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SOUND MASKING DONE RIGHT

Simple Solutions for Complex Problems

First Edition

Robert Chanaud, Ph.D.

Definitions, equipment, design, equalization, applications, and advantages of sound masking as a cost-effective privacy tool.

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Atlas Sound®

SOUND MASKING DONE RIGHT:
SIMPLE SOLUTIONS FOR COMPLEX PROBLEMS

Robert Chanaud, Ph.D.

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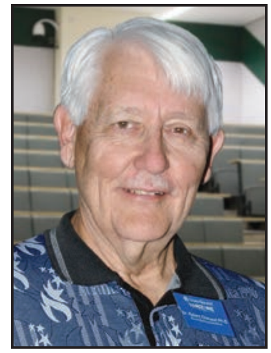
About Bob Chanaud



Dr. Robert C. Chanaud received his BS from the US Coast Guard Academy, his MS from the University of California and his PhD from Purdue University. Active in the field of acoustics since 1958, he taught at Purdue University and the University of Colorado and, in 1975, founded Dynasound, Inc. He has developed software programs to facilitate the design and equalization of masking systems.

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- Atlas Sound
- Cambridge Sound Management
- Dynasound
- Soft dB
- Sound Advance

Notation

Square brackets [ ] are references contained at the end of the manual.
Parentheses ( ) refer to other sections in the manual.

PREFACE

This manual attempts to cover enough material on acoustical privacy in rooms to help the designer to appreciate the value of sound masking as a key privacy tool. Over the last thirty years there have been innumerable articles on privacy and how to achieve it, in both professional journals and trade literature. In particular, the reader is referred to the large number of comprehensive documents published by the National Research Council, Canada. Unfortunately, they refer to that restful sound masking as “noise”.

Sound masking is still steeped in mythology. The important difference between quiet and privacy is still unclear to most. Architects are trained primarily in the visual arts, so structural factors, such as walls, are the key privacy elements for them. Although privacy caused by background sound is an everyday event for all of us, the idea of controlling it *deliberately* still meets resistance. The social context is one reason. I am always amazed to find someone who thinks masking in the workplace is too loud at 45 dBA, but is not bothered by the 78 dBA found in the cabin of a commercial aircraft. Another reason is the contractor that installs a sound masking system that creates nothing but noise from the ceiling, resulting in the justified comment that “masking doesn’t work”. One purpose of the manual is to give the potential user and the contractor enough information to prevent these disasters.

This manual focuses on “open” systems. For open systems, the end user is free to choose from among several contractors and the contractor is free to choose products from among several manufacturers based on their performance and price. For proprietary systems, the end user may be restricted to one manufacturer who may have only one authorized distributor locally.

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CHAPTER 1

CRITERIA FOR DESIGN OF SOUND MASKING SYSTEMS

1.1 What is masking and what does it do?

Masking is merely the covering up, or disguising, of something. The something is not changed but simply hidden. Physical masks cover the face of the wearer. Deodorants mask odors; they do not eliminate them. One-way windows mask the persons on the other side so they are not visible. Sound can mask other sounds to cover them up. In every case, the objective is to hide something that exists.

Many people have heard of noise cancellation and incorrectly believe that it is a form of sound masking. In noise cancellation, the sound to be eliminated is sensed by a microphone, reversed, and then added back to the sound so that it is removed. Unfortunately, this technique works only in spatially constrained areas, such as headphones, so it is not applicable to entire rooms.

When unwanted sounds are covered up, the listener is less distracted. This results in more satisfaction with one's environment and permits the person to be more productive. Sound masking can provide speech confidentiality in situations where otherwise it cannot be obtained without inordinate expense.

Distraction is caused by transient sounds that are sufficiently above the steady background to attract the inadvertent listener's attention. The higher the level of that transient sound above the background and the more information contained in that sound, the greater is the disturbance. The standard way to reduce these distractions has been to add sound attenuating materials that reduce the unwanted sounds to the point where they do not protrude above the existing background. A newer way to reduce distractions is to increase the existing background level to complement the existing sound attenuation. This idea took a long time to take root, but it has been found to be not only cost effective, but also much more versatile than the standard way.

The primary function of masking, whether done structurally with sound attenuating materials or active background level control, is to reduce the range of fluctuations in sound level.

For every situation there is an optimum background sound level, just as there is an optimum lighting level. In the home that sound level is low, and at sporting events that level is high. Therefore, we can consider the function of sound masking to be bringing the background level *up* to the optimum. If the background is already above the optimum, sound reduction materials must be applied, not sound masking. A classic example is a noisy restaurant, where the background sound level is already above the optimum level and the listeners have difficulty understanding others at their own table.

1.2 What's in a Name?

The equipment and technology of *active* masking has gone under several names. By active we refer to background sound that is under the control of the user for privacy purposes, not the background sound that is generated by air handling systems for temperature control. The term *sound masking* is now most widely used to describe this technology. The term *noise masking* is also used to help imply that masking blocks your unwanted sound or noise. Some practitioners avoid this term because of its negative connotation. These terms and their word order are best at describing what masking does. The terms *white noise* and *speech privacy system* are also used but are less accurate. White noise is a purely theoretical concept where there is equal energy at every frequency; there is no relationship whatsoever between true white noise and any useful or acceptable sound masking spectrum. The term speech privacy system is descriptive of its use, but it gives a potential user the impression that masking can be applied *only* to speech. As discussed in later chapters, speech is the major reason for applying sound masking, but not the only one.

1.3 The Fallacious Quest for Quiet

When people are annoyed by the activity sounds around them (noise), they futilely search for "quiet". By common definition, noise is the presence of *unwanted* sound, so "quiet" is considered the absence of noise. The word "unwanted" implies a subjective human response. Not everyone will agree that a given sound is, or is not, noise. Most people think of noise as a distracting or interfering sound, which usually causes annoyance and complaints. Most people believe that "quiet" is a desirable condition of low background sound level, but what they are really searching for is the freedom from the acoustical distractions that ultimately cause annoyance. Those distractions are caused by transient sounds, such as speech, that rise above the background level and are noticeable. Thus, a better definition of "quiet" is the absence of those distracting sounds, not an absence of all sound. The only way to achieve the former definition of "quiet" is to maintain a low background sound level with *no* transient sounds; a condition that requires complete isolation from all activity sounds.

