soundmasking for speech privacy

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A technical guide to achieving effective
speech privacy in open-plan offices
and other environments

Sound Masking Systems

WHITE PAPER

Part 1

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Introduction and Executive Summary
What is Sound Masking?

A sound masking system emits low-level, non-distracting masking noise designed to reduce speech intelligibility and thereby improve speech privacy. This improvement in speech privacy can be of great value in open-plan offices, doctors' examination rooms and other environments where confidentiality is important.

Sound masking can also reduce the distraction caused by traffic, office machinery and other unwanted sounds. Because this benefit is limited to situations where the unwanted sounds are of relatively low level, however, speech privacy is the focus of most sound masking systems.

A typical sound masking system consists of a masking noise generator, an equalizer, one or more power amplifiers and a group of special loudspeakers installed above a dropped ceiling. Well-designed room acoustics are an important component of a successful masking system.

The Economic Benefits of Sound Masking

The economic benefits of sound masking vary from application to application but can be significant. Consider a large insurance company selling life insurance over the telephone. Many times each day, an agent will ask a prospective client for financial and health information. The insurance company must maintain a reasonable degree of confidentiality for this kind of information. Yet, if the agents work in a traditional open office environment, the lack of speech privacy makes it nearly impossible to acheive this goal.

One way to provide speech privacy would be to construct a private office for each agent. Yet, as anyone who has ever slept in a cheap motel room knows, even doors and walls do not guarantee privacy! A truly "private" office must include sound insulating walls, sealed doors and baffles in the air-handling ducts — not a low-cost solution.

A lower cost solution is an open plan office with well-designed acoustics and a sound masking system. This kind of environment can achieve normal speech privacy while maintaining the flexibility of the open plan office. As a side benefit, the sound masking system will reduce the distraction of unwanted sounds like office machinery and traffic, enabling the insurance agents and other office workers to maintain a higher level of productivity.

Purpose of this Paper

This paper discusses the acoustics and electronics of a successful sound masking system and provides case histories as illustrations. Appendix A contains definitions of sound masking and acoustical terms. Appendix B is a useful sound masking worksheet that can help estimate the degree of privacy achievable in a new or retrofitted system.

Although it is detailed and accurate, this paper cannot make the reader into a sound masking expert. For this reason, avlelec.com recommends that architects, building owners and systems contractors seek our assistance when contemplating the design and installation of a sound masking system.

Part 1

A Discussion of Sound Masking

Applications for Sound Masking Systems Open-Plan Offices Definition of Terms (also see Appendix A)

In this paper, the term "talker" refers to a person. The term "speaker" refers to a loudspeaker. The term "listener" refers to anyone hearing sounds, whether or not they intend to hear those sounds.

"Marginal", "normal" and "confidential" speech privacy are subjective terms that are discussed more completely in the section entitled "Predicting Privacy in the Masking Environment". In general, however, "marginal" refers to an unacceptable level of speech privacy. "Normal" speech privacy is acceptable for open-plan office environments. "Confidential" speech privacy is desirable for confidential conference rooms, psychiatrist's and lawyer's offices and other highly confidential environments. Modern open-plan office environments function as a group of independent offices in a single large open space. Movable screens between offices act as both acoustical and visual barriers. Sound masking completes the environment by adding speech privacy. Compared to the completely open "typing pool" concept, each employee has a comfortable working zone with both visual and speech privacy.

Medical Examination Rooms

Medical examination rooms are often small (perhaps 100 square feet) and close together. The low-cost construction used for these rooms provides walls and doors for visual privacy but offers very limited speech privacy. In fact, it is not uncommon to hear and understand every word of a conversation between a doctor and patient in adjacent examination rooms! This can be very inhibiting for the patients. Sound masking can create effective speech privacy in these rooms at a lower cost than construction improvements alone.

Confidential Offices

Psychiatrists, lawyers, law enforcement personnel and marriage or school counselors all require confidential privacy in their offices. This privacy can be achieved with construction techniques alone. However, the required sound isolating walls, doors, and windows can be very expensive. The alternative of sound masking, in conjunction with less costly construction techniques, can achieve the required privacy at a lower overall cost.
Some environments, such as psychiatrists' offices, may require an extremely high degree of privacy. Other situations, in existing structures, may involve significant acoustical problems or building layout issues.

Court Rooms

Sound masking can be useful in a courtroom when the judge needs to have a private conference with lawyers and prosecutors at the bench. Equip the judge's microphone with a mute switch that also engages sound masking through loudspeakers located over the audience and the jury.

Buildings near Major Roads, Railroads, and Airports

In most buildings, it is not feasible to completely mask higher-level noises like those from heavy trucks, trains, or aircraft. However, sound masking can soften the impact of these noises. If a client wants masking to cover up these sounds, make sure their expectations are not too high. In most cases, the intruding sounds will still be audible after masking is installed. However, masking will minimize the startle effect because the sound level changes less.

Personal Masking Units

Personal masking units, which are commonly sold as sleep aids, offer a selection of masking sounds and other pleasant sounds like breaking surf, babbling brooks, train clickity-clack, rain, waterfall, and church bells. Do not confuse these units with the self-contained masking units (described later in this paper) which are designed for professional use in offices. Other than this brief discussion, personal masking units are not covered in this paper.

Security Systems

Specialized masking systems emit high intensity masking sound outside the windows and doors of top-secret conference rooms in buildings that require extremely high levels of security. These systems are not covered in this paper.

When Sound Masking Should Not Be Used

Unrealistic Client Expectations

A successful masking system requires careful coordination of an acoustical ceiling, office partition screens, absorptive furniture, overall building acoustics and the electronic sound masking system. Yet, some clients, having heard about a "miracle" at another facility, may expect electronic sound masking alone to solve their problems.

Educate these clients about the limits of sound masking and about the acoustical and construction requirements. If the client is unwilling to make necessary acoustical or construction improvements, tell them clearly that only the electronic functionality of the system is guaranteed, not the acoustical results.

Rooms Requiring Very Low Ambient Noise

The acoustic echo cancellers, used in audio and video teleconferencing systems, work best in rooms with very low ambient noise. Thus, masking sound is not a good way to maintain voice privacy or to mask unwanted noises in teleconferencing rooms or in other environments which require very low ambient noise.

Space Used by Sight-Impaired People

Masking sound and an absorbent environment can hide the aural clues used by the visually impaired to sense their immediate surroundings.

Space Used by Hearing-Impaired People

Masking sound can impair the ability of people with acute hearing loss to understand speech, especially in situations where face-to-face communication is not possible.

Benefits of Masking to the End User

Cost-Effective Speech Privacy

Normal (not confidential) privacy can usually be achieved with floor-to-ceiling walls between workspaces. However, sound masking allows normal privacy to be achieved in an open-plan office with simple partitions between cubicles. This is a cost-effective solution that allows a building owner or leasee to retain the flexibility of an open-plan office.

Confidential privacy, without sound masking, requires multiple-layer walls, from the floor to the deck above the ceiling, combined with special sound-isolation doors, door seals and careful caulking of all penetrations of the wall to stop sound leaks. This kind of construction can be very costly. In contrast, masking sound allows confidential privacy to be achieved with normal building partitions that extend from floor to ceiling.

Increased Productivity

Without sound masking, employees in an open-plan office must deal with constant audible distractions, including office machinery noises, traffic noises and clearly heard conversations from adjacent workspaces. Even when working in a private office, employees may hear noises and conversations coming from adjoining offices or hallways.

With sound masking, these noises will be less irritating and the conversations, while still audible, will be unintelligible and therefore much less distracting.

Flexibility

Without sound masking, the open-plan office is little more than an old-fashioned typing pool with partitions. Noises and clearly audible conversations from nearby cubicles distract workers and limit their productivity. Lack of speech privacy may even inhibit some employees from performing necessary job functions.

With sound masking, the open office gains the speech privacy of individual private offices yet retains the flexibility of the open-plan concept. Just move partitions to add or delete offices, combine offices into a conference area or to create an open space for use as a break-room or file-room area. In most cases, lighting and air ducts, which are located in the ceiling, need not be moved. Also, in a well-planned open-office space, it's easy to reconfigure electrical, telephone, fax and computer connections.

Part 2

A Discussion of Sound Masking

Three Steps to Successful Sound Masking

Carefully planned acoustics, combined with masking sound, make it possible to achieve the goal of increased speech privacy between workstations.

There are three steps to successful sound masking:

1. Attenuate the Direct Sound
   "Direct sound" from a talker reaches a listener by the shortest path without being reflected by any object.
2. Reduce Sound Reflections
   Reflected sound from a talker reaches a listener after being reflected from one or more hard objects.
3. Raise the Ambient Sound Level Using Sound Masking

Sound masking adds low-level background noise to reduce the speech-to-noise ratio and reduce intelligibility.

Discussion

It's not always necessary to take all three steps to achieve a desired level of speech privacy. In private offices, for example, floor-to-ceiling walls may attenuate the direct sound enough to achieve normal speech privacy.

In open-plan offices, however, even normal speech privacy requires all three steps. Use absorptive furniture and screens (partitions) to attenuate the direct sound and reduce unwanted reflections. Use acoustical ceilings to further reduce reflections between adjacent office spaces. Sound masking completes the job by adding a low level of random electronic noise to mask the remaining unwanted sounds.

In effect, the first two steps, which involve acoustics alone, reduce the level of unwanted sound. The last step, adding masking noise, masks the remaining unwanted sound in such a way as to create speech privacy and reduce distractions.

A Basic Sound Masking Example

Figure 1 illustrates these concepts. Part A shows a poorly-designed open-plan office environment. There is no barrier to reduce the direct sound level between the talkers and the listener, the hard ceiling reinforces the direct sound with reflections, and the low level of background sound does not mask the speech. The dashed line represents the level (as a graph) of speech and the dotted line represents the room or background sound level. Notice that the room level is much lower than the speech level.

In Part B, the screen attenuates direct sound, an absorptive ceiling reduces reflected sound energy, and the masking loudspeakers in the ceiling plenum add masking sound. The result is effective (normal) speech privacy.

Figure 2 introduces the concept of sound masking in octave bands. The solid line in Part A shows the octave-band sound levels of a talker as heard at a nearby workstation. The dotted line in Part A shows quiet back

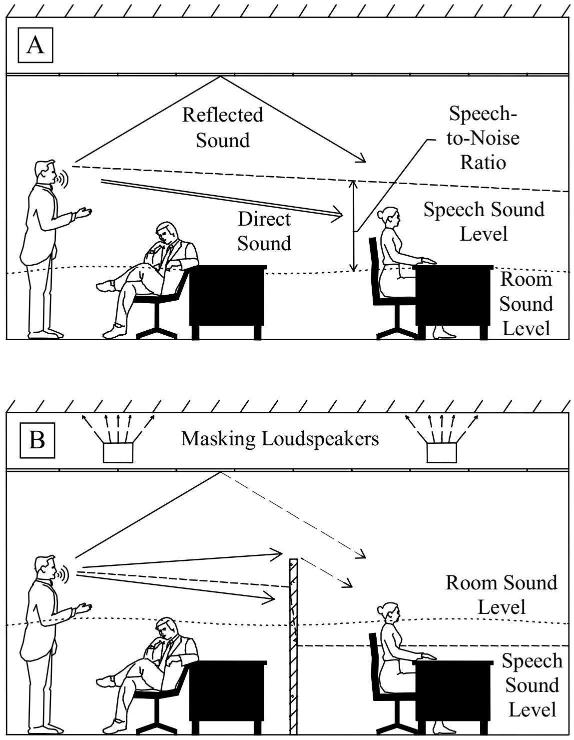


FIG. 1 - In Part A, direct sound from the talker and reflected sound off a hard ceiling contribute to poor speech privacy. In Part B, an absorptive ceiling and screen reduce the direct and reflected sound level, and masking sound provides effective (normal) speech privacy.

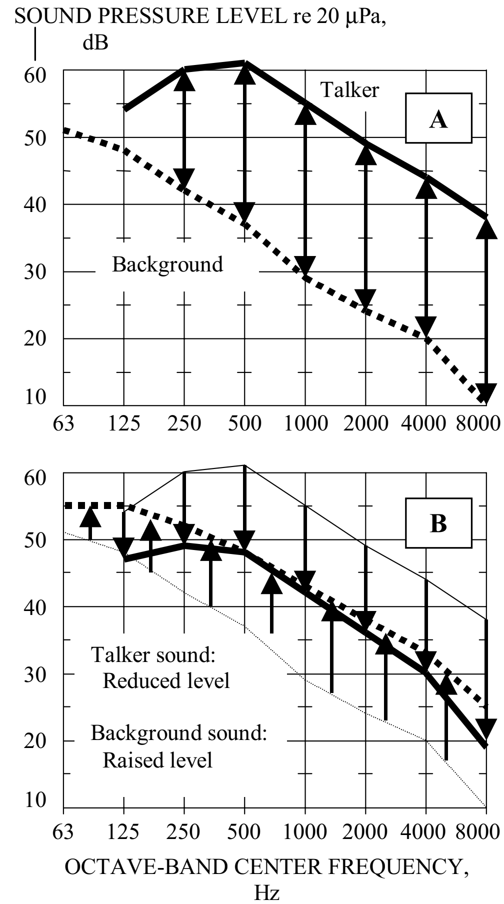


FIG. 2 - This two-part graph illustrates the concept of sound masking by showing octave-band sound levels of a talker and background sound before (Part A) and after (Part B) acoustical improvements and sound masking are installed.

ground sound levels typical in an open-plan office. Thus, Part A shows a high speech-to-noise ratio in every octave band resulting in high articulation and no speech privacy. Part B shows a lower speech-to-noise ratio and a more desirable level of speech privacy achieved with partitions, absorptive surfaces and masking sound.

Evaluating the Acoustical Environment

In existing spaces, it may not be possible to improve the acoustics by installing absorptive partitions and furnishings, improving the ceiling or applying new interior finishes. In new spaces, the building owner or lessee may have very specific ideas about building decor which limit the ability to optimize the acoustics.

It is always important, however, to be able to evaluate the acoustical environment and provide advice to a prospective client. The acoustical information in this section and the worksheet in Appendix B are designed to aid that process and help avoid some common pitfalls.

Attenuation of Direct Sound

The direct sound is speech from a talker that arrives directly at the ear of a listener without being reflected. Figure 3 shows the direct peak sound levels for male and female talkers at a distance of one meter.

