has also been described. This new product offers less cluttered ceiling design, remotely located dynamic lighting controls and emergency lighting central battery backup system, elimination of AC conduits in the ceiling plenum and allows diffusive surfaces to be optimally located to improve intelligibility.

REFERENCES

1. F. Toole, 8th Audio Engineering Conference (1990)
3. Philips Dynamic Lighting Classroom System.

FIGURE 10. Typical large conference room, with absorptive ceiling, floor and walls and a reflective soffit. This leads to a very acoustically “dead” room with no ambiance and poor sound distribution. People seated near the rear of the room have little chance of understanding what is being said.

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