There are three ways to reduce the magnitude of transient sounds. First, one may use the age-old technique, once used by librarians, of simply asking persons not to talk. Administrative controls such as these are generally ineffective. The second way is to physically isolate people from sources of sound by putting them behind sound attenuating structures, such as enclosed offices. One favorite method is to add materials that are highly sound absorbing. Unfortunately, these materials cannot decipher "wanted" from "unwanted" sounds so the distraction merely occurs at a lower level. This is not to imply that sound absorbing materials are ineffective, but rather that they may not be sufficient by themselves. Another method is to increase the amount of materials between the listener and the source of the sound, to block transmission of the transient sounds. Both methods can be expensive and, as will be shown later, may, or may not, be adequate to achieve the desired freedom from distraction. The third way is to alter the background sound level so that the transient sounds do not penetrate significantly above the ambient level at the listener. Persons not familiar with this method ask "How can you make it 'quiet' by adding noise?" Hopefully, this document will convince the reader that, if done properly, adding sound masking will make it possible to achieve the new definition of "quiet". By implementing this technique, it is possible to achieve a level of background sound that is socially acceptable. Low levels are required for bedrooms yet when most people are questioned about aircraft flights, they do not object to the level of "noise" despite the fact that the sound energy is thousands of times greater than that in a bedroom. Acceptance depends on the context.

1.4 The Evolution of Sound Masking

It is very likely that primitive people never camped near a rushing stream. They understood that the stream noise could mask the approach of enemies or predators. The fountains in Roman villas may have served a useful purpose in blocking out the sound of iron-rimmed chariot wheels on the cobble-stoned streets. The sound of water is still used as sound masking; visit shopping malls or buildings that have a large atrium. Water is too expensive and impractical, among other factors, to be used as a universal masking tool so electrical means of sound masking were developed. There is evidence that, after World War II, a dentist in New York used earphones with broadband random noise to cover up the sound of his drills. Shopping catalogs have carried advertisements for small masking devices to be used in homes. The serious development of commercial sound masking began with the introduction of the open plan office by a design firm from Germany in the 1960s. The General Services Administration, Public Buildings Service, published documents (PBS-C.1 and PBS-C.2) in the early 1970s on open office acoustics. They developed a rating called Speech Privacy Potential and Interzone Attenuation. Central to these documents was the use of sound masking. Since that time, the use of sound masking has increased. The American Society for Testing and Materials (ASTM) and the Acoustical Society of America (ASA) have developed several standards that address office acoustics and sound masking establishing the correct way to use sound masking. Currently, there are a number of manufacturers of sound masking equipment and it is being used worldwide.

1.5 The Major Reason for Developing Sound Masking

As many American manufacturers switched to making furniture panel systems (cubicles), the open office grew rapidly, as did the loss of speech privacy that employees had been accustomed to in closed offices. Office workers have clearly expressed this problem in office surveys:

> *"The ability to concentrate without noise and other distractions rates FIRST among office workers as the one functional characteristic of an office that is most important in helping them to get their jobs done well."*
>
> *"Most office workers give their offices low scores on the ability to concentrate without noise and other distractions and on conversational privacy."*
>
> *"The implications for office planners and designers here are very straightforward: no matter what kind of office is being planned, a great deal of attention has to be paid to the issue of limiting noise and other distractions in the office."*
>
> *"Cutting down on the amount of noise and distraction is considered likely to be implemented by 73% of the business executives interviewed in 1978."*
>
> (Steelcase/Harris Survey 1978)

A later survey showed:

> *"The other element of discomfort to which office workers are powerfully attuned is the unmet need for a place to work when they need to concentrate without distractions. As was found in the first study, the need for quiet and privacy is a deeply felt one, and one that many office workers feel is unfilled. Confirmed in this study is the fact that not only is it felt that this affects productivity, but it is a cause for complaints about physical discomfort and inhibits job performance."*
>
> *"49% of the office workers say they do not have quiet in their office."*
>
> (Steelcase/Harris Survey 1980)

Many later surveys have shown the same result, namely that about 75% of office employees had complaints about privacy. These complaints drove the audio industry to develop sound masking equipment to improve the privacy between individuals in open offices. Unfortunately, owners have been slow to adopt sound masking as a privacy tool, as they are generally unfamiliar with it.

1.6 The Reputation of Sound Masking

As with all change, denial is the first response. Sound masking has suffered the same rejection (and with some justification). When the first open offices were developed in the late 1960s, only freestanding panels were used. The employees realized that adding plants, although nice to look at, did not provide any improvement in speech privacy. Designers searched for a quick and inexpensive solution: sound masking. After it was found that too much added sound was needed to overcome the privacy deficiencies, it was concluded that masking was an excuse for a poorly designed job. An unwarranted extrapolation was: *any* job that needed masking was a poorly designed job.

With the evolution of excellent panel systems by major manufacturers, that assumption has changed. Control of projects by experienced interior designers, acoustical consultants and other specialists, development of quality sound masking equipment, scientific research, and standards have caused the change. Since the author's first involvement with sound masking in 1972, use and acceptance has grown enormously.

1.7 Sound Masking vs. Noise Cancellation

Since sound masking covers up other sounds by adding more sound, it is appealing to consider use of noise cancellation methods to totally eliminate the offending sound.

The theory that describes sound in a three-dimensional volume by values at its periphery was developed over one hundred years ago. It requires complete knowledge at each point on the boundary. To eliminate the sound in that volume the sound impinging on each point must be detected with a microphone, reversed in polarity at every frequency and transmitted back nearly instantly. The television show Get Smart used such an idea in the "Cone of Silence". However, they forgot to mention that Smart's voice was also cancelled.

Noise cancellation has some practical applications. One of the earliest was to reduce the (blade passage) tone generated by a ducted fan. The sound passing down the duct was a low frequency plane wave. The system had to handle only one frequency and the time coincidence was assured by having the speaker an appropriate distance downstream from the microphone. Because it was a plane wave, only one microphone on the duct wall was required. A more recent application is in headphones. The volume inside the headphone is so small that only one microphone and speaker is needed. The advent of modern electronics has made the time delay from input to output so short that cancellation is highly effective, mostly at lower frequencies.