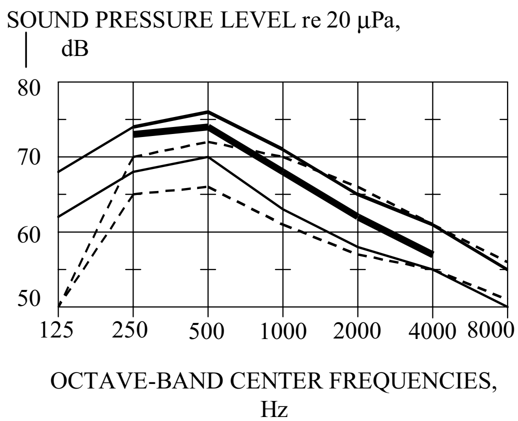


FIG. 3 - Octave-band speech peak sound levels for male and female talkers at a distance of 1 meter. The solid curves are for male talkers with normal (lower curve) and raised voices (upper curve). The dashed lines are for female talkers with normal and raised voices. The heavier solid curve is the ANSI S3.5 standard voice level.

Orientation of Talker

Speech sound level varies as a talker turns away from a listener. Speech levels are highest during face-to-face conversation where the talker is "on axis" (0∞) with the listener. As the talker turns away, the A-weighted sound level at the listener is reduced by approximately 1.5 dB for each 30º(the talker is off axis from the listener (see Figure 4).

The head orientation of the listener with respect to the talker makes little difference in terms of received level, and is therefore unimportant in sound masking calculations. For speech privacy calculations, assume that the talker is on-axis with the listener (worst case) unless the talker/listener orientation is fixed.

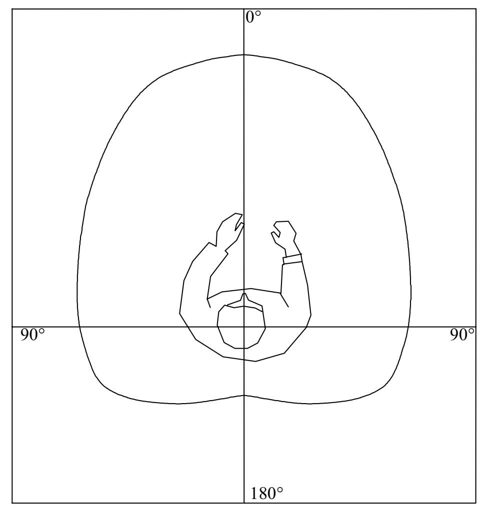


FIG. 4 - This polar plot shows the relative level from a talker versus angle. The speech level at a listener's position decreases by approximately 1.5dB for every 30º the talker is off-axis from the listener. The orientation of the listener's head is unimportant in speech level calculations.

Screens

The partitions between work areas in an open-plan office are called screens. Because these screens function as sound barriers, they must be designed to attenuate the sound passing through them and they must be tall enough to provide a barrier to sound passing over them. Finally, screens must be absorptive enough to prevent sound build-up within each workstation. Figure 5 illustrates these concepts.

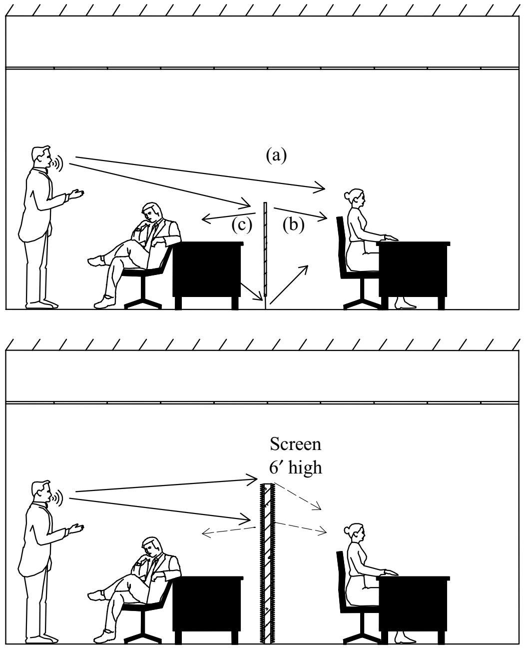


FIG. 5 - Screens should (a) be high enough to reduce sound passing over them, (b) provide a good barrier to sounds passing through them, and (c) absorb incident sound.

Sound Transmission Class

Sound transmission class (STC) is a standard way to specify the attenuation of sound through a wall, an open-plan office screen or other barrier. A higher STC is better. A screen with a high STC rating will attenuate the sound more than a screen with a low STC rating.

STC values for typical gypsum board office walls are 30 - 35. Very thick and massive wall constructions may have STC values of 60 or more. Open-plan office screens should have an STC value of at least 20. However, once the STC exceeds 25, the sound passing over the screen becomes the limiting factor. Thus, most commercially available screens have STC ratings between 20 and 30.

Diffraction

Even if the ceiling is non-reflective, sound can pass above a screen by a process known as “diffraction”. Lower-frequency sounds will diffract over a screen of a given height more easily than higher-frequency sounds. Fortunately, the higher-frequency sounds are the most important for speech privacy and this suggests that a screen higher than a tall person’s mouth level should be high enough to block diffraction of the most important speech frequencies.

Following this line of thinking, a 4-foot high barrier, which is barely above the level of a seated person’s mouth, provides only marginal attenuation between workstations, a 5-foot high barrier provides adequate attenuation if the ceiling and walls are very absorptive, and a 6-foot high barrier usually provides good attenuation.

For best results, the screen should be at least 3 times as wide as it is high although that implies 15-foot to 18-foot cubical widths which is often impossible. Ideally, the bottom of the screen should make direct contact with the floor. The maximum acceptable gap along the bottom of a screen is 1 inch.

Screens must be absorptive to prevent sound build-up in an individual workspace. A workspace surrounded by absorptive screens can be 5 to 6dB quieter than a hard-surfaced work area. However, screens can have their upper surface (no more than the top 1-foot) made of glass for visual openness.

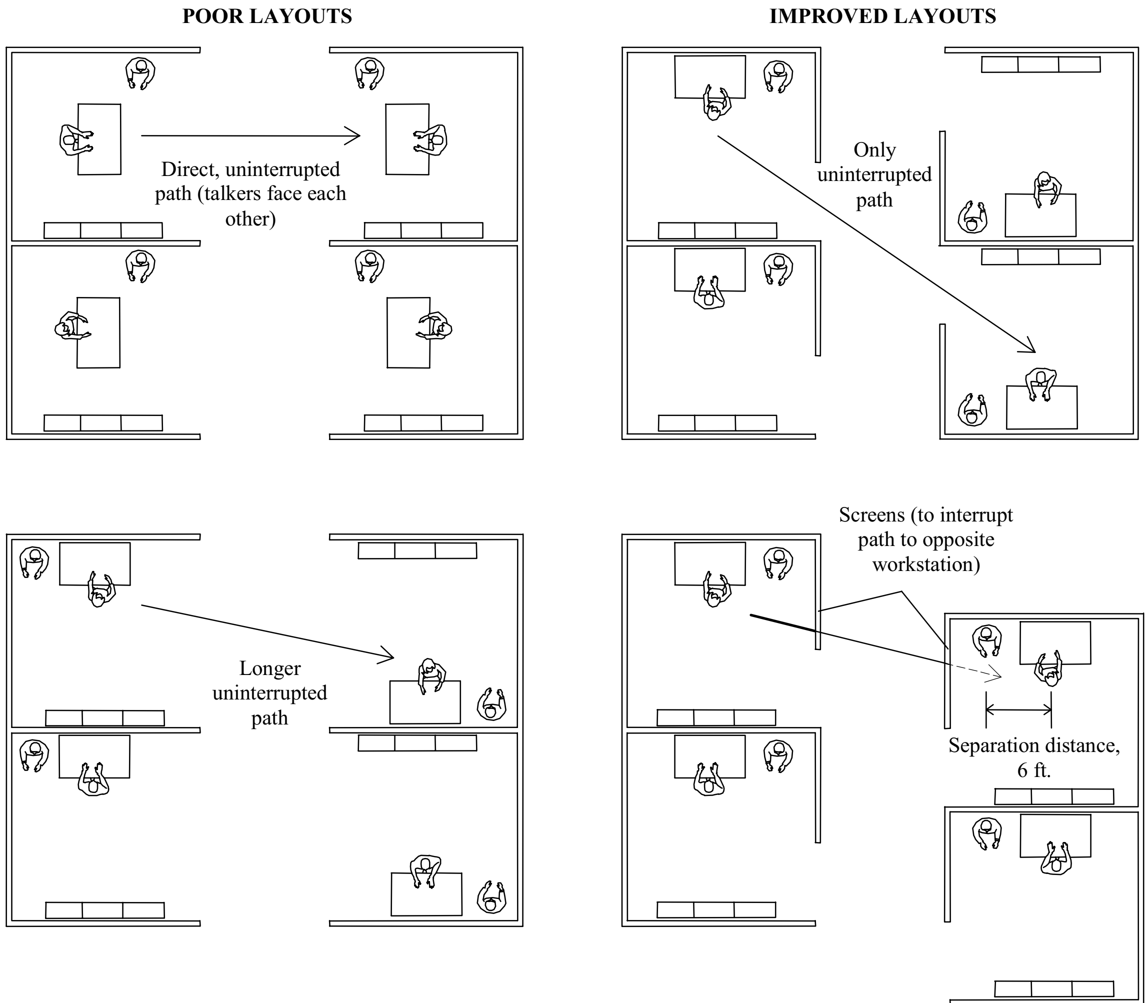


FIG. 6 - Examples of good and bad layouts for workstations in open-plan spaces.
Reduction of Reflected Sound Energy

Layout

Simple layout changes can often improve speech privacy in an open-plan office. And, even though these changes will disrupt daily routine in an existing space, clients with severe privacy problems are usually willing to comply. In general, an effective layout means avoiding these problems:

* Adjacent workstations closer than 10 feet (16 feet preferred)
* Workstation openings directly across from each other (line of sight)
* Side-by-side openings of two adjacent workstations
* Desks facing each other on each side of a screen (see page 12).
* Openings near windows or building curtain wall (external perimeter)
* Openings to a common corridor or other area with an opposite hard wall

Figure 6 shows poor and improved layouts for open-plan workstations.

Ceiling

The ceiling in an open-plan office affects speech privacy more than any other acoustical element. A hard ceiling reflects sound from one workstation to another, bypassing the sound barrier provided by the workstation screens. This problem is worse when the angle of reflection is between 40º and 60º. For this reason, open-plan offices should always have absorptive ceilings.

Absorption Ratings

The unit of absorption is the sabin. One "sabin" (in the US customary measurement system) is equal to one square foot of perfect (total) absorption. We often think of this as one square foot of an open window. "Absorption coefficients" rate the absorptivity of a surface between 0.00 (perfect reflector) and 1.00 (perfect absorber) and are written as two-decimal numbers. Specifications for typical interior finish materials provide absorption coefficients in octave bands. Absorption coefficients higher than 1.00 are sometimes given for very highly absorptive materials. This is an artifact of the testing procedure since it is impossible to absorb more than 100% of the incident sound.

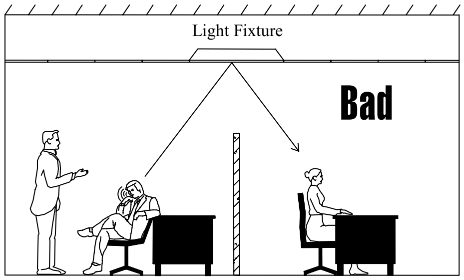
Noise Reduction Coeffcient

Ceiling tile absorption is rated with an acoustical descriptor called the "noise reduction coefficient" (NRC) which is an average of the absorption coefficients of the 250-Hz, 500-Hz, 1000-Hz, and 2000-Hz octave bands, rounded to the nearest 0.05. Typical 3/4-inch thick mineral fiber ceiling tile has an NRC value between 0.50 and 0.70 but normal speech privacy in open-plan office environments commonly requires 1-inch thick compressed fiberglass ceiling tiles with an NRC value of 0.90 or more.

Articulation Class

"Articulation Class" (AC) is a new rating for acoustical performance. A material's articulation class rating is the sum of the attenuations (in dB) of the 15 third-octave bands from 200 Hz to 5000 Hz.

Articulation class is measured between a source (talker) workstation and a receiver (listener) workstation in an actual open-plan office space. Because it measures effectiveness in real-world conditions, articulation class is the preferred rating method for ceiling tile. Select ceiling tile products with AC ratings of 200 or more for open-plan offices. If a ceiling tile product does not have an AC rating, use the NRC rating.



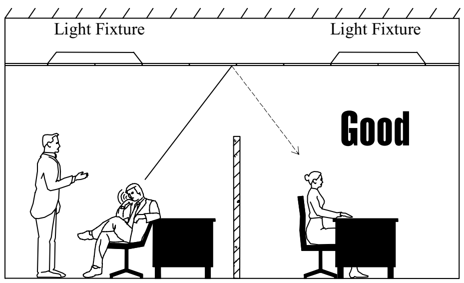


FIG. 7 - Speech frequencies reflect off the flat lenses of ceiling fluorescent fixtures. If the fluorescent fixtures are mounted over workstation partition screens, this reflected sound can reduce speech privacy.

Lighting Fixtures

Typical ceiling-mounted fluorescent lighting fixtures have flat plastic lenses flush with the ceiling. These fixtures reflect speech frequencies between workstations, "short-circuiting" the acoustic privacy provided by the workstation partition screens. To avoid this problem, do the following:

* **Best** — use indirect lighting in the work station and eliminate fluorescent ceiling fixtures.
* **Good** — use parabolic lens or open grid lighting fixtures and avoid placement over workstation partition screens.
* **Marginal** — use flat lens fluorescent fixtures but avoid placement over screens. When a client is unwilling to spend the money to replace flat lens lighting fixtures with parabolic lens types, ensure that the flat lens fixtures are not located over workstation partition screens. Often, fluorescent fixtures utilize flexible electrical conduit and can be moved to a new position without re-wiring. Figure 7 shows good and bad placement of fluorescent fixtures.

Masking Loudspeakers and the Ceiling

Sound masking loudspeakers are usually installed above the ceiling. Thus, the ceiling in an open-plan office must be capable of passing masking sound without excessive attenuation.