As an application to offices, its use would imply that microphones and speakers be placed about every six inches on the surrounding surfaces and have a response time less than one-half a millisecond, since the maximum intelligibility of speech is near 2000 Hz. Such an installation is both financially and technically impossible. In addition, noise cancellation cannot tell the difference between wanted and unwanted sounds, while masking does through the use of distance.

1.8 Two Characteristics of Office Noise

Office noise can be divided into two types. The first is that from transient sounds, such as conversation, paging, interior machine sounds as well as exterior sounds such as passing aircraft and road traffic. The other is that from steady sounds such as air conditioning equipment or light fixtures.

1.8.1 Transient Sounds

A transient sound is short term; such sounds generally distract a person's attention if the level is high relative to the steady sound level (a rise of about 10 dB is a common criterion). The distraction is further strengthened if the sound has high information content, such as conversation. People conversing with each other typically create transient sound levels of 70 dBA. Paging will create higher levels and alarms may run as high as 90 dBA. Exterior sounds, such as traffic noise, also may contribute. Since these sounds are short term, they have no known physiological effect, but the major concern about transient sounds is the psychological effect of distraction and annoyance [2].

1.8.2 Steady Sounds

Steady sounds are the background sounds in any environment that are continuous and long term, so might be considered to have the most effect on employees. In an office, it is mostly composed of sound from the air handling system or light fixtures. Good design keeps such levels below 40 dBA. If sound masking is used, it is an addition to the steady sounds rather than the transient ones. Steady sound can be tonal or random. Light fixtures are primarily tonal while air handling noise is random (it consists of many frequencies). A general observation is that continuous random sound becomes "normal" to the listener after a time because it is unchanging and conveys no information. Therefore it can become less noticeable and less distracting. Tonal sounds are more likely to elicit negative responses based on the listener's evaluation of the sound's utility. Very few individuals are aware of refrigerator noise in their home, even though it is tonal and clearly audible, but lighting fixture sounds in the office often generate complaints. Higher pitched tonal sounds are less acceptable than lower pitched sounds.

The above discussion suggests that for sound masking to be acceptable, it should be a steady (continuous in time) random sound with more low frequency than high. Since people move about in an office, "steady" must also mean spatially uniform.

1.9 The Needs of Employees in Offices

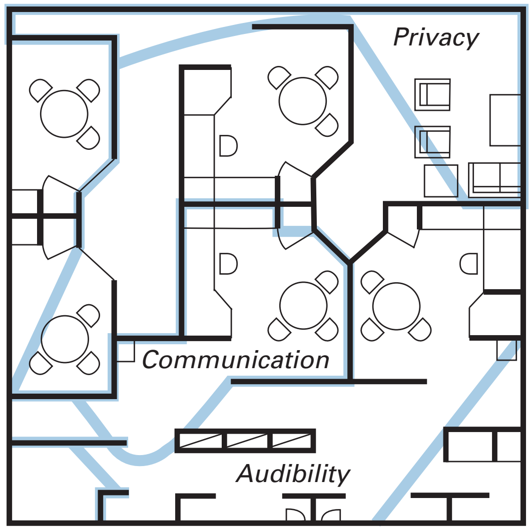


Figure 1-1

There is a spectrum of needs for employees in offices (***Figure 1-1***).

1.9.1 Communication

There is little value in an office unless ideas can be communicated, and since most of that communication is in the form of speech, the design of a sound masking system must not inhibit speech when it is needed. Similarly, *over communication* must be avoided, i.e., preventing persons for whom the speech was *not* intended from understanding the speech.

1.9.2 Privacy

There is a need to be productive, so distractions must be minimized. Also, there is a need to protect sensitive conversations.

1.9.3 Community

People need to feel a part of their organization. Sound is one means of keeping in touch with other people in the office. When workers hear the low-level activity sounds of others, it enhances their sense of community. People want privacy, but not isolation, from their community of fellow workers.

Sound masking system design must try to satisfy all three needs of office workers. Since these needs can conflict, there are upper and lower bounds on how much sound is introduced into a space.

1.10 The Effects of Noise on People

For an in-depth discussion, the reader is referred to the seminal work on this subject [19]. Addressed here are only those aspects that relate to the office environment.

Noise is defined as unwanted sound. Noise can be interpreted as anything from a dripping faucet at home to an exceedingly loud workplace. This range of sound levels runs from those that cause only annoyance to those that do physical damage. Managers of businesses always have had a concern about the effect of the office environment on the health and productivity of their employees; noise being one such concern. To get an appreciation of the relative magnitude of the sounds, we must resort to the standard unit, the decibel (dB). It ranges from very low levels, such as 0 in a very quiet room, to very high levels, such as 170 near a rocket launch. Every time the sound level *increases* by 10 dB, the sound energy *multiplies* by 10. If the sound level is 45 and is raised to 75, the sound energy increases by 30 dB so the sound energy increases by 10x10x10 or 1000 times. 45 dB is a typical level of an office with masking while the 75 dB is typical of a "quiet" airliner.

There are three classes of effects of sound on the human being: physical, physiological, and psychological. Typical occupied office levels range from 40 dBA to 75 dBA.

1.10.1 Physical

These are mechanical changes in a person, such as heating of the skin, rupture of the eardrum, or vibration of the eyeballs or internal organs. The continuous levels required are above 140 dB and it takes a very special situation to cause this; the energy for these to occur is ten million times more than what is found in the office environment. So physical effects on the human body do not occur in the office and should be of no concern.

1.10.2 Physiological

These are biological changes in a person, such as elevation of blood pressure, hearing loss, or stress. The Occupational Safety and Health Administration (OSHA) considers that levels in the workplace of 80 dBA or more during 8 hours per day over a working lifetime of exposure puts people *at risk* for moderate hearing loss. This is a very high level and long term exposure like that does not occur in the typical office. The lowest level at which a physiological effect has been found to occur is near 70 dB and it was a barely detectable dilation of the pupils of the eye and small changes in galvanic skin response with no permanent result. It appears that physiological effects should be of no concern in typical offices.

1.10.3 Psychological

These effects are mental changes in a person due to exposure to noise, manifested most often by annoyance. Such effects can occur at any sound level. Dripping faucets in the home may create annoyance at sound levels of 25 dB, while sound levels of 120 dB caused by a passing ambulance may elicit the same response. The response is totally subjective, based on factors such as the person's evaluation of the necessity of the noise, or whether it can be controlled, or whether it is normal for the environment. Since psychological effects can occur at any level, they are a concern in the office.

1.11 Specific Studies of Noise in the Office Environment

Many cognitive psychology studies have been made that relate specifically to the office environment. In one study [57], it was found that there was a modest stress (physiological) increase and diminished motivation caused by typical office noises, including speech. They recommended the use of sound masking under the control of the worker. In another study [58] they suggested that changes in level are an important factor, but that habituation to the noise can occur. In the office, habituation can be interpreted to mean "I've grown used to the noise and it no longer distracts me" or "Since I cannot do anything about it, I will have to live with it". The authors of another study [59] point out that the specific meaning of the speech intrusion is not important, nor is the "intensity" of the sound between 48 and 76 dBA. Since the energy level of the louder was 1000 times that of the least, one must assume that distraction occurred for all levels of noise. For arithmetic tasks, both speech and nonverbal intrusive noises caused significant performance decreases. For "prose tasks" it was found that speech caused a greater performance decrease than nonverbal noises. In another study [60] the author added several significant observations. It was found that "during a serial recall task, the accuracy of report decreases 30 to 50%." When the intrusive speech was increasingly filtered to a meaningless mumble, there was a monotonic increase in performance. Finally, the author states: "Perhaps the single feature that makes the irrelevant speech phenomena so fascinating is that the processing of sound is *obligatory*; it appears beyond the individual's control." Within the references cited above are further references to earlier works on this subject.

The implications for the designer of a sound masking system are several. The masking must reduce the difference between the steady background level and the transient levels associated with both speech and other sounds. Motivation and productivity are improved when this is accomplished. The masking sound itself must not change rapidly and should be as meaningless as possible.

1.12 Common Opinions about Sound

The following is not an attempt at "pop" psychology, but was deduced from employee comments about their office environment. These are questions the listeners implicitly ask themselves to determine their response to their environment. The design of good sound masking systems must take these opinions into account.

1.12.1 Is the sound made by me or made on my behalf?

Noise is often described as the sound made by other people. Our own sounds are always more acceptable. For example, a manager in an office may complain about the noise created by another manager's secretary, but not that of his own. Employees must be convinced that any change in their acoustical environment is made on their behalf. The desire to have personal control over that environment is implied. Several attempts have been made in this direction with sound masking with little success. It is akin to the thermostat problem.

1.12.2 Is the sound "normal" for this environment?

When all encounters with a situation are the same, people grow to accept it. When there is a crowd or an abundance of human activity (e.g., a football game) or when there is mechanical power or machinery (e.g., an auto race), most people will accept the sounds as normal. When there are rapid changes in the office environment, an employee's sense of normalcy is dislocated. For example, in the classic change from closed offices to "cubicles", there is often a strong negative response.

1.12.3 Is the sound necessary and can anything he done to control it?

Even though a sound may not be normal, it may be accepted if the listener believes that nothing *should* be done about it. For example, police or ambulance sirens are accepted because they are believed necessary. A negative response often occurs when a person believes nothing *can* be done to prevent an unnecessary sound.

1.12.4 Does the sound have meaning?

Extraneous sounds with high information content are more likely to be unacceptable than sounds that mean nothing. As noted in the referenced articles, the brain diverts attention to it. Because speech is rich in information, speech sounds are significant.

1.12.5 Is the sound frightening?

Sounds that change abruptly startle listeners, particularly if they are at higher levels. Responses of fear and concern make a sound more unacceptable. Generally, this is not an issue in the office.

1.12.6 Will the sound have an adverse effect on my health?

The regulations against very high noise levels in the workplace have created concern that office noise can adversely affect a person's health. Typical health complaints are headaches, dizziness, nausea and even disruptions of biological functions. While the manifestations may be real, it is not clear that eliminating the "noise" would solve the problem. There is no evidence that typical office sounds cause health problems other than through a stress response to chronic annoyance. Offices with good acoustical design generally have no health complaints related to noise.

1.12.7 What is the pitch of the sound?

Sound with a great deal of bass (low frequency) is normally associated with something large and powerful. Sound with a great deal of treble (high frequency) is associated with small or delicate objects. Generally, high-pitched sounds cause more annoyance than low pitched ones at the same level. Experience has shown that there is a "preferred" spectrum of sound that minimizes the annoyance of the sound caused by its pitch. Several standards suggest desirable spectra.

1.12.8 How reverberant is the room?

People will judge how reverberant (live) a room is, based on how they hear the echoes of voices or footsteps. Generally, a reverberant room is considered more "noisy", and therefore less acceptable than a "quiet" room. Subjectively, people interpret a "quiet" room as "plush", "expensive" or "important". Not surprisingly, "quiet" is best described as a place free of distractions. Sound masking is most acceptable in offices with some degree of sound absorption such as carpet and suspended acoustical ceilings.

1.13 Noise Complaints in the Office

As examples of psychological responses, some employees cite the occurrence of headaches, nausea, dizziness, and disturbance of biological functions caused by excessive "noise." The seminal work on the effect of noise on people [19] had this to say:

> *"The general finding that the performance of the more anxious personality types is more affected by noise than that of nonanxious types would attest to the existence of a stimulus-contingency factor. In terms of learning or conditioning, the task becomes disliked and is performed relatively poorly because it is related to or contingent upon the aversive noise."* [p 582]

> *"A possible teaching of much of the data presented in this book is that, other than as a damaging agent to the ear and as a masker of auditory information, noise will not harm the organism or interfere with mental or motor performance."* [p 587]

It appears that many office complaints of the type noted above are associated with anxious personalities, and complaints about noise, (along with drafts, temperature, or lighting) are the manifestation of that anxiety. In conclusion, there does not appear to be any evidence that office noise of any type causes the adverse effects noted above. In fact, in earlier offices with vinyl floors, metal furniture, and gypsum board ceilings, the ambient and activity levels were considerably higher than those in modern offices.