Special ceiling tiles

Foil-backed ceiling tile may be specified to diffuse the masking sound above the ceiling. High transmission loss tile may also be specified for sound masking. However, these special tile types are not really necessary in a correctly-designed masking system. In fact, they can cause problems. There are always small sound leaks in the ceiling. With normal ceiling tile the masking sound coming through these leaks is low in level and generally not a problem. If, however, the masking sound level is increased to force sufficient masking sound through high transmission loss ceiling tiles, then the masking sound eminating from the leaks may increase to the point that it becomes audible and distracting.

High transmission loss ceiling tiles can increase speech privacy between standard walled offices when masking is not provided.

Sound leaks

Although small ceiling leaks may not be a problem, it's best to avoid all leaks to the extent possible. The first place to look for sound leaks is the return air system.

In a typical open-plan space, room air returns to the building mechanical system through a ceiling plenum (the space between the ceiling and the deck). The air gets into the plenum through air return grilles installed directly in the ceiling. These grilles provide an open door for masking sound to leak into the office space below. Beneath these grilles, the masking sound will be louder and more high-pitched

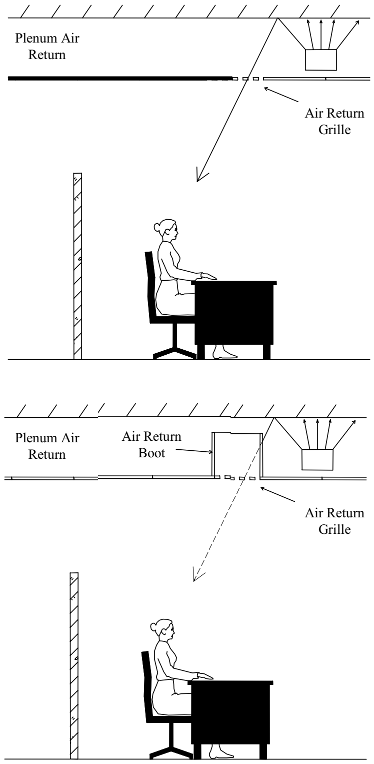


FIG. 8 - Install boots above open return air ducts in ceiling plenums.

and the masking sound coverage will be uneven. These are very undesirable results. Lighting fixtures with open grid diffusers can cause similar problems.

Other Causes of Unwanted Reflections

Ceilings aren't the only source of reflected sound problems in an open-plan office. As illustrated in Figure 9, hard floors and walls and even office furniture can contribute to unwanted reflections.

Boots

To prevent leaks in the ceilings of new buildings, install a length of fiberglass duct (called a boot) at each return air register. Figure 8 shows a return air register before and after the installation of a boot. In existing spaces, the ceiling contractor can fabricate boots. Use four 2' x 4' ceiling tiles (matching the tiles in the ceiling) set on end to form a 4' high vertical boot that is 2' x 2' in section. Attach the tiles together

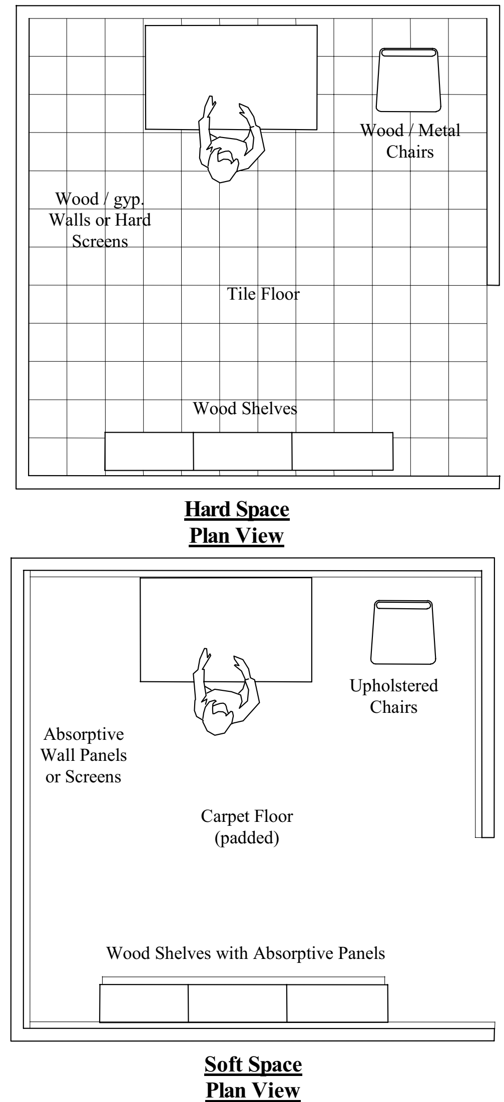


FIG. 9 - Use absorptive office furnishings and thick, padded carpet to reduce unwanted reflected sound.

with duct tape. Maintain the full opening area (typically four square feet), especially if the ceiling to deck distance is short (do not "pinch" air between the boot and the deck).

Open-plan offices must be carpeted. Thick padded carpets provide more voice frequency absorption than thin, direct glue-down carpets. Carpeting also reduces the irritation of footfall noises.
Choose absorptive office furniture including cloth-covered and thickly padded chairs (avoid leather chairs). If possible, select office furniture with absorption on its sur-

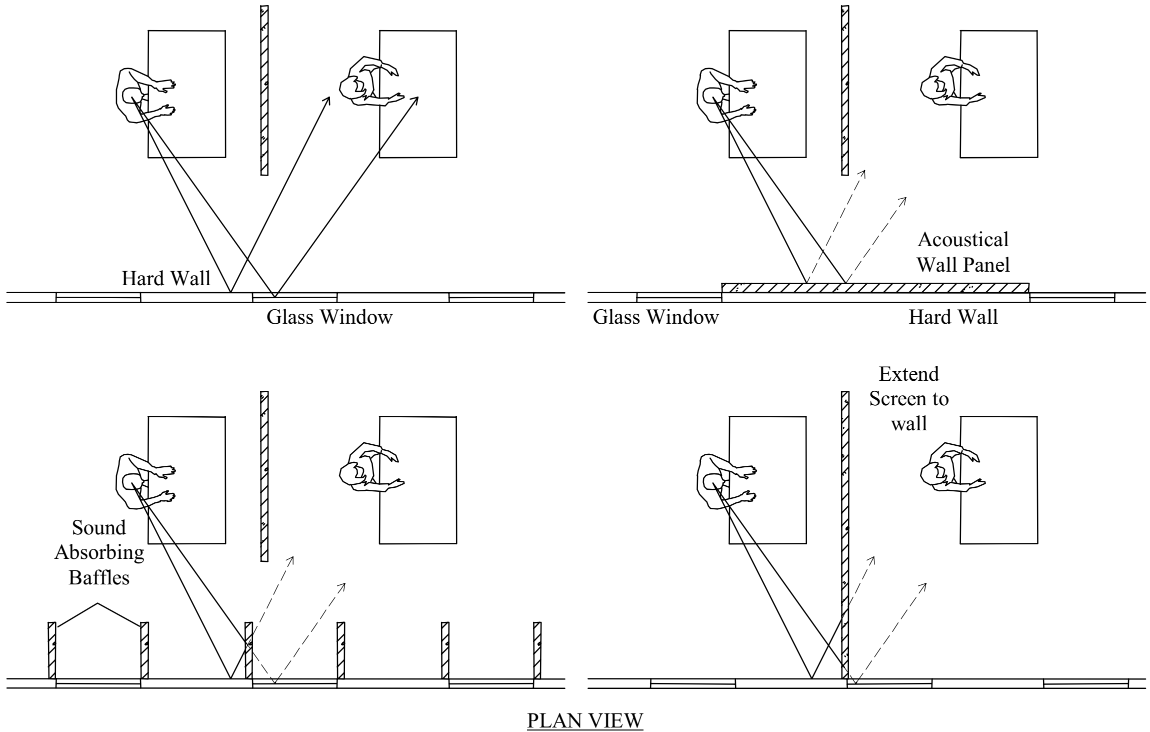


FIG. 10 - Walls, doors, windows and curtain walls can reflect sound into adjacent workstations.

faces such as shelf covers and drawer faces. Of course, workstation partition screens must be highly absorptive.

Hard walls, doors and windows can seriously degrade speech privacy in both open-plan spaces and in standard offices. Any hard, flat vertical surface such as a fixed wall, movable wall (curtain wall), window, or door can bypass the workstation screen barrier and reflect speech sound into an adjacent workstation (see the previous discussion of ceiling lighting fixtures). Figure 10 shows wall reflections and some possible solutions.

Sometimes, the best way to solve reflection problems is to change the room layout so that sound (speech) coming from one workstation can't reflect into openings in another workstation. When room layout changes aren't possible, add absorption to reduce the level of the reflected sound.

For walls, add the kind of acoustical wall panels that have an absorptive core material (usually rigid fiberglass board), a cloth covering (special fabrics for interior finish use), and a mounting system. Standard acoustical wall panels come in 2´x 2´, 2´x 4´, and 4´x 4´ sizes and in 1 inch and 2 inch thicknesses. Options include custom artwork or logo design, impact-resistant core material, and alternate mounting methods.

The outside wall in a glass building (the "curtain wall"), reflects sound between nearby open-plan workstations, reducing speech privacy. Acoustical wall panels could attenuate this reflected sound but would also block incoming light. One way to solve this problem is to install acoustic wall panels at 90º to the curtain wall as shown in Figure 10.

Ambient Noise

To the extent possible, keep building and office equipment noises below the level of the masking system. The heating, ventilating, and air conditioning (HVAC) system makes a sound similar to an electronic masking sound. However, the level and spectrum will be different from workstation to workstation and, in many buildings, the system cycles on and off.

Acousticians use one of two descriptors to rate HVAC system noise: Noise Criteria (NC) or Room Criteria (RC). Since the masking sound will be approximately RC 40, the HVAC sound should be no higher than RC 35 or NC 35. Evaluate the office equipment and building noise in an existing space by measuring the octave band sound levels with the HVAC system operating and office equipment being used. Ensure that each octave band sound level is 5 dB lower than the corresponding masking sound octave band level (See "Masking Spectrum" in Part 6) for the 250-Hz through the 4000-Hz octave bands. Then add electronic masking sound to raise background sound levels high enough to mask voices, but not so high that people subconsciously raise their voices.

It's okay to put a general-purpose conference area in an open-plan office environment. Highly private conference rooms, however, must be traditional separate spaces with high STC wall partitions that extend from the floor to the deck above the ceiling, sealed heavy doors and no sound leaks. These conference rooms may still benefit from reduced levels of masking sound. For teleconferencing, use very absorptive interior finishes, very high STC walls, and no sound masking.

Part 3
The Basic Electronic Sound Masking System

The electronic sound masking system creates a “blanket” of background noise carefully controlled in level, spectrum, and coverage. Masking sound should not call attention to itself in any way. It should merely seem to be part of the general building noise. In fact, if people are unaware that a masking system is in operation, they usually believe they are hearing the ventilation system.

Concept - Don’t Tell the Employees?

One of the early rules of sound masking installations was “Don’t tell tell the employees that we just installed sound masking”! Many believed the employees would complain about headaches or other maladies, or that the masking system was some type of corporate manipulation. Of course, these concerns were unfounded. Masking simply reduces the speech-to-noise ratio and masking sound is no more harmful than any other low-level mid-frequency sound.
Today, partly because of the popularity of personal masking units, this early rule no longer applies. In fact, it is difficult if not impossible to “sneak” a masking system into an existing office space. It is better to tell employees about the masking system and sell them on its benefits.

Self-Contained Masking Units

Large sound-masking systems may cover entire floors or even entire office buildings. Small systems may cover only one office or workstation. For these small systems, with only a few loudspeakers, consider self-contained masking units. These self-contained devices have a built-in masking sound generator, simple equalizer, small amplifier, and loudspeaker. Generally, self-contained units use local (workstation) AC power. In some cases, they can utilize a circulated DC power supply.

Single-Channel vs Multi-Channel Masking

For budget reasons, masking systems commonly use a single generator, equalizer, and power amplifier. However, a two-channel, or even a multi-channel masking system has a distinct performance advantage.
In a single-channel system, all masking loudspeakers have the same coherent signal. As employees walk out of the coverage of one loudspeaker into the next, they hear phase cancellations between the two loudspeakers. This “phase shift” sound draws unwanted attention to the masking system (ventilation sounds would not produce this effect). Two-channel systems minimize this problem by connecting adjacent loudspeakers to separate masking generators. Multi-channel systems reduce this problem to negligible levels.

Basic Electronics

For larger systems, with many masking loudspeakers, economics dictate a central rack of equipment containing the masking sound generators, equalizers, and amplifiers. To enhance security, terminate all cables inside the rack and close and lock the rack doors to prevent tampering with

the equipment. Ensure the rack has adequate ventilation for uninteruppted usage 24 hours a day, 365 days a year.
For an existing space, include the cost of an electrical subcontractor to provide dedicated AC circuits hardwired into the rack.
Consider an uninterruptible power supply (UPS) to prevent system shutdown during brief power outages or brownouts.

Sound Masking and Background Music or Paging

Background music and paging systems normally use loudspeakers installed in holes in the ceiling, facing downwards to provide intelligible, clear sound to the listeners.
Sound masking systems normally use loudspeakers installed above the ceiling tiles, facing upwards or sideways to randomize the distribution of the masking sound.
Following these suggestions will make the most of a combined system. A combined masking and paging system usually involves compromise in performance to one system or the other. However, it is not impossible.
Background music and paging take place at a higher level than masking. Thus, in a combined system, choose a higher power amplifier and loudspeakers and tap the loudspeakers at a higher level. Always use separate equalizers for the masking sound and the background music and/or paging.
Do not allow the masking sound to be ducked or attenuated during a page. Never combine masking with a life-safety system.

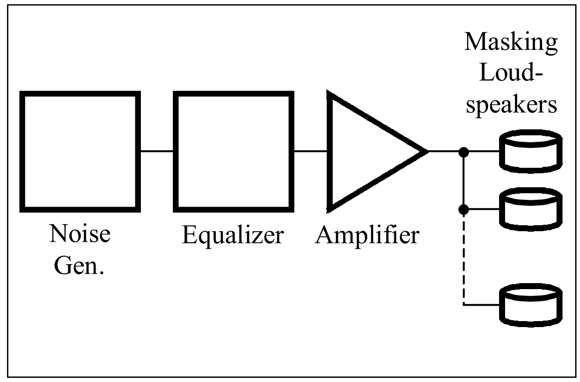


FIG. 11 - Wiring diagram of a basic sound masking system.

Basic System Electronics

A basic masking system includes a masking sound generator, an equalizer, a power amplifier and one or more loudspeakers.
Figure 11 is the wiring diagram for a basic masking system. Electronically, basic sound masking systems are among the simplest types of sound systems.

Masking Sound Generator

The electronic masking generator (noise generator) is the heart of the masking system. Pink noise (equal energy per octave) is the most common masking noise. In rare situations, a white noise generator (equal energy per hertz) may benefit the system.
Choose a generator that is rack-mounted, AC powered and produces a stable noise signal.
An ideal masking noise generator produces true random noise that never repeats.
Digital noise generators generate a pseudo-random signal that repeats every so often.
Choose either a true random noise generator (analog) or a digital noise generator

with a pseudo-random sequence of at least several seconds. Test equipment noise generators usually repeat too frequently to be acceptable for sound masking.
Some masking sound generators have computer controls that gradually reduce the normal daytime masking sound to a preset nighttime level. This reduction usually begins just after normal office hours and slowly takes place over one to two hours. Then, one to two hours before the office reopens, the masking sound level gradually ramps back up to the normal level. The level change is usually on the order of 6 dB. However, in some circumstances, masking sound is more critical during quiet after-hours times.

Equalizer

For sound masking, use a third-octave equalizer with included high and low pass filters, interpolating filter interaction response and overall shaping filters. Interpolating filters allow a boost or cut at a frequency between two adjacent third-octave frequencies by the relative settings of the adjacent filter controls. Alternately, use a parametric equalizer. The best parametrics have control over the complete audio range in each filter. Other signal processing devices such as delays, crossovers, and notch filters are not normally required for masking systems.

Amplifier

Use high quality professional or commercial grade power amplifiers with 70-volt outputs for sound masking. The ability to run continuously year in and year out is much more important in a masking amplifier than good audio performance.

Part 4

Multi-Channel Masking, Background Music, and Paging

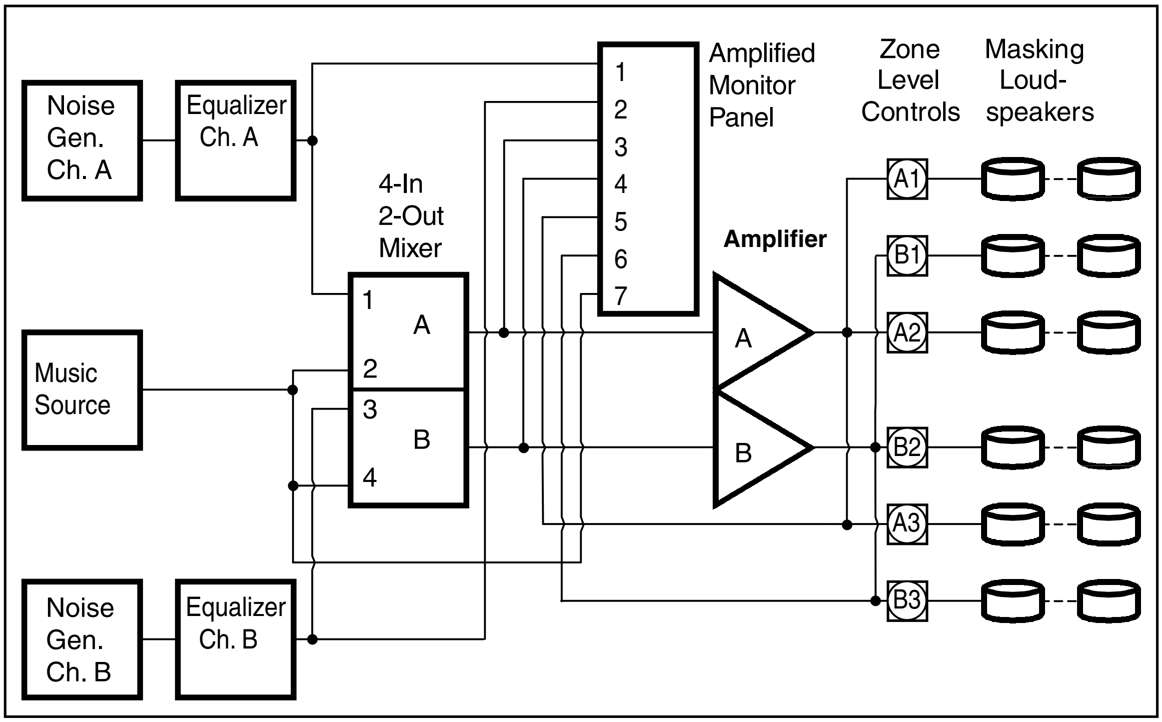


FIG. 12 - Wiring diagram of a two-channel sound-masking system with zone level controls, background music, and an amplified monitor panel.

Very simple masking systems, with only the bare minimum of components, are fairly rare. More commonly, a masking system includes a two-channel generator, signal monitoring for troubleshooting and sometimes even paging or background music. Figure 12 is the wiring diagram for a two-channel system with background music, zone level controls and signal monitoring.

Two (and more) Channel Masking

Two-channel masking systems route separate masking signals to adjacent loudspeakers. Because the sound from adjacent loudspeakers is no longer coherent, employees can walk from place to place in the workspace without hearing the “phasing” sound typical of single-channel systems.
To create a two-channel masking system, add a second masking generator, equalizer and power amplifier to the basic system (or use a two-channel power amplifier).

Zone Level Controls

Larger masking systems may cover more than one workspace in a building. Unless the workspaces are acoustically very similar, each deserves its own masking sound level control. Even in a single large room, it may be useful to provide separate level controls for open areas, walled offices, conference rooms and corridors.

Discuss level-control zones with the client early in the masking system design. Use autoformer-type level controls with 1.5 dB steps and sufficient power capacity to serve all of the loudspeakers in the zone. In multiple-channel systems, use a separate control for each channel in each zone.

Provide a rack-mounted panel when the quantity of controls exceeds one or two. To avoid tampering, locate zone level controls behind locked doors (or in the equipment rack).

Some systems use multiple power-amplifier channels in place of zone level controls. Although this method adds cost, it may be a good solution in systems that include background music or paging.

Amplified Monitor Panel

An amplified monitor panel makes troubleshooting easy. Choose one that allows monitoring at each point in the system block diagram, after the masking generator(s), after the equalizer and after each power amplifier. The monitor panel should include a VU or LED meter and a loudspeaker. Complex systems may need more than one monitor panel.

Background Music / Paging

It may be easier to sell a masking system to certain clients if the system includes background music or paging. Intergrating masking, paging, and background music using the same speakers and amplifiers can be full of compromises for one or all of the intended uses if not designed properly.

When installing any background music system to avoid copyright infringment, use a licensed music service to provide the music.

Always use a separate equalizer for the music so that it sounds natural after penetrating the acoustical ceiling.

Paging requires a higher sound level than either masking or background music.

When paging is combined with a masking loudspeaker system, the paging sound must be loud enough to penetrate the ceiling tile. For these reasons, a combination masking and paging system requires higher-power amplifiers and loudspeakers. This also suggests that it may be difficult to add paging to an existing masking system. Remember to never mute or duck the masking sound in a combined system.

Paging Sound Level

To calculate the paging sound level of a masking loudspeaker at the listener, first gather the following information:

* S = loudspeaker sensitivity
  (from the manufacturer's data sheet)
  This must be given as dB SPL with 1 watt input at 1 meter distance
* P = power delivered to the loudspeaker in watts (from the system designer)
  Usually equal to the power tap on the loudspeaker transformer
* D = distance, in meters, from loudspeaker to listener, including the reflected path.
  To convert feet to meters, divide feet by 3.28
* 15dB = SPL level lost as the sound passes through the ceiling tile.

Substitute the actual loss if it is different from this typical value for ceiling tile.

After obtaining the data, calculate L, the paging level at the listener, in dB SPL, with the following formula:

$$L = S + 10\log_{10}P - 20\log_{10}D - 15dB$$

Consider a typical masking system with a loudspeaker rated at 95 dB sensitivity (1w/1m), tapped at 2 watts, and aimed at the deck above the ceiling. The reflected path length is approximately 14 feet to a typical listener and the sound must pass through a mineral-fiber ceiling tile. What is the expected paging level at the listener's position?

Insert these values into the formula to obtain:

$$L = 95 + 10\log_{10}(2) - 20\log_{10}(14/3.28) - 15$$

$$\text{or } L = 95 + 3.0 - 12.6 - 15 = 70.4 \text{ dB SPL}$$

In a quiet office, paging levels must be 5 to 6 dB louder than this (about 76dB SPL). This extra 6dB means quadrupling the transformer wattage tap to 8 watts. Chances are, that means a more expensive transformer and a higher power amplifier.

Paging Equalizers

Use a separate paging equalizer to compensate for the uneven transmission loss (with frequency) of the ceiling tile. It may be possible for one equalizer to handle both music and paging, but the masking equalizer must be separate. Multi-channel masking complicates a system that includes paging or background music. Study the block diagram in such a system to ensure the paging or background music distribution doesn't compromise the multi-channel masking.

Part 5

Masking Loudspeakers and Self-Contained Masking Units

Masking Loudspeakers

Masking loudspeakers are special assemblies designed for installation in ceiling plenums. A typical assembly consists of a 4 or 8-inch cone speaker, a 70.7-volt speaker line transformer, a metal enclosure with baffle, and a hanging/mounting hardware kit. Since masking does not pose difficult performance requirements, most masking loudspeakers are general purpose types with 10 to 20-watt power ratings.

System Integrators, such as AVL Electronics commonly offer several models of masking loudspeaker to meet different system requirements.

Upwards Loudspeaker Orientation

Masking loudspeakers usually face upwards, towards the deck. In new construction, a system of light-gauge chain suspends each masking loudspeaker. In existing construction, where the plenum is cluttered, choose a masking loudspeaker designed to be installed on top of the ceiling tile grid.

A typical office has a 9-foot height to the ceiling tile, a plenum extending about 4 feet above the ceiling tile and a hard deck at the top of the plenum. In this kind of construction, mount the masking loudspeakers low in the plenum space with the bottom of each loudspeaker about 6 to 8 inches above the ceiling tile. Point the loudspeakers upward at the hard deck as shown in Figure 13.

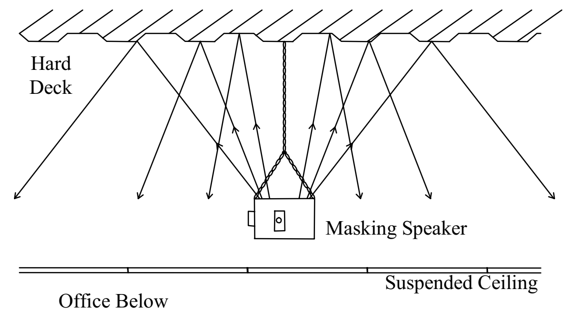


FIG. 13 - Typical masking loudspeaker suspended in a ceiling plenum with a hard deck.

Space the loudspeakers about 12 to 14 feet apart horizontally. The sound will reflect off the deck down through the ceiling tile and into the space below. This ensures an even coverage of masking sound because the sound mixes fairly well in the plenum.

Downwards Loudspeaker Orientation

Roof decks (above the ceiling on the top floor of a building) usually have sprayed-on thermal insulation that is also an efficient acoustical absorber. In this situation, mount the masking loudspeakers high in the plenum and point them downward as shown in Figure 14.

The effective distance from loudspeaker to listener is shorter with downward-pointing loudspeakers because the sound does not reflect off the deck. This reduces the loudspeaker's horizontal coverage (compare Figure 13 and Figure 14). Also, an absorptive deck does not diffuse the sound as well as a hard deck. Thus, to ensure even coverage in this situation, place the loudspeakers no more than 8 feet apart horizontally.

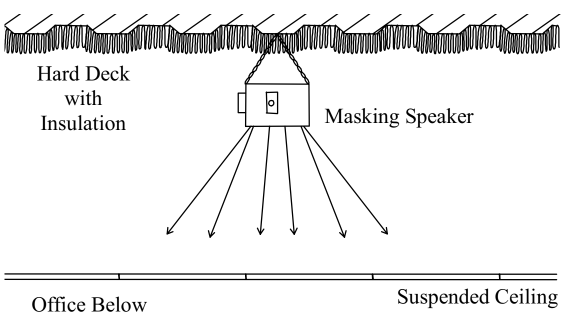


FIG. 14 - If the underside of the deck is absorptive because of sprayed-on thermal insulation (top floor of many buildings), mount the masking loudspeakers as high as possible and point them downwards. This configuration requires more loudspeakers to maintain even coverage.

Horizontal (Sideways) Loudspeaker Orientation

Some masking loudspeakers can be suspended sideways so that they radiate sound horizontally. In general, horizontal orientation has no advantage over upward orientation and upward orientation will usually provide more even coverage.

However, horizontal orientation can be an advantage near an unavoidable leak in the ceiling. Orient the masking loudspeakers horizontally to radiate sound away from the leak during the system commissioning process.

In-Ceiling Placement

Occasionally, the plenum may be crowded with obstructions which would prevent even coverage of the masking sound.

Occasionally, the space between the ceiling tiles and the deck may be very short. In these cases, install standard, down-firing ceiling speakers, like those used for background music or paging. To prevent "hot spots," do the following:

* Space the loudspeakers very close together and overlap their coverage.
* Use 4-inch ceiling speakers which have wider dispersion than 8-inch models.
* Use at least two masking channels so the sound is not mixed in the plenum.
* Use back box enclosures to keep rear-radiated sound from reflecting through ceiling leaks and causing hot spots.

Valuable Masking Loudspeaker Features

Some masking loudspeakers include a rotary switch, mounted on the outside of the assembly, to select the internal 70-volt transformer's wattage taps. This makes it possible to adjust the power to each loudspeaker without disassembling the unit. During system testing, select a wattage tap that produces masking sound approximately 10 dB above the background sound in the voice-range third-octave bands (typically the 2-watt tap). As stated earlier, combined paging and masking systems usually require a higher wattage tap.

Choose masking loudspeakers that come with electrical boxes mounted to the sides of their enclosures or with conduit-compatible access plates. Whether the installation uses conduit or plenum-rated cable without conduit, make the loudspeaker connections inside the electrical box or inside the enclosure to avoid violating local building safety codes. Always comply with all state and local codes, as well as the National Electrical Code, for any masking loudspeaker installation.