1.14 Applications of Sound Masking

Sound masking as a privacy tool can be used in many applications, speech privacy being the most common one.

In open offices of all types, from call centers with high activity levels to research areas where distractions need to be minimized, masking reduces employee distractions. Chapter 3 covers this subject in more detail.

In closed offices, added masking can provide confidentiality more inexpensively than improvements in the structural elements such as walls and doors. It is also used to cover the traffic sound of nearby freeways or airports. Chapter 3 covers this subject in more detail.

In hospitals and medical facilities, masking keeps patients from being disturbed by exterior sounds, such as traffic and helicopters, as well as the sounds of nursing staff, equipment, or other patients. Masking is used to insure the confidentiality of patient information, as required by the Health Insurance Portability and Accountability Act (HIPAA). Chapter 4 covers this subject in more detail.

In secure facilities, such as corporate boardrooms, military contractor meeting rooms, or military and government offices, sound masking is used to protect against deliberate attempts at eavesdropping with sophisticated devices. Chapter 8 covers this subject in more detail.

In residential settings, such as homes, condominiums and apartments, sound masking is used to block out aircraft fly-overs, traffic noise and other street sounds as well as noisy neighbors and barking dogs. This results in domestic tranquility and better sleep. Many persons living in southern states slept with a fan running all night. Now, masking devices for the home can be found in specialty catalogs or at internet sites.

Financial institutions are required by the Gramm, Leach, Blily Act to insure the confidentiality of customer information and must protect against any threats to the security of such information.

In travel settings, such as motels and hotels, privacy between rooms is often inadequate. Some travelers bring home maskers with them because these institutions are reluctant to use masking as a privacy tool.

Dentists and doctors have used masking and/or music in headphones to reduce patient tension. Persons with tinnitus (ear ringing) can avail themselves of in-ear maskers.

Judges have mandated that sound masking be applied to jurors while the attorneys in a case approach the bench for discussions. Chapter 3 covers this subject in more detail.

1.15 The Advantages of Sound Masking

As will be shown, sound masking has a number of significant advantages in providing privacy. We list them here; justification is provided in the succeeding chapters.

1. Sound masking is dynamic (variable) as are the sounds it is intended to block. Building elements that provide sound attenuation are static (fixed) and cannot adapt to intruding sounds that change in level. This permits masking to vary from location to location, and from time to time, to adapt to the changing needs within the environment. Modern masking systems have a number of advanced features that make this easy to accomplish.

2. Sound masking is by far the least expensive tool for providing privacy.

3. Sound masking systems are special audio systems designed to create spatially uniform sound levels. As a result, they can also be used to provide uniform music and paging, further improving system cost effectiveness.

4. Sound masking works at the listener's ear and is independent of the building structure (acoustically) so concern about how the sound gets from one place to another is unimportant.

1.16 Potential Disadvantages of Sound Masking

Because sound masking must be complementary to the other acoustical factors in the environment, it can be applied in circumstances where excessive levels are required to create privacy.

It is critical that the spectrum and level of the masking be set correctly for each environment. Inexperienced persons often miss this step, making matters worse.

Even if sound masking is done properly, it can have a negative influence on three types of people. The first is the person with a hearing loss. Even with hearing aids, these persons have more privacy (particularly speech) than persons with normal hearing. These people should be identified early and the system design must take them into account. The second is the visually handicapped person. These people make exceptional use of auditory cues provided by various sounds and sound reflections. Sound masking can effectively mask these cues making navigation difficult. Identification of such individuals is important early in system design. The third is the person that is habitually resistive to sound masking. Engineers are members of that type, but once the physics of sound masking is explained, criticism evaporates. Librarians can be members of that type, primarily because they have been trained in the "shush" technique. Unhappy persons have been found to complain about sound masking causing headaches, dizziness, and in one case causing their teeth to become loose because of the bodily vibration caused by the masking. These persons can create problems for the facility manager and have been the reason some systems have been turned off. The first situations can be handled by the masking system designer; the latter is a management problem.

CHAPTER 2
SPEECH PRIVACY

To determine the proper design of a sound masking system, we first must define the types and degrees of privacy required and the principles for achieving it.

Although sound masking can be applied to many kinds of unwanted sounds, the most important is speech. Although the most frequent application is in the work environment, the principles can be applied to other situations. But what is speech privacy? It is both objective and subjective.

As to speech privacy, we can use standardized metrics to determine objectively the amount of intelligibility. For other types of privacy, e.g., transient traffic noise or air handling noise, objective metrics do not exist so we must resort to the concept of burying the noise in the background.

When a person is asked what his or her concept of acoustical privacy is, the response is generally freedom from noise. The word "noise", being subjective (unwanted sound), opens Pandora's box. The meaning of "freedom" can be either the total, or partial, absence of distractions. Distractions can be based on subjective evaluations of the sound (1.11). The propensity to be annoyed or to complain about distractions probably has a bell curve associated with it. Consequently, there can be a wide range of complaints about lack of acoustical privacy from reasonable to unreasonable.

Persons involved in office design must separate objective privacy from subjective privacy. Fortunately, speech privacy (the major factor) can be measured and there is a long history associated with it. This gives facility managers a tool with which to separate reasonable complaints from unreasonable ones. The purpose of this chapter is to define objective speech privacy.

2.1 Types of Speech Privacy

It is important to determine how well sound masking can block intruding speech. There are many cases, such as call centers, where it is not economically feasible or socially acceptable to provide privacy from everyone else. This type of privacy is called *Partial Privacy.* Associated with this is the distance at which acceptable privacy is achieved. It is called the *Radius of Distraction*. Within that radius, people can be distracted by the conversation of the person at the center of the circle. In some cases, it is possible to provide a person privacy from everyone else. Examples are open offices with high panels and closed offices. This type of privacy is called *Universal Privacy.*

2.2 Degrees of Privacy

The degree of privacy defines how private a person is. It varies from complete privacy to none. Below is a list of the degrees and typical applications for them.