Self-Contained Masking Units

Self-contained masking units consist of a masking sound generator, equalizer, amplifier, and loudspeaker in one compact unit, basically a complete sound masking system in a box. Some self-contained masking units operate from standard AC power, while others operate from a shared DC power supply. In general, if the application requires only one or two units, the AC power version is easier to install. If the application requires several units, it is cheaper to provide one DC power supply that feeds several units.

Install self-contained masking units in the ceiling plenum just like any other masking loudspeaker, or place them in an inconspicuous place in an office to accomplish "spot" masking as shown in Figure 15.

Sometimes, self-contained masking units can help sell a prospective client on the benefits of a permanent masking system. Install one or more self-contained masking units in a small area of their space on a trial basis.

Self-contained masking units can be mounted either above or below the ceiling. For this reason, they must have level controls and filters to adjust the masking sound for the chosen location.

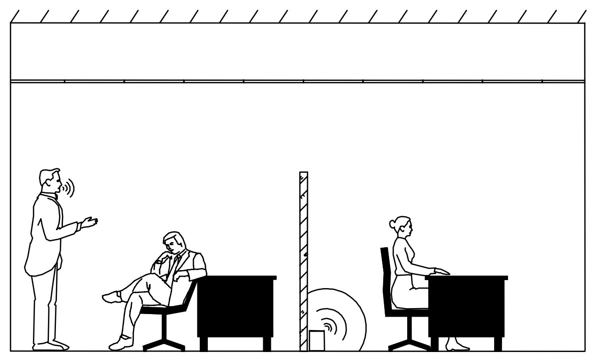


FIG. 15 - A self-contained masking unit used as a "spot" masker in an office.

Part 6

Commissioning the Masking System

"Commissioning" the masking system takes place in two steps:

1. Confirm the proper installation and function of all system components.

2. Adjust the system level, spectrum and coverage to the design specification.

Good coverage simply means every listener hears masking sound at the desired level and spectrum given in the initial specification.

Level

Proper masking sound level is very important. If the masking level is too low, it won't do its job of increasing speech privacy. If the masking level is too high, people in the space will subconsciously raise their voices, negating any improvements in speech privacy.
Masking sound level for the listener should be between 45 and 50 dB(A) (A-weighted SPL decibels). Implementing the third-octave band levels given in the Part 6 section entitled "Ideal Masking Spectrum" will result in a masking level of 47 dB(A).

Connecting Spaces

Sometimes one part of a building has masking sound while a connecting space does not. Taper the masking sound level between these areas. An abrupt level difference would make the masking sound much more noticeable to people walking between the two spaces. To achieve the tapering, add a few masking loudspeakers between the two spaces tapped at a lower wattage setting.

Setting the Level During System Adjustment

During system adjustment, set the masking level above background sounds such as those created by the building heating, ventilating, and air-conditioning (HVAC) system. This makes it possible to adjust the masking spectrum without influence from these background noises. Ideally, the masking level should be 10 dB above background noises during this phase. However, it may not be possible to achieve this goal for the lower octave bands since HVAC sounds may be quite loud in those lower bands. After adjusting the spectrum, reduce the masking level to its proper speech privacy level of approximately 47 dB(A).

Gradually Adjust to Final Level

It's a good idea to let people in the masking environment become accustomed to a new masking system over a period of several weeks. Start by setting the masking level 6 dB lower than the desired level. Operate the system at this reduced level for one week, then increase the level 1.5 dB during off-hours. Raise the level another 1.5 dB at the end of each week until the system reaches the desired masking level. Use precision attenuators, with 1.5 dB steps, or use a loudspeaker zone level control panel if the system has one. If the system is easy to adjust, the client can make the adjustment after the close of business each week. To gradually change the level automatically, use the kind of microprocessor-controlled masking sound generators described previously. If a client has a severe speech privacy problem, accelerate the level step-up program or dispense with it altogether.

Masking Spectrum

Figure 16 shows a typical masking spectrum compared to typical “quiet” building sound, pink noise, and white noise.

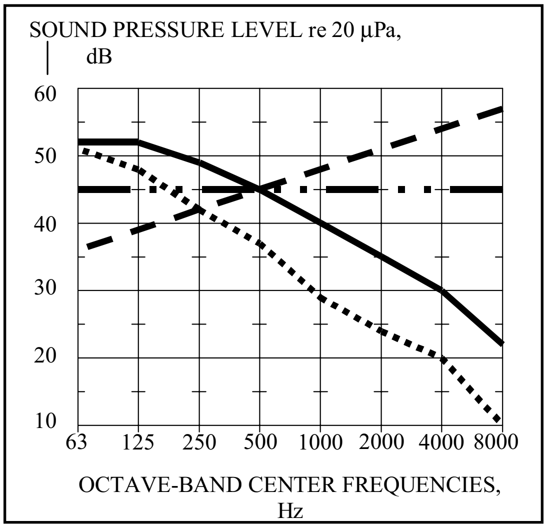


FIG. 16 - Octave-band sound pressure levels of typical masking sound (solid line curve), typical “quiet” building background sound (dotted line curve), pink noise (horizontal straight line plot), and white noise (upward-sloping straight line plot). The white noise and pink noise spectra are shown normalized to match the masking level at 500 Hz.

Ideal Masking Sound Spectrum

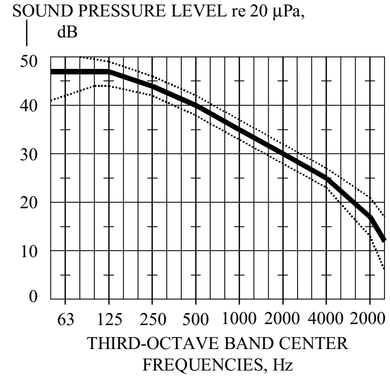
To achieve the best speech privacy at a listener’s position, the masking sound spectrum should be similar to the spectrum of average voices. Because the spectrum of average voices depends on the acoustical environment, the ideal masking spectrum also changes with the acoustical environment. Following are three masking spectra chosen to illustrate this ideal in different acoustical environments. All three curves are given to the nearest tenth of a dB only to show the trend of the curve. In actual practice, it is challenging to stay within desired dB tolerances at all locations.

Masking Spectrum 1

Masking Spectrum 1, given in the table below, is appropriate for a walled space or ideal open-plan space (5-foot minimum height screens, absorptive ceilings and furnishings, and proper layout).
Masking Spectrum 1 above is plotted in Figure 17 and is the preferred spectrum for properly designed interiors because its sound quality is very neutral and unobtrusive.

FIG. 17

1/3rd-Octave Band	dB SPL
50 Hz:	47.0 (+4/-6) dB
63 Hz:	47.0 (+4/-5) dB
80 Hz:	47.0 (± 4) dB
100 Hz:	47.0 (± 3) dB
125 Hz:	47.0 (± 3) dB
160 Hz:	46.0 (± 3) dB
200 Hz:	45.0 (± 2) dB
250 Hz:	44.0 (± 2) dB
315 Hz:	42.7 (± 2) dB
400 Hz:	41.3 (± 2) dB
500 Hz:	40.0 (± 2) dB
630 Hz:	38.3 (± 2) dB
800 Hz:	36.7 (± 2) dB
1000 Hz:	35.0 (± 2) dB
1250 Hz:	33.3 (± 2) dB
1600 Hz:	31.7 (± 2) dB
2000 Hz:	30.0 (± 2) dB
2500 Hz:	28.3 (± 2) dB
3150 Hz:	26.7 (± 2) dB
4000 Hz:	25.0 (± 2) dB
5000 Hz:	22.3 (± 2) dB
6300 Hz:	19.7 (± 3) dB
8000 Hz:	17.0 (± 4) dB
10,000 Hz:	12.0 (+4/-6) dB

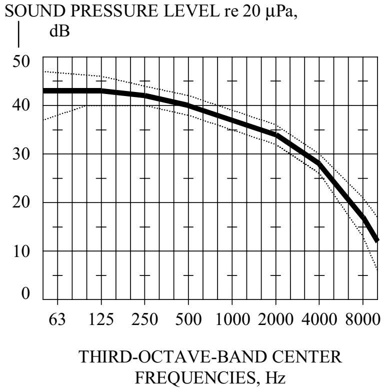


Masking Spectrum 2

Masking Spectrum 2, given in the table below, and charted in Figure 18, is appropriate for good open-plan spaces (screens 4 - 5 feet high, some reflective surfaces, and moderate furniture absorption). Compared to Masking Spectrum 1, Masking Spectrum 2 increases the sound level slightly (2 dB) at 2000 Hz, the band that contributes most to intelligibility. This spectrum still results in fairly neutral masking sound quality.
The dotted-line curves show the tolerance of the spectrum which is appropriate for good open plan spaces.

FIG. 18

1/3rd-Octave Band	dB SPL
50 Hz:	45.0 (+4/-6) dB
63 Hz:	45.0 (+4/-5) dB
80 Hz:	45.0 (± 4) dB
100 Hz:	45.0 (± 3) dB
125 Hz:	45.0 (± 3) dB
160 Hz:	44.3 (± 3) dB
200 Hz:	43.7 (± 2) dB
250 Hz:	43.0 (± 2) dB
315 Hz:	42.0 (± 2) dB
400 Hz:	41.0 (± 2) dB
500 Hz:	40.0 (± 2) dB
630 Hz:	38.7 (± 2) dB
800 Hz:	37.3 (± 2) dB
1000 Hz:	36.0 (± 2) dB
1250 Hz:	34.7 (± 2) dB
1600 Hz:	33.3 (± 2) dB
2000 Hz:	32.0 (± 2) dB
2500 Hz:	30.3 (± 2) dB
3150 Hz:	28.7 (± 2) dB
4000 Hz:	27.0 (± 2) dB
5000 Hz:	23.7 (± 2) dB
6300 Hz:	20.3 (± 3) dB
8000 Hz:	17.0 (± 4) dB
10,000 Hz:	12.0 (+4/-6) dB

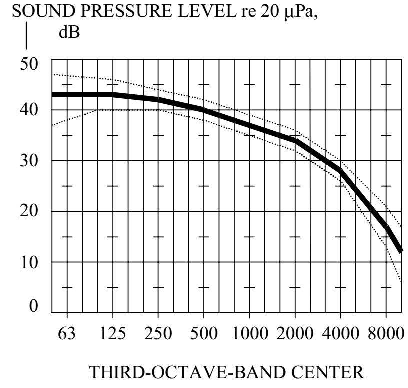


Masking Spectrum 3

Masking Spectrum 3, given in the table below, and charted in Figure 19, is appropriate for non-ideal open-plan spaces (no screens or screens under 4 feet high, reflective surfaces, and moderate furniture absorption).
Compared to Masking Spectrum 1, Masking Spectrum 3 increases the sound level by 4 dB at 2000 Hz. This spectrum will result in less neutral masking sound quality than either Masking Spectrum 1 or 2. The dotted-line curves show the tolerance of this spectrum which is appropriate for non-ideal open-plan spaces.

FIG. 19

1/3rd-Octave Band	dB SPL
50 Hz:	43.0 (+4/-6) dB
63 Hz:	43.0 (+4/-5) dB
80 Hz:	43.0 (± 4) dB
100 Hz:	43.0 (± 3) dB
125 Hz:	43.0 (± 3) dB
160 Hz:	42.7 (± 3) dB
200 Hz:	42.3 (± 2) dB
250 Hz:	42.0 (± 2) dB
315 Hz:	41.3 (± 2) dB
400 Hz:	40.7 (± 2) dB
500 Hz:	40.0 (± 2) dB
630 Hz:	39.0 (± 2) dB
800 Hz:	38.0 (± 2) dB
1000 Hz:	37.0 (± 2) dB
1250 Hz:	36.0 (± 2) dB
1600 Hz:	35.0 (± 2) dB
2000 Hz:	34.0 (± 2) dB
2500 Hz:	32.0 (± 2) dB
3150 Hz:	30.0 (± 2) dB
4000 Hz:	28.0 (± 2) dB
5000 Hz:	25.0 (± 2) dB
6300 Hz:	21.0 (± 3) dB
8000 Hz:	17.0 (± 4) dB
10,000 Hz:	12.0 (+4/-6) dB



Comparison of All Three Masking Spectra

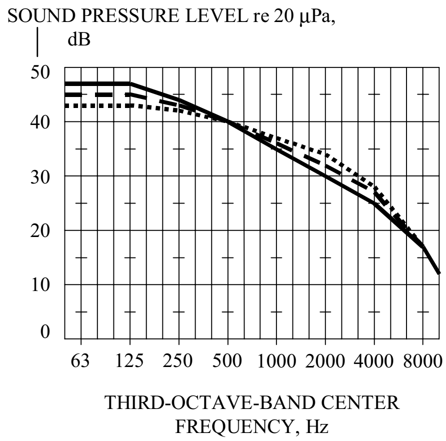


FIG. 20 - Comparison of Masking Spectra:
Sound Masking Spectrum 1 ——————— *(preferred)*
Sound Masking Spectrum 2 — — — — — — —
Sound Masking Spectrum 3 ----------------

Equalizing the System: The Equalization Process

After selecting one of the three masking spectra, equalize the system as follows: Use a 1/3-octave spectrum analyzer, measuring microphone, sound level meter (SLM) and oscilloscope. It may be possible to use the SLM as the measuring microphone. See the section entitled "Test Equipment" for a more thorough discussion of test equipment requirements.

Locate the microphone in a typical listening position, as described below, and locate the spectrum analyzer at the equipment rack.

* Set all amplifier input controls fully counter-clockwise so there is no masking sound through the loudspeakers.
* Set the system equalizer controls to the flat position.
* Set any equalizer gain controls to achieve unity gain on all channels.
* Place the measuring microphone in a typical listening position at ear level.
* Increase the gain for the amplifier feeding this listening position until the masking sound level is 50 dB SPL in the 500-Hz third-octave band as seen on the spectrum analyzer.
* Ensure the amplifier is not clipping. Connect the oscilloscope to the amplifier output and look for squared-off wave tops which indicate clipping.
* Increase the amplifier gain 10 dB so the sound level at 500 Hz is 60 dB SPL.
* Again, ensure the amplifier is not clipping.
* Now, adjust the equalizer to reach the desired spectrum between 200 Hz and 5000 Hz.
* Try moving the measuring microphone if it seems necessary to adjust any individual equalizer control more than 3 dB above the unity gain position. This will avoid over-stressing the amplifier and loudspeakers.
* If low frequencies cannot be adjusted to this elevated level, readjust these bands later when the masking sound level has been reduced to the final level.
* Reset the amplifier gain fully counter-clockwise (no masking sound).
* Repeat the previous steps for each channel in the system, ending with all amplifier controls fully counter-clockwise.
* Finally increase the amplifier gain controls equally on all channels until the sound level meter reads 47 dB(A) at all listening positions.
* If necessary, readjust the low-frequency bands.
* Fine-tune the equalizer so that the building HVAC noise and masking sound together achieve the desired spectrum.
* Check the coverage at additional listening positions as described next.