2.2.1 Secret Privacy

When people have Secret Privacy, their conversations cannot be intelligible to others even when *deliberate* attempts to listen are made using sensing devices. This degree of privacy is addressed in Chapter 8, and is more difficult to achieve than other degrees. Typical applications are:

- Classified Conversations
- Corporate Boardrooms
- Critical Legal Conversations
- Corporate Planning Rooms

2.2.2 Confidential Privacy

When people have Confidential Privacy, their conversations are unintelligible to *casual* listeners. The conversations may, or may not, be audible. Typical applications are:

- High Level Management
- Labor Negotiators
- Contract Negotiators
- Personnel Interviewers
- High Level Legal Staff
- High Level Financial Staff
- Medical Counselors
- Conflict Resolution Situations

2.2.3 Normal Privacy

When two people have Normal Privacy from each other, their conversations do not distract each other. Their speech will be audible and partially intelligible. The choice of the word "normal" is based on its use in ASTM standards; a better descriptor might have been "acceptable". Typical applications are:

- Middle Level Management
- Computer Programmers
- Researchers and Engineers
- Persons doing mathematical tasks
- Persons reading or writing difficult material
- Self-learning situations

2.2.4 Transitional Privacy

When two people have Transitional Privacy from each other, their conversations may distract each other occasionally. Their speech will be audible and partially intelligible. Typical applications are:

- Sales Staff
- Purchasing Staff
- Administrative Assistants
- Executive Secretaries
- Draftsmen
- Customer Service Staff (telephone use)
- Secretarial Staff
- Clerical Staff
- Order Processing Staff

2.2.5 No Privacy

When two people have No Privacy from each other, their conversations are clearly intelligible and completely distracting. Typical applications are:

- Receptionists
- Customer Service Staff (face-to-face)
- Staff handling customers or visitors
- Conference, lectures, or seminars

Degree of Privacy	None	Transitional	Normal	Confidential	Secret
Area	Communication	Audibility	Audibility	Privacy	Privacy
Intelligibility	Clear	Partial	Partial	None	None
Distractions	Total	Many	Few	None	None

Table 2-1

Although it may appear that these degrees are simply a hierarchy of privacy, there are significant differences that a sound masking system designer must appreciate.

For both Secret and Confidential Privacy, the listeners are the people *outside* the room, which means masking must be placed around the room, not in it (6.1). For Confidential Privacy the listener is considered to be casual and listening by ear, while for Secret Privacy the listener is assumed to be deliberate and may use listening devices with signal enhancement to improve intelligibility so performance requirements are more stringent. The privacy for these two degrees must be maintained continuously, so the sound masking system must insure that there is no loss of privacy.

For Normal and Transitional Privacy, the listener is the person wishing freedom from distraction, so the masking must be placed there. The privacy for these degrees is statistical, since distraction depends both on the level and character of the sound, as well as its duration. This leaves room for various means of applying masking.

For No Privacy, either good intelligibility is the requirement or it is not relevant. This situation has complications. There are areas, such as mail rooms or storerooms where privacy is not important. There are areas, such as inside board, conference, or training rooms, where good intelligibility is a requirement. Sound masking is not applied in these cases. In open reception areas, good intelligibility is a requirement. The nature of the operation may be such that others in the open reception area should not understand conversations at the desk so masking may be applied in the waiting area, but not at the desk (corporate reception desks, doctors' offices or pharmacists' windows). Many commercial facilities are in a constant state of flux, so that an area that may require good intelligibility at one time, but may be changed to an open or closed office that requires good privacy. It is prudent for a masking system designer to place masking speakers in those areas that have potential for change, but with the speakers turned off.

2.3 Factors Determining Speech Privacy

The obvious question is: How can sound masking be used to provide the desired degrees of privacy? If two people near each other desire high degrees of privacy, the required sound level would be excessive. An important limitation on the application of sound masking is that the sound not be so loud that it becomes an annoyance itself. Similarly, if two people are well removed from each other acoustically, sound masking may not be needed. To determine the range of applicability of masking, it is necessary to review all the factors that play a role in creating privacy.

From the design viewpoint, sound is just a means of getting information from a sound maker to a listener. This can be reduced to a simple formula:

SOUND SOURCE (TALKER VOICE LEVEL)
Minus
SOUND ATTENUATION (VOICE LEVEL REDUCTION)
Minus
BACKGROUND (SOUND MASKING LEVEL)
=
SPEECH INFORMATION

Sound masking is only one of three factors that result in speech privacy (the opposite of speech intelligibility). So within what range of the other factors can the use of sound masking be considered practical?

First, voice levels are variable (dynamic) ranging from hushed tones to the stressed voices associated with persons in argument. Designing a building structure to handle this range of voice levels would be economically wasteful. The building would have to be designed to handle the loudest sounds (the ones with lowest probability). Fortunately, a number of studies have defined typical voice levels taking into account the dynamic variations in level.

Second, a person's voice is carried by a number of paths to the listener, the weakest path being the one that carries the most intelligible information. The sound attenuation of any path may be caused by absorption of reflected sound (e.g. ceilings) or by loss through solid materials (e.g. walls), or simply by distance. In a typical building, there may be a dozen paths carrying information and it is not always possible to readily determine which path is the problem. Often an expensive guessing game is played as to which path is important, what to do about it, and how much improvement is sufficient. Seldom is "sufficient" defined, so it may be a choice between an expensive overkill or just "throwing batts in the ceiling". Further, once a building is constructed, it is very expensive to correct any privacy deficiencies. ***Figure 2-1*** graphically shows the problem with structural solutions. The person trying to solve the problem has to decide what path is the critical one and how critical it is. As any consultant knows, this is not a simple problem. The standard approach is to make an estimate of the problem path, or paths, and then recommend a solution, or stepped solutions. The most difficult part is estimating how much improvement any recommended solution will provide, so typically the stepped solution is recommended. This can require several trips by a contractor until satisfaction is obtained. Sound masking bypasses this problem, since it works at the point where all the paths come together: the listener's ear. And definitive measurements can be made there, provided the most likely location of the listener is known.