Using an Octave-Band Equalizer for Troubleshooting

Although it cannot be used to commission the system, a hand-held, octave-band analyzer is a convenient way to troubleshoot or survey the masking system. Because each band in an octave-band analyzer receives the energy from three 1/3-octave bands, proper levels are approximately 5 dB higher than those given in the 1/3-octave tables above. The following three tables give octave-band levels for the three masking spectrums discussed earlier.

Masking Spectrum 1		Masking Spectrum 2		Masking Spectrum 3	
Octave Band	dB SPL	Octave Band	dB SPL	Octave Band	dB SPL
63 Hz:	52 dB	63 Hz:	50 dB	63 Hz:	48 dB
125 Hz:	52 dB	125 Hz:	50 dB	125 Hz:	48 dB
250 Hz:	49 dB	250 Hz:	48 dB	250 Hz:	47 dB
500 Hz:	45 dB	500 Hz:	45 dB	500 Hz:	45 dB
1000 Hz:	40 dB	1000 Hz:	41 dB	1000 Hz:	42 dB
2000 Hz:	35 dB	2000 Hz:	37 dB	2000 Hz:	39 dB
4000 Hz:	30 dB	4000 Hz:	32 dB	4000 Hz:	33 dB
8000 Hz:	22 dB	8000 Hz:	22 dB	8000 Hz:	22 dB

Coverage

With the system in normal operation, walk the space, using your ears and a meter to assess the masking level and spectrum throughout the entire space. If necessary, fix problems and readjust the system as follows:

* While walking the space, listen and observe the meter to find any "hot spots."
* Determine the cause of any hot spots (open return air grill, etc.).
* Fix the problems before re-adjusting the masking system (return air boot).
* Remember to check levels in any walled offices served by the masking system.
* If the level is too high in these walled offices, which is typical, adjust the transformer taps for the appropriate masking loudspeakers.
* If the system has zone controls, adjust them to achieve the same level in all zones.
* Re-check all areas, adjusting transformer wattage taps as required.
* If uneven coverage remains, re-orient, move, or turn off loudspeakers as required.

Ensuring good coverage is a tedious process, but it is necessary to achieve the desired masking performance throughout the space. The final masking sound level should not deviate more than 2 dB(A) from the desired spectrum throughout the entire space, except where it is deliberately tapered down like entry ways.

Test Equipment

Masking system installers need proper test equipment to set masking levels and spectra. Start with a sound level meter (SLM) meeting American National Standards Institute (ANSI) Class 1 standards for precision accuracy. Ideally, this SLM should have A-weighting, C-weighting, linear (flat) response, octave filters, and third-octave filters. An ANSI Class 1 real time analyzer will make the job easier because it displays all third-octave bands at one time.

Changes in temperature, humidity, and barometric pressure can cause changes in the accuracy of the sound level meter or analyzer. For this reason, they must have dedicated acoustic calibrators. The acoustic calibrator is a precision sound pressure source that couples to the measurement microphone of the unit. Use the calibrator before every measurement session to ensure that the instrument is reading true sound levels. Return the instrument and the calibrator to the manufacturer once a year to be re-calibrated to national standards.

Part 7

PREDICTING PRIVACY IN THE MASKING ENVIRONMENT

As originally discussed, the goal of most masking systems is to increase speech privacy. A well-planned sound masking system achieves this goal by reducing speech sound energy and increasing background sound (with masking sound). But how can speech privacy be quantified? This section shows how to predict articulation and privacy and it discusses how to use the speech privacy worksheet given as Appendix B.

Articulation Index and Privacy Category Definitions

The Articulation Index (AI), rates speech intelligibility with a two-decimal place fraction between 0.00 (no intelligibility) and 1.00 (perfect intelligibility). Specifically, AI rates speech intelligibility in relation to background noise, so this is a very useful measurement term in the field of sound masking.

ANSI Standard S3.5 gives three methods for calculating AI: the 20-band method, the third-octave band method, and the octave band method. Of the three, the 20-band method is the most accurate, but also the most difficult to implement. The octave band method is easy to calculate, but is the least accurate. For the purposes of this paper however, the octave band method is accurate enough.

Speech privacy can be considered the inverse of speech intelligibility. The higher the intelligibility, the lower the privacy, and vice versa. Therefore, calculating speech intelligibility makes it possible to predict speech privacy. The following table relates AI to subjective speech intelligibility and speech privacy:

Subjective Speech Intelligibility	Articulation Index	Subjective Speech Privacy
Excellent	0.75 – 1.00	none
Good	0.60 – 0.74	none
Fair	0.45 – 0.59	none
Poor	0.33 – 0.44	none
Bad	0.20 – 0.32	Marginal (0.20 to 0.30)
Bad	0.05 – 0.19	Normal
Bad	0.00 – 0.04	Confidential

Subjective Speech Intelligibility Articulation Index

The terms Excellent, Good, Fair, Poor, and Bad are standard subjective terms used to describe speech intelligibility and to rate AI scores. Similarly, the terms Marginal, Normal, and Confidential are subjective terms used to describe speech privacy. Notice that all the privacy ratings fall under the Bad intelligibility category.

Marginal Privacy

Marginal is the minimum rating that could be used to describe speech privacy. Eavesdropping is very easy in a marginal speech privacy environment and audible conversations may distract employees.

Normal Privacy

Normal is usually the best level of speech privacy achieveable in an open-plan office space. A masking installation that achieves normal privacy will reduce distractions from nearby conversations, footfall noise, and the sounds of office equipment. However, even in a normal privacy installation, listeners will still be able to hear speech, and they may even be able to eavesdrop, if they listen carefully and know something about the subject of the conversation.

Confidential Privacy

Confidential privacy is expected in certain offices and conference rooms. With Confidential privacy, listeners may hear conversations from adjacent rooms, but these conversations will not be intelligible. Eavesdropping is not usually possible in environments with confidential privacy.

Total Privacy

Occasionally, a client may expect total privacy, so that speech from one space is completely inaudible in adjacent spaces. Sound masking alone will not ensure Total privacy. Total privacy requires special construction techniques, materials, and building layouts, and is therefore beyond the scope of this paper.

Predicting Speech Privacy

When an acoustical consulting firm designs a sound masking system, they will tell the client what speech privacy can be expected. The acoustical consulting firm is usually part of a design team working closely with the architect. As a result, the consultant will recommend the screens, ceilings, furniture, wall types, and layouts. The acoustical consultant will also design the sound masking system to meet the client's needs.

Because the results of a sound masking system are so heavily dependent upon the acoustics of the space, it is usually better for the sound masking contractor to let the acoustical consultant predict the privacy criteria.

In retrofit situations, the client will often contact a sound contractor directly for sound masking. In that case, the contractor should make a reasonable prediction of the achievable speech privacy.

The worksheet in Appendix B is an aid to sound contractors evaluating spaces for sound masking. By cataloging the layout, furniture, screens, ceiling, and other items, the worksheet helps calculate the articulation index, which can be converted to a subjective privacy rating.

Run the worksheet calculations for the existing condition, then for hypothetical improvements such as addition of masking sound, increased screen height, and absorptive ceiling tile. Of course, the accuracy of the worksheet is directly related to the detail level and accuracy of the acoustical assessment. To aid in this assessment, the worksheet instructions contain information about evaluating building furnishings and fixtures.

After the worksheet, several examples show the typical process of evaluating a space. Examples are given for open plan and standard walled office spaces.

The following case histories describe real problems and solutions encountered on actual projects. These cases illustrate principles given in this paper.

Part 8

Case Histories

Masking Improves Speech Privacy in a Quiet Space

In the open-plan offices of a major oil company, nighttime ambient noise levels were very low. As a result, employees could carry on normal-voice line-of-sight conversations over distances greater than 60 feet and speech privacy was effectively impossible. Masking sound was an obvious and successful solution.

Boots Reduce Hot Spots Problem

In one project, the client wanted a masking system design for an existing space. Even though the design specified boots over the air registers, the ceiling contractor did not install them resulting in hot spots in masking sound coverage.

The client needed to move into the space immediately, so the masking sound contractor moved and re-aimed and re-tapped the masking loudspeakers to create acceptable coverage. However, this did not completely solve the hot spots problem.

Finally, the masking sound contractor created simple boots by duct-taping four ceiling tiles together to form a 2-ft square duct, four feet tall. Each boot was set upright on the 2 ft x 2 ft return air grills. These boots completely eliminated the hot spots under the return air grills. After re-equalization, the resulting coverage was much smoother.

Problems Resulting from Uninstalled Boots

A client had an existing open-plan office area with speech privacy problems. A site survey showed that the ceiling had many (seemingly hundreds!) open return air registers. To work around the problem, the designer specified that no loudspeaker could be located closer than 4 feet to a return air register.

The contractor did a professional installation. However, final testing revealed a nightmare of hot spots and uneven coverage. To achieve even coverage, the contractor turned many of the loudspeakers completely off.

The contractor grumbled audibly (and with good reason) about installing so many loudspeakers that were not even used.

To avoid this kind of problem, check the ceiling and HVAC configuration before designing the masking system. The sound contractor should install return air boots if there is no mechanical contractor on the job site.

Leaky Luminaires Cause Hot Spots

On one project, the client had selected fluorescent light fixtures with open louvered grids instead of plastic lenses. This type of fixture scatters reflected sound from below making it preferrable, for speech privacy, to a flat lens fixture. However, the metal casing of this particular fixture had many holes and slots (possibly for venting) that leaked masking sound into the office below.

To make things worse, the system loudspeakers were aimed downward because of the thermal insulation applied to the underside of the deck above. The contractor could not install boots above the fixtures because there were a great many fixtures, the electrical conduits were in the way, and service personnel would have removed the boots the first time they serviced a fixture. To solve the problem, the contractor re-oriented the loudspeakers nearest these fixtures to point horizontally rather than downward. This reduced the amount of high frequency energy directed at the fixture itself without having to rely on bouncing sound off the absorptive deck.

Masking Loudspeakers Tapped Too Low

For one low-budget system, the designer specified a small power amplifier and loudspeakers tapped at 1/2 watt each. The system did the job, but could not achieve a sound level much above the background noise making equalization difficult. Also, the contractor could not tap the loudspeakers downwards to compensate for hot spots, since 1/2 watt was the lowest tap on the transformers.

To avoid this problem, specify 4-watt transformers tapped at 2 watts for a normal loudspeaker location. Then, the contractor can re-adjust loudspeakers in problem areas 3 or 6 dB lower (1-watt or 1/2-watt setting), or 3 dB higher (4-watt setting). Choose an amplifier to handle twice the initial load to allow for expansions to the system and for tapping loudspeakers to higher wattage settings.

Complicated System

One very complicated, multi-floor, sound masking system included background music, priority zoned paging and supervised lines. The system also had remote priority attenuators that increased sound levels whenever paging occurred in the zone. The challenge was to design a system that would maintain constant masking sound level and constant line supervision.

After a very complicated installation, the system finally met its design goals. However, the designers learned a valuable lesson. For a highly complex design, implement the sound masking portion as a standalone system using loudspeakers above the ceiling. Then, install the paging and background music portions separately through standard ceiling loudspeakers. The result will be better clarity, less equalization, and much lower power draw. If the masking system requires supervised lines, try to avoid speaker-level switching circuits.

Medical Suite Masking Test

Some years ago, sound masking was uncommon in medical suites. During that time, one designer proposed sound masking to a group of doctors who were about to move to a new professional building. The doctors, who were unfamiliar with sound masking, were rightly worried that masking might drown out the sounds of pulses, breathing, and other audible symptoms heard through their stethoscopes.

For this reason, the designer proposed a trial masking system which was installed between two examination rooms and the area just outside these rooms. The improvement in speech sound isolation was immediate and dramatic and the doctors had no problems using their stethoscopes or other instruments.

Prior to the test system installation, doctors and patients could hear every word from the next examination room. After the installation, the doctors reported that patients were much more at ease because speech from the next examination room was unintelligible. In fact, the doctor with the examination suite with the trial masking system was the envy of all his colleagues!

Medical Professional Building Masking

This case history involves the experience of a patient visiting two doctors. One doctor's office had a masking system, the other didn't. When visiting the doctor without a masking system, the patient reported clearly hearing every word the doctor and another patient said in an adjoining examination room even though the doors to both rooms were closed.

In contrast, when visiting the doctor whose office had a masking system, the patient reported hearing but not understanding, the voices of the doctor and patient talking in the next room. This masking system had achieved confidential privacy.

Masking Improves Privacy in a Pastor's Office

In a large church, the senior pastor provided marriage counseling and other personal advisory services in his office. The pastor's secretary, whose desk was right outside the pastor's office, could hear some of the counseling sessions. When the secretary informed the pastor about this problem, he requested an inexpensive solution to the speech privacy problem. A contractor installed self-contained masking units in the pastor's office, the secretary's office and the waiting room. This solved the problem and shut down a primary source of gossip in the church!

Masking and Unwanted Reflections in a Psychiatrist's Office

Psychiatrist's offices require extremely confidential privacy. For one particular job, the doctor wanted to be able to leave her door open unless it was absolutely necessary to close it. The door opened to a corridor that opened to other therapists' offices in the same suite. The doctor decided to install sound masking.

The masking sound designer warned the doctor that the gypsum board wall in the corridor would reflect sound into the other offices, but she and her architect elected not to treat the wall at first. As a result, the hard corridor wall almost completely negated the benefits of sound masking, high STC walls, and special room finishes that had been installed in the offices.

Finally, with all the other treatments in place, the problem of sound reflecting from the corridor wall was so obvious that the doctor finally decided to add acoustical treatment to the wall. This solved the problem.

Part 8

Conclusion

Basic masking systems are relatively simple to design, install and commission but results are greatly influenced by the acoustics of the ceilings, screens, furniture and interior finishes.

When designing a masking system,remember these three steps:

1. Reduce the direct speech sound level (screens, distance)
2. Reduce the reflected speech sound level (ceiling, furniture, wall treatments)
3. Raise the background sound level (sound masking system)

In an open-plan space, the system designer and installer must carefully coordinate all three of these items to achieve acceptable privacy. In normal offices, adding masking alone will often make a noticeable difference in speech privacy.

When designing the masking system itself, remember to optimize these three items:

1. Level (between 45 dB(A) and 50 dB(A)
2. Spectrum (chosen masking curve)
3. Coverage (± 2 dB throughout space)

Masking sound can lower the speech-to-noise ratio in a space, thereby increasing speech privacy. Clients in open-plan spaces, normal office spaces, educational spaces, medical examination rooms and offices and many other spaces can benefit from this increased privacy.

Appendix A

Definitions

ambient noise - The background noise in a given environment, usually composed of many sound sources from many directions, near and far.

articulation class (AC) - The sum of the weighted sound attenuation values in the one-third octave bands between from 200 Hz to 5000 Hz. The rating correlates with transmitted speech intelligibility between office spaces. The articulation class is approximately 10 times the difference in A-weighted levels for sound propagating between talker and listener positions. Some ceiling tile products carry an articulation class rating. For sound masking in open-plan offices, design for an articulation class greater than 200.

articulation index (AI) - A number ranging from 0.00 to 1.00 which is a measure of the intelligibility of speech - the higher the number, the greater the intelligibility.

A-weighted sound level - The sound level in decibels as processed through an A-weighting filter. The A-weighting electronic filter approximates average human hearing at low to moderate sound levels. The unit symbol is dB(A).

background noise - The total noise from all sources except for a particular sound that is of interest. (See ambient noise.)

confidential privacy - Confidential privacy implies extremely low intelligibility. An articulation index (AI) of less than 0.05 is considered confidential privacy.

decibel - A decibel is 10 times the base 10 logarithm of the ratio of two power levels. Since we measure sound pressure level more commonly than sound power level, we extend the definition of the decibel for sound to be 20 times the base 10 logarithm of two pressure levels. The decibel is abbreviated as "dB".

diffraction - A process whereby a wavefront changes direction, usually at the edge of an obstacle or other nonhomogeneity in the medium, in some way other than reflection or refraction.

direct sound - Sound which reaches a given location in a direct line from the source, without reflections.

free field - A sound field (in a homogenous isotropic medium) whose boundaries exert a negligible influence on sound waves.

frequency - Of a function that is periodic in time, the number of times that the quantity repeats itself in 1 second (cycles per second). Unit: hertz. Unit symbol: Hz.

marginal privacy - Marginal privacy implies somewhat low intelligibility. An articulation index (AI) between 0.20 and 0.30 is considered marginal privacy.

masking sound - Masking sound is an electronically-generated random noise signal (usually pink noise) filtered to achieve a specific spectrum, amplified to achieve a specific level, and emitted as sound through loudspeakers to achieve a specific coverage. The purpose of masking sound is to raise ambient sound levels in interior spaces for increased speech privacy.

noise - (1) Any disagreeable or undesired sound. (2) A random sound or electronic signal whose spectrum does not exhibit clearly discernable frequency components.

noise criterion (NC) curves - A series of curves of octave band sound spectra used for rating the noisiness of an occupied indoor space. The actual noise spectrum is compared to the noise criteria (NC) curves to determine the NC level of the space.

noise isolation class (NIC) - A single-number rating derived from measured values of noise reduction between two enclosed spaces that are connected by one or more paths; this rating is not adjusted or normalized to a standard reverberation time.

noise isolation class prime (NIC') - The speech privacy noise isolation class. A single-number rating similar to the NIC except that the frequency range under consideration is narrower and the allowable deviations are less. This descriptor is often specified in open-plan acoustics.

noise reduction coefficient (NRC) - A single-number rating of the sound absorption properties of a material like acoustical ceiling tile or acoustical wall panels; the arithmetic mean of the sound absorption coefficients at 250, 500, 1000, and 2000 Hz, rounded to the nearest multiple of 0.05. For open-plan sound masking, if a ceiling product does not have an articulation class (AC) rating, then refer to its noise reduction coefficient. A value of 0.90 or higher is preferred, with 0.70 minimum value for adequate speech privacy.

normal privacy - normal privacy implies low intelligibility. An articulation index (AI) between 0.05 and 0.20 is considered normal privacy.

pink noise - An electronically-generated random noise signal which has equal energy per octave or fractional octave bands. Pink noise has a flat response on octave or third-octave band analyzers.

room criterion (RC) curves - A series of curves of octave band spectra used for rating the noisiness of an unoccupied indoor space. The actual noise spectrum is compared to the room criteria (RC) curves to determine the RC level for the space.

sabin - A unit of measure of sound absorption. One sabin is the equivalent of 1 ft2 of a perfectly absorptive surface. A metric sabine is the equivalent of 1 m2 of a perfectly absorptive surface.

sound - (1) A physical disturbance in a medium (usually air) that is capable of being detected by the human ear. (2) The hearing sensation excited by a physical disturbance in a medium.

sound absorption - The property possessed by materials, structures, and objects of converting sound to heat, resulting from either propagation in a medium or dissipation when sound strikes a surface.

sound absorption coefficient - The fraction of the randomly incident sound power which is absorbed (or otherwise not reflected) by a material. Sound absorption coefficients are given in octave bands for many materials with values ranging from 0.01 (very hard surface like polished marble) to 1.00 and higher (very absorptive products such as glass fiber boards).

sound pressure level (SPL) - The sound level in decibels that in air is 20 times the logarithm (base 10) of the ratio of a given sound pressure and the reference sound pressure of 20 micropascals. If weighting is specified, the term "sound level" or "weighted sound pressure level" is used.

sound transmission class (STC) - A single number rating used to compare the sound insulation (isolation) properties of walls, floors, ceilings, windows, or doors.

white noise - An electronically-generated random (usually) noise signal which has equal energy per equal bandwidth in hertz. White noise has a rising response (3 dB per octave) on octave or third-octave analyzers.

Appendix B

Worksheet

To evaluate the acoustics of an office space, use the worksheet titled “Sound-Masking, Octave-Band, Articulation-Index Worksheet” found at the end of this Appendix. This worksheet has the following sections:

* Octave-band data and calculations
* Input for talker voice level and orientation
* Input for talker-to-listener distance
* Input for furniture, screens, and ceiling
* Input for masking sound levels
* Simple calculation of resulting data to AI
* Conversion of AI to speech privacy

General Instructions

Refer to the worksheet while reading these instructions. Also see the Detailed Instructions section that follows. The purpose of the worksheet is to predict speech privacy for one talker and one listener. To begin, select a typical talker-listener configuration, then enter data and run the calculations. If desired, repeat the process for different talker-listener configurations or to predict the improvement from new building furnishings or from added sound masking.

Entering the Data

At the top of the worksheet are the column headings for the octave bands. The octave band columns carry through all sections of the worksheet.

Use Worksheet sections A - F to enter octave-band acoustical data for the space being evaluated. Each section includes typical data already entered on the sheet.

There are two ways to enter data in the row entitled “Your Values”. First (and ideally), perform the indicated measurements in the actual space. Second, simply transfer data from one of the preprinted rows based on good judgement about the space.

For example, in Section A, use an octave-band sound level meter to measure the typical talker levels in the space. Or, if the talker levels are fairly normal, just copy the numbers from the row entitled “ANSI Standard”. In either case, write a one-line explanation of the data source below the entered values.

Calculating the Speech Level at the Listener

Section G is a sum of the values in each octave band. These summed values represent the voice level of the talker from Section A modified by the talker orientation, and distance, office partition screens, acoustical ceiling, and other building furnishings from Sections B through F. The results at Section G are the octave-band sound levels expected at the listener’s position.

Calculating the Articulation Index

Enter the background sound levels (including masking sound) in Section H. Then, in Section I, subtract the numbers in Section H from the numbers in Section G. Next, in Section J, multiply the Section I levels by the articulation index weighting factors. Finally, add the numbers in the last row of Section J to yield the articulation index. Enter this result in the single box of Section K. Refer to Section L to interpret this final result.

Section A Instructions

The worksheet gives data for three voice levels: Raised, ANSI Standard, and Normal. These levels are peak levels for male voices. For female voices use the following data:

Octave Band Center Frequency:	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Raised Female Voice, dB SPL:	70 dB	72 dB	70 dB	66 dB	61 dB
Normal Female Voice, dB SPL:	65 dB	66 dB	61 dB	57 dB	55 dB

Use the ANSI Standard level unless the situation clearly fits one of the other descriptions.

A. Select talker voice level and enter values (or measured values) in last row of table:

Octave Bands	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Raised:	74	76	71	65	61
ANSI Standard:	73	74	68	62	57
Normal:	68	70	63	58	55
Your Values:	________	________	________	________	________

Section B Instructions

This section modifies the values entered in Section A to compensate for talker orientations other than face-to-face. Listener orientation does not affect the values. Choose one of the orientations and enter the values in the "Your Values" line at the end. Interpolate between rows if necessary.

Notice that the first line of data (0°) contains all zeros. Use this line if the talker faces the listener or if the talker's orientation is unknown or changes frequently.

B. Select talker orientation to listener and enter values (or interpolated values) in last row of table:

Octave Bands	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
0° (facing listener):	0	0	0	0	0
45°:	-1	-2	-2	-2	-3
90°:	-3	-4	-4	-5	-6
135°:	-5	-6	-7	-7	-8
180°:	-7	-8	-9	-9	-10
Your Values:	________	________	________	________	________

Section C Instructions

This section reduces the values entered in Section A to compensate for the normal attenuation of direct sound at increasing distance from the talker. Measure the direct path from the chosen talker to the chosen listener. Ignore any obstacles for this measurement.
If this measure distance corresponds to one of the worksheet rows, simply copy the numbers from that row to the row entitled "Your Values". Alternately, use the values given in the table below. Use the same number for each octave band since, at these distances, distance does not affect the spectrum, only the level.

Distance, ft	Reduction, dB
4	-1
5	-3
6	-5
8	-7
10	-9
12	-11
16	-13
20	-15

To calculate the exact reduction in level for an odd distance, use the following formula:
dB reduction = 20log 10(3.28/distance) +1

Where distance is in feet. Use the direct distance from talker to listener ignoring obstacles (screens or walls). The +1 at the end of the formula is a correction for interior acoustics.

SOUND MASKING

C.

Octave Bands	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
6 feet:	-5	-5	-5	-5	-5
10 feet:	-9	-9	-9	-9	-9
16 feet:	-13	-13	-13	-13	-13
Your Values:	________	________	________	________	________

Section D Instructions

This section modifies the values entered in Section A to compensate for the acoustics of the furniture, walls, and carpet. The first row of data is entitled “Absorptive”.

Use this data if the acoustics meet the following criteria:

* Chairs are softly cushioned and covered with upholstery cloth (not leather)
* Book shelves and file cabinets have absorptive surfaces where possible
* Walls have acoustical wall panels or other absorptive treatment
* Carpet is deep pile and thickly padded.

Unless the space was designed for speech privacy, it’s unlikely that it will meet the above criteria. Typical workspaces meet the “Mixed” row criteria as follows:

* Chairs are normal cushioned office types covered with upholstery cloth
* Book shelves and file cabinets are standard wood or metal
* Walls have little or no acoustical treatment
* Carpet is standard padded commercial grade

If a space has the following characteristics, use the data from the “Hard” row:

* Chairs do not have much padding or are not cloth-covered
* Book shelves and file cabinets are wood or metal
* Walls are hard
* There is no carpet on the floor

Interpolate values if a space seems to fall between these descriptions.

D. Select walls/furniture/carpet absorption and enter values (or interpolated values) in last row of table:

Octave Bands	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Absorptive:	0	0	0	0	0
Mixed:	+2	+2	+2	+2	+2
Hard:	+4	+4	+4	+4	+4
Your Values:	________	________	________	________	________

Section E Instructions

This section modifies the values entered in Section A to compensate for the acoustical effect of screens and ceiling. These two elements are grouped together because the effectiveness of one depends upon the other.

Use one of the rows for "hard ceiling" if the space has a plaster, gypsum board, or wood ceiling that reflects sound. Use one of the rows for "absorptive ceiling" if the space has a typical mineral fiber ceiling tile with an NRC range of 0.55 - 0.65. If the space has very absorptive fiberglass ceiling tiles, use the following data:

Octave Bands	250	500	1,000	2,000	4,000
No screen, very absorptive clg:	0	0	0	0	0
4′ screen, very absorptive clg:	-3	-4	-4	-4	-4
5′ screen, very absorptive clg:	-4	-5	-6	-6	-7
6′ screen, very absorptive clg:	-5	-7	-9	-9	-10
7′ screen, very absorptive clg:	-6	-8	-10	-11	-12

E. Select screen/ceiling condition and enter values (or interpolated values) in last row of table:

Octave Bands	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
No screen, hard clg.:	+2	+2	+2	+2	+2
No screen, abs. clg.:	+1	+1	+1	+1	+1
4′ screen, hard clg.:	0	0	0	0	0
4′ screen, abs. clg.:	-2	-3	-3	-3	-3
5′ screen, hard clg.:	0	-1	-1	-2	-2
5′ screen, abs. clg.:	-3	-4	-5	-5	-6
6′ screen, hard clg.:	-1	-2	-2	-2	-3
6′ screen, abs. clg.:	-4	-5	-6	-6	-8
7′ screen, hard clg.:	-2	-2	-2	-3	-4
7′ screen, abs. clg.:	-5	-6	-6	-8	-10
Ceiling-ht partition:	-19	-30	-36	-24	-28
Your Values:	________	________	________	________	________

Section F Instructions

Hard surfaces can reduce speech privacy by reflecting sound energy from the talker's workstation into adjacent spaces. The position of the hard surface, with respect to the talker and listener, is most important. A hard surface that directly reflects sound (a first-order reflection), just like a mirror, is a problem surface. To determine if a hard surface will be a problem, imagine a mirror on the surface. If it's possible to see into an adjacent workstation by looking at this imaginary mirror, then sound will also reflect into the adjacent workstation. Typical reflective surfaces include walls, windows (or curtain walls), and flat lenses on fluorescent lighting fixtures.

Section F of the worksheet modifies the values entered in Section A to compensate for these anomalies. Use the first row of data if the space has no problematic acoustically reflective surfaces. Use the second row of data if the space includes ceiling-mounted lighting fixtures with flat lens panels over the screen between two workstations. Use the third row of data if the space includes a hard wall that can reflect sound between two workstations. If both the second and third row conditions exist, add +8 to all octave bands.