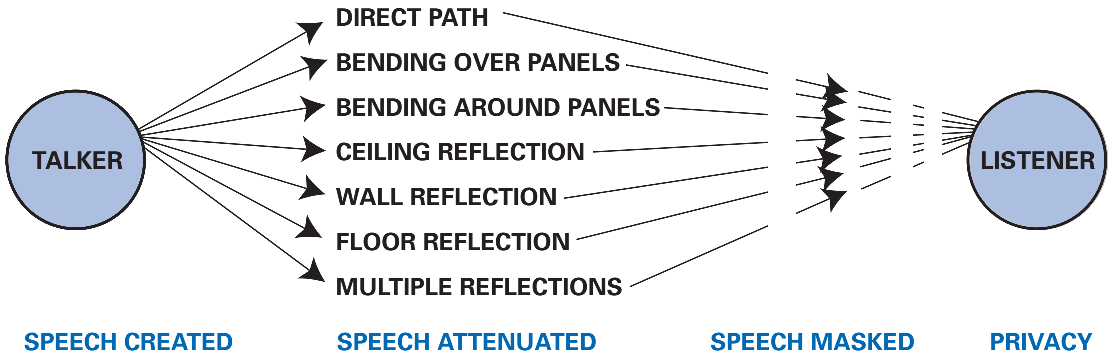


Figure 2-1

2.4 Standards for Determining Speech Privacy

Considerable attention has been paid to speech privacy over the last thirty years and several standards related to it have been developed. Several organizations have addressed this issue: Public Buildings Service of the General Services Administration, the Acoustical Society of America (ASA) promulgating their standards through the American National Standards Institute (ANSI), and the American Society for Testing and Materials (ASTM). See the Appendix A for more details of the ratings described below.

2.4.1 PBS/GSA

This agency developed a standard in the early 1970s for speech privacy in mostly open offices [14, 15]. One part pertained to objective measurement of speech privacy. One term, *functional interzone attenuation,* was used to describe the sound attenuation spectrum between the talker and listener. The associated one-number rating is the *Noise Isolation Class Prime (NIC')*. The prime in the rating was meant to signify that the frequency range has been truncated from that defined for the *Noise Isolation Class (NIC)* rating. Another rating is of the background (or masking) sound and is called *Noise Criterion 40 (NC40).* The number "40" designates the particular spectrum contour which is found in the more familiar rating of *Noise Criterion (NC)* and refers only to the contour shape not the actual level. A privacy rating called *Speech Privacy Potential* (*SPP*) is the sum of these two ratings, i.e., SPP=NIC'+NC40. The requirement for freedom from distraction in those standards is an SPP of 60 or higher.

2.4.2 ANSI

Two standards have been developed for determining speech intelligibility [12,16]. The first was published in 1969 and defines *Articulation Index (AI)*. AI is a number between 0 and 1, where 0 implies no understanding of sentences while 1 implies complete understanding. The second standard was published in 1997 and defines *Speech Intelligibility Index (SII*). It is similar to AI but is more detailed and covers more applications of speech intelligibility. AI is the preferred rating for use in sound masking.

2.4.3 ASTM

A number of standards related to office acoustics have been developed [1-11]. In one [1], a rating of privacy (instead of intelligibility) was introduced; it is called *Privacy Index (PI)*. Instead of AI going from 0 to 1, PI goes from 0 (no privacy) to 100 (complete privacy). The reason for adopting this rating is that persons unfamiliar with acoustics have no feel for relating privacy to a set of numbers between 0 and 1, especially when lower is better.

2.5 Privacy Index and Speech Privacy

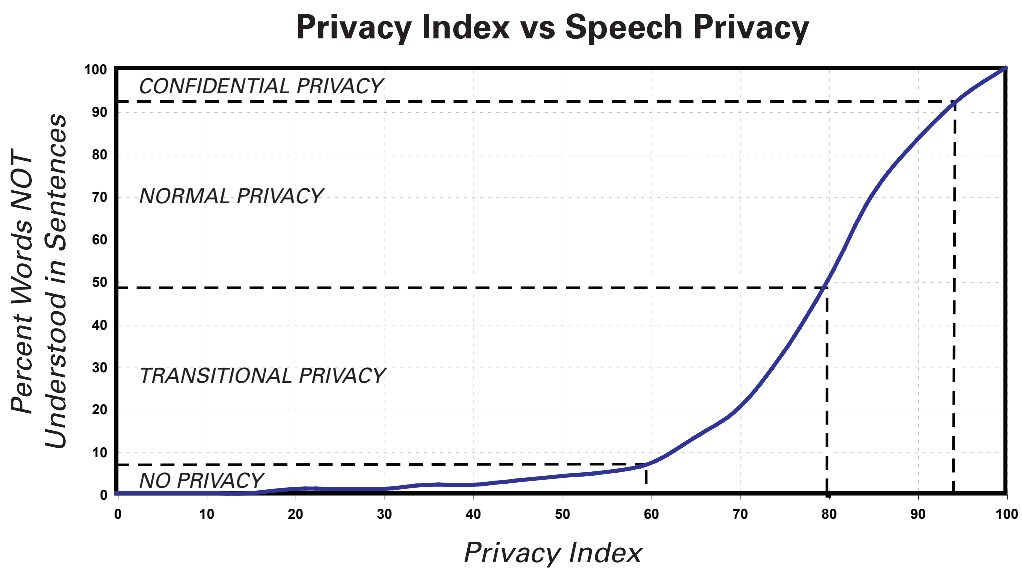


Figure 2-2

The challenge of creating speech privacy is encapsulated in ***Figure 2-2***; it shows the relationship between the objective rating of PI and the ability of people to understand sentences being heard for the first time (normal conversation). The most important observation is that the line in the graph is not straight (non-linear), i.e. going halfway on one axis does not result in going halfway on the other. As the acoustics of the space are improved (lowered voices, more sound attenuation, higher masking levels) and costs are incurred, one moves right along the horizontal axis. When people are close to each other in a totally open area, the PI is near 10. The slope of the curve at this value is very shallow, so increases in PI cause very little improvement in privacy as can be seen by moving horizontally and then vertically to the curve. In short, when you start with an open area, you get very little for your money. This was the case in early open offices. Manufacturers provided high quality workstations, and measurements showed that the Privacy Index was significantly improved, say up to 50 or 60. However, occupants detected no improvement in privacy as the graph clearly shows.

An important point for designers is:

Most of the investment in acoustical privacy is used to set the pre-conditions for it; the remainder is used to achieve it.

If the pre-conditions are not met, installation of a sound masking system may result in nothing more than ineffectual noise.