F. Select anomaly and enter values (or interpolated values) in last row of table:

Octave Bands	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
No refl. surf./no screen:	0	0	0	0	0
Flat light panels:	+2	+3	+4	+5	+6
Hard wall:	+6	+6	+6	+6	+6
Your Values:	________	________	________	________	________

Section G Instructions

Sum the "Your Values" rows from Sections A through F and enter these values in the "Sum of Your Values" row in Section G. These are the predicted octave-band speech sound levels at the listener's workstation. The following sections use the data from Section G levels to calculate the articulation index.

G. Sum Your Values from tables A through F:

Octave Bands	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Sum of Your Values:	________	________	________	________	________

Section H Instructions

Enter the background sound levels (including masking sound) in the "Your Values" row of Section H. Measure the actual background sound level or choose one of the data sets in the table.

Choose the first row of data for an office with no masking. For a space where masking sound will be installed in the future, use data from the "47 dB(A)" row. Background sound levels can be highly variable from space to space, and even within one space. Use data from the 45 dB(A) or 50 dB(A) rows if the space is likely to be above or below the normal 47 dB(A) masking sound space level.

H. Select masking sound level and enter values (or measured/interpolated values) in last row of table:

Octave Bands	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Office, no mask'g:	42	37	29	24	20
45 dB(A):	47	43	38	33	28
47 dB(A):	49	45	40	35	30
50 dB(A):	52	48	43	38	33
Your Values:	__________	__________	__________	__________	__________

Section I Instructions

Calculate the speech-to-noise ratio in dB by subtracting the octave-band background noise levels in Section H from the speech levels determined in Section G. If the result is less than 0, enter 0. If the result is greater than 30, enter 30.

I. Subtract Your Values in Table H from Your Values in Table G:*

Octave Bands	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Your Values:	__________	__________	__________	__________	__________

*(if result is <0, enter 0; if result is >30, enter 30)

Section J and Section K Instructions

Section J calculates the actual articulation index (AI). First multiply the values from Section I by the AI weighting factor given in Section J for each octave band. Enter these results in the bottom row. Then, add all of the numbers in the bottom row to calculate the AI. Enter this final result in the box in Section K.

J. Multiply Your Values in Table I times the factors below:

Octave Bands	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Multiplication Factors:	0.0024	0.0048	0.0074	0.0109	0.0078
Multiplication Results:	__________	__________	__________	__________	__________

K. Sum the Multiplication Results from Table J to get the Articulation Index, AI

Sum of Multiplication Results =	____________

Section L Instructions

Use Section L to interpret the articulation index in terms of expected speech privacy. If the AI from Section K is less than 0.05, the space should achieve "confidential privacy". If the AI is 0.05 - 0.20, the space should achieve "normal privacy". If the AI is 0.21 - 0.30, the space should achieve only "marginal privacy". If the AI is greater than 0.30, there will be little or no speech privacy.

Sound-Masking, Octave-Band, Articulation-Index Worksheet

L. Interpretation of Privacy Level based on AI from Table K

AI	Privacy Rating
< 0.05	Confidential
0.05 to 0.20	Normal
0.21 to 0.30	Marginal
> 0.30	None

Worksheet Example 1

Open Plan Environment

Part 1 - No Speech Privacy

Assume a client wants a masking system in an open-plan space with standard office furniture, 4-foot high screens, commercial padded carpet, mineral fiber ceiling tile, and workstations spaced approximately 8 feet apart.

First, determine the speech privacy without masking sound by entering the following data and performing the calculations on the worksheet:

	Octave Band Center Frequency	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
A.	ANSI Standard voice level:	73	74	68	62	57
B.	0° orientation:	0	0	0	0	0
C.	8 feet distance:	-7	-7	-7	-7	-7
D.	Mixed ambient absorption:	+2	+2	+2	+2	+2
E.	4-ft screen/ abs. ceiling:	-2	-3	-3	-3	-3
F.	No nearby reflections:	0	0	0	0	0
G.	Sum of rows A - F:	66	66	60	54	49
H.	Office sound, no masking:	42	37	29	24	20
I.	Subtract H from G:	24	29	30	30	29
J.	Multiply row I by:	× 0.0024	× 0.0048	× 0.0074	× 0.0109	× 0.0078
K.	AI = sum of row K = 0.97	0.0576	0.1392	0.2220	0.3270	0.2262
L.	Speech Privacy in this example is None!					

Part 2 - Add Masking Sound

Not only is there no privacy in the above example, the speech intelligibility will be Excellent!

To see the effect of adding masking sound to the space without other modifications, re-calculate the worksheet with the 47 dB(A) (normal level) masking sound data from Section H of the Worksheet:

	Octave Band Center Frequency	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
A.	ANSI Standard voice level:	73	74	68	62	57
B.	0° orientation:	0	0	0	0	0
C.	8 feet distance:	-7	-7	-7	-7	-7
D.	Mixed ambient absorption:	+2	+2	+2	+2	+2
E.	4-ft screen/ abs. ceiling:	-2	-3	-3	-3	-3
F.	No nearby reflections:	0	0	0	0	0
G.	Sum of rows A - F:	66	66	60	54	49
H.	Masking, 47 dBA normal level	49	45	40	35	30
I.	Subtract H from G:	17	21	20	19	19
J.	Multiply row I by:	× 0.0024	× 0.0048	× 0.0074	× 0.0109	× 0.0078
K.	AI = sum of row K = 0.64	0.0408	0.1008	0.1480	0.2071	0.1482
L.	Speech Privacy in this example is None!					

Part 3 - Substitute 6-Foot-High partition Screens

Even with masking, there is still no speech privacy. Next, recalculate the worksheet replacing the 4-foot high screens with 6-foot high screens as follows:

	Octave Band Center Frequency	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
A.	ANSI Standard voice level:	73	74	68	62	57
B.	0° orientation:	0	0	0	0	0
C.	8 feet distance:	-7	-7	-7	-7	-7
D.	Mixed ambient absorption:	+2	+2	+2	+2	+2
E.	6-ft screen/ abs. ceiling:	-4	-5	-6	-6	-8
F.	No nearby reflections:	0	0	0	0	0
G.	Sum of rows A - F:	64	64	57	51	44
H.	Masking, 47 dBA normal level	49	45	40	35	30
I.	Subtract H from G	15	19	17	16	14
J.	Multiply row I by:	× 0.0024	× 0.0048	× 0.0074	× 0.0109	× 0.0078
K.	AI = sum row K = 0.54	0.0360	0.0912	0.1258	0.1744	0.1092
L.	Speech Privacy in this example is None!					

Part 4 - Move Workstations Farther Apart

The improvements in Part 3 still do not result in effective speech privacy. To reach an AI of 20 or less, try separating the workstations to 16 feet rather than the 8 feet in the original example. Also, add more absorption to the space in the Section D data for less sound build-up.

	Octave Band Center Frequency	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
A.	ANSI Standard voice level:	73	74	68	62	57
B.	0° orientation:	0	0	0	0	0
C.	16 feet distance:	-13	-13	-13	-13	-13
D.	Absorptive environment:	0	0	0	0	0
E.	6-ft. screen/abs. ceiling:	-4	-5	-6	-6	-8
F.	No nearby reflections:	0	0	0	0	0
G.	Sum of rows A - F:	56	56	49	43	36
H.	Masking, 47 dBA normal level:	49	45	40	35	30
I.	Subtract H from G:	7	11	9	8	6
J.	Multiply row I by:	0.0024	0.0048	0.0074	0.0109	0.0078
K.	AI = sum of row K = 0.27	0.0168	0.0528	0.0666	0.0872	0.0468
L.	Speech Privacy in this example is Marginal.					

Worksheet Example 1

Continued

Part 5 - Install a High Articulation Class (AC) Ceiling

Part 4 results in marginal speech privacy even with most of the elements correctly implemented. To achieve better privacy, install a high articulation class (AC) ceiling and increase the masking level to the maximun recommended setting of 50 dB(A) as shown in the following worksheet:

	Octave Band Center Frequency	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
A.	ANSI Standard voice level:	73	74	68	62	57
B.	0° orientation:	0	0	0	0	0
C.	16 feet distance:	-13	-13	-13	-13	-13
D.	Absorptive environment:	0	0	0	0	0
E.	6-ft. screen/ Hi AC ceiling:	-5	-7	-9	-9	-10
F.	No nearby reflections:	0	0	0	0	0
G.	Sum of rows A - F:	55	54	46	40	34
H.	Masking, 50 dBA high level:	52	48	43	38	33
I.	Subtract H from G:	3	6	3	2	1
J.	Multiply row I by:	0.0024	0.0048	0.0074	0.0109	0.0078
K.	AI = sum of row K = 0.09	0.0072	0.0288	0.0222	0.0218	0.0078
L.	Speech Privacy in this example is Normal.					

Summary and Conclusions

This final space would be ideal for an open-plan office and it shows that "normal privacy" can only be attained by very carefully integrating the layout of the space with its partition screens, furniture, finishes, ceiling, ad masking sound. This example also shows that it is impossible to achieve "confidential privacy" in the open-plan environment at any practical workspace distance.

Worksheet Example 2

A Walled Space

Part 1 - No Masking Sound

The following worksheet assumes that the dividing partition is a standard interior office building wall, the acoustical absorption in Section D is mixed, and there is no masking sound.

	Octave Band Center Frequency	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
A.	ANSI Standard voice level:	73	74	68	62	57
B.	0° orientation:	0	0	0	0	0
C.	8 feet distance:	-7	-7	-7	-7	-7
D.	Mixed absorptive/hard environment:	+2	+2	+2	+2	+2
E.	Wall:	-19	-30	-36	-24	-28
F.	No nearby reflections:	0	0	0	0	0
G.	Sum of rows A - F:	49	39	27	33	24
H.	Office sound, no masking:	42	37	29	24	20
I.	Subtract H from G:	7	2	0	9	4
J.	Multiply row I by:	× 0.0024	× 0.0048	× 0.0074	× 0.0109	× 0.0078
K.	AI = sum of row K = 0.16	0.0168	0.0096	0.0000	0.0981	0.0312
L.	Speecy Privacy in this example is Normal.					

Part 2 - Add Masking Sound

Given the construction from Part 1, masking sound can have a very benefical effect as shown in the following worksheet example:

	Octave Band Center Frequency	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
A.	ANSI Standard voice level:	73	74	68	62	57
B.	0 orientation:	0	0	0	0	0
C.	8 feet distance:	-7	-7	-7	-7	-7
D.	Mixed abs./hard environment:	+2	+2	+2	+2	+2
E.	Wall:	-19	-30	-36	-24	-28
F.	No nearby reflections:	0	0	0	0	0
G.	Sum of rows A - F:	49	39	27	33	24
H.	Masking, 47 dBA normal level	42	37	29	24	20
I.	Subtract H from G:	7	2	0	9	4
J.	Multiply row I by:	0.0024	0.0048	0.0074	0.0109	0.0078
K.	AI = sum of row K = 0.00	0.0000	0.0000	0.0000	0.0000	0.0000
L.	Speech Privacy in this example is Confidential.					

Summary and Conclusions

In this case, masking sound achieves confidential speech privacy with no other changes to the building. This example shows that sound masking can have many benefits to clients other than those with open-plan office spaces.

Sound Masking Worksheet

A. Select talker voice level and enter values (or measured values) in last row of table:

Octave Bands	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Raised:	74	76	71	65	61
ANSI Standard:	73	74	68	62	57
Normal:	68	70	63	58	55
Your Values:	________	________	________	________	________

B. Select talker orientation to listener and enter values (or interpolated values) in last row of table:

Octave Bands	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
0° (facing listener):	0	0	0	0	0
45°:	-1	-2	-2	-2	-3
90°:	-3	-4	-4	-5	-6
135°:	-5	-6	-7	-7	-8
180°:	-7	-8	-9	-9	-10
Your Values:	________	________	________	________	________

C. Select talker-to-listener distance and enter values (or interpolated values) in last row of table:

Octave Bands	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
6 feet:	-5	-5	-5	-5	-5
10 feet:	-9	-9	-9	-9	-9
16 feet:	-13	-13	-13	-13	-13
Your Values:	________	________	________	________	________

D. Select walls/furniture/carpet absorption and enter values (or interpolated values) in last row of table:

Octave Bands	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Absorptive:	0	0	0	0	0
Mixed:	+2	+2	+2	+2	+2
Hard:	+4	+4	+4	+4	+4
Your Values:	________	________	________	________	________

E. Select screen/ceiling condition and enter values (or interpolated values) in last row of table:

Octave Bands	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
No screen, hard clg.:	+2	+2	+2	+2	+2
No screen, abs. clg.:	+1	+1	+1	+1	+1
4′ screen, hard clg.:	0	0	0	0	0
4′ screen, abs. clg.:	-2	-3	-3	-3	-3
5′ screen, hard clg.:	0	-1	-1	-2	-2
5′ screen, abs. clg.:	-3	-4	-5	-5	-6
6′ screen, hard clg.:	-1	-2	-2	-2	-3
6′ screen, abs. clg.:	-4	-5	-6	-6	-8
7′ screen, hard clg.:	-2	-2	-2	-3	-4
7′ screen, abs. clg.:	-5	-6	-6	-8	-10
Ceiling-ht partition:	-19	-30	-36	-24	-28
Your Values:	__________	__________	__________	__________	__________

F. Select anomaly and enter values (or interpolated values) in last row of table:

Octave Bands	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz

G. Sum Your Values from tables A through F:

Octave Bands	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Sum of Your Values:	__________	__________	__________	__________	__________

H. Select masking sound level and enter values (or measured/interpolated values) in last row of table:

Octave Bands	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Office, no mask'g:	42	37	29	24	20
45 dB(A):	47	43	38	33	28
47 dB(A):	49	45	40	35	30
50 dB(A):	52	48	43	38	33
Your Values:	__________	__________	__________	__________	__________

I. Subtract Your Values in Table H from Your Values in Table G:*

Octave Bands	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Your Values:	__________	__________	__________	__________	__________

*(if result is <0, enter 0; if result is >30, enter 30)

J. Multiply Your Values in Table I times the factors below:

Octave Bands	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Multiplication Factors:	0.0024	0.0048	0.0074	0.0109	0.0078
Multiplication Results:	__________	__________	__________	__________	__________

K. Sum the Multiplication Results from Table J to get the Articulation Index, AI

Sum of Multiplication Results =	____________

L. Interpretation of Privacy Level based on AI from Table K

AI	Privacy Rating