The knee of the curve appears at PI of 60; above that the slope is steeper, so one gets more privacy for the dollars spent. Getting to the knee the curve is a necessary, but not sufficient, condition to achieve good privacy. Many closed offices have pre-conditions beginning at the knee, so small improvements in the environment do yield significant increases in privacy. How to move right on this graph so that the privacy goal is met with minimum cost will be the subject of Chapter 3.

A simple relationship can be established between Privacy Index and the sound masking level when the Privacy Index is greater than 70:

A change of 1 dBA in masking level is equal to 3 points of Privacy Index

The range of Privacy Index assigned to each of the various degrees of privacy is shown in ***Table 2-2*** below. Most people are familiar with the non-linear nature of school grades; getting half the questions correct in an exam is definitely failing. This analogy has been added to the table.

Speech Privacy	Privacy Index	Grade
Secret	100+	A+
Confidential	95-100	A
Normal	80-95	B
Transitional	60-80	C
None	< 60	F

Table 2-2

Considering the complex geometry of the typical office, it is not simple to estimate, or even hand calculate, the Privacy Index nor to determine the requirements for a sound masking system. A software program to make these calculations is described in Chapter 3. The user can create a model of a planned facility, evaluate acoustical performance, and from that determine how much sound masking is needed to achieve the desired degree of privacy.

2.6 Determining the Value of Sound Masking

The ratings in italics below are all defined in Appendix A.

The sound attenuation from one location to another can be rated in several ways. The older ratings are *Sound Transmission Class (STC), Noise Isolation Class (NIC) and Noise Isolation Class Prime (NIC')*. Although widely used, these are graphical methods developed prior to computers and have limited applicability to speech privacy. Although higher ratings indicate better privacy, the actual amount of privacy cannot be determined from them. A more recent rating called *Articulation Class (AC)* has a frequency weighting that relates to speech intelligibility, but it is numerically too large for comparison against the earlier ratings. A rating called *Speech Weighted Loss (SL)* is now being introduced, and is the actual amount of speech attenuation.

If both the speech and the sound attenuation characteristics are known, the speech spectrum at the listener can be determined and from that, a sound masking spectrum can be chosen to achieve the desired degree of privacy. If the speech at the listener is too high, the sound masking level also must be high and masking may not be a viable solution. If the speech level at the listener is below the background sound level there, the Privacy Index already may be high enough so that masking is not required. Only when the speech level at the listener is within a certain range is the application of sound masking beneficial. That range is determined by the first two factors, so information on them is needed.

Again, given that speech levels are reasonably known, privacy is determined by the sum of the sound attenuation and the sound masking. How can these two factors be combined so that common terminology can be used? The value of sound masking can be shown by considering sound masking as an additional sound (speech) attenuation mechanism. A rating called *Effective Speech Weighted Loss (ESL)* is being introduced to show that value; it is discussed in Appendix A. ESL answers the following question: Since we get a certain degree of privacy *with* masking, how much more sound attenuation would be needed to achieve the same degree of privacy *without* masking? Often ESL is 6 dB greater than SL, implying that one would have to design a room with that much more sound attenuation. For closed offices, that would imply twice the wall thickness. In open offices, to add this much sound attenuation with panel or ceiling upgrades would be very expensive indeed, and often impossible to achieve. This rating clearly demonstrates the value of sound masking as a privacy tool.

2.7 Variability of Privacy Needs

The need for speech privacy is not constant in a given environment. Prudent design implies handling the worst case, which is a talker speaking continually and facing a listener. However, allowance must be made during the workday for the changing balance between the possibly conflicting needs for privacy, communication, and a sense of community.

The number of people in an office typically varies from full occupation during the workday to low occupation during evening hours and on weekends. During the workday employees need more privacy because of the enhanced activity level while in later hours, with fewer fellow workers being present, they need to experience a sense of community by being aware of those around them. During night hours, security guards want no privacy at all. The sound attenuation factor is static and therefore cannot satisfy this need, while sound masking, being dynamic, can. Even during the workday, the amount of speech will vary significantly, so it is desirable for the masking level to vary also.

In the home environment, the reverse is generally true. Masking is desired during night hours to rest and sleep, but not necessarily during the day.

Experience has suggested that people do not like abrupt changes in their environment (everyone is for progress, it is change they dislike). So, despite the need for privacy, when an office is *initially* occupied, the sound masking level should be increased slowly from the pre-existing background level. The same concept applies to recovery from power failures.

CHAPTER 3

ACHIEVING ACOUSTICAL PRIVACY

To determine the proper design of a sound masking system we first must examine the other factors that play a role in creating acoustical privacy in open and closed rooms to ensure that the sound masking system will be successful.

Most of this chapter will relate both to open offices where furniture panels are used to define workstations and to closed offices where walls define the space. The purpose of this chapter is to provide the masking system designer some justification for examining a space prior to installation in order ensure that the sound system will result in satisfaction. This chapter will also provide information on potential privacy problems that need to be reported to the client prior to system operation.

3.1 Privacy in Open Rooms

Many of the examples in this section are for the "worst case situation", i.e., where a seated talker, speaking horizontally, faces a seated listener, each being three feet from a separating panel. The sound attenuation for such an arrangement is least.

3.1.1 Factors that Reduce Speech Transmitted to Listeners

The two factors that play an important role in reducing speech transmitted to a listener are (1) the talker's voice characteristics and (2) the amount of speech that is lost en route to the listener. The first factor is dynamic and is determined by:

- The sex of the person speaking
- The amplitude and frequency characteristics of their voice
- The direction in which they are speaking

The second factor is static and is controlled by the building structure. There are two types of paths, the open-air path and the path through a solid object.

In the open-air path, there are several loss mechanisms: loss due to distance, loss due to reflection from a surface, and loss due to bending (diffraction) around a solid object. Some of these paths are:

- Single or multiple reflections from the ceiling
- Single or multiple reflections from the floor
- Single or multiple reflections from various furniture panels
- Single or multiple reflections from surrounding walls or windows
- Bending over the top of the panel that separates the talker from the listener
- Bending around the side of non-enclosing workstation panels

In the path through a solid object there are two loss mechanisms: loss due to distance, and the loss as sound passes through the material. The latter can be combined with single or multiple reflections both before and after passage through the material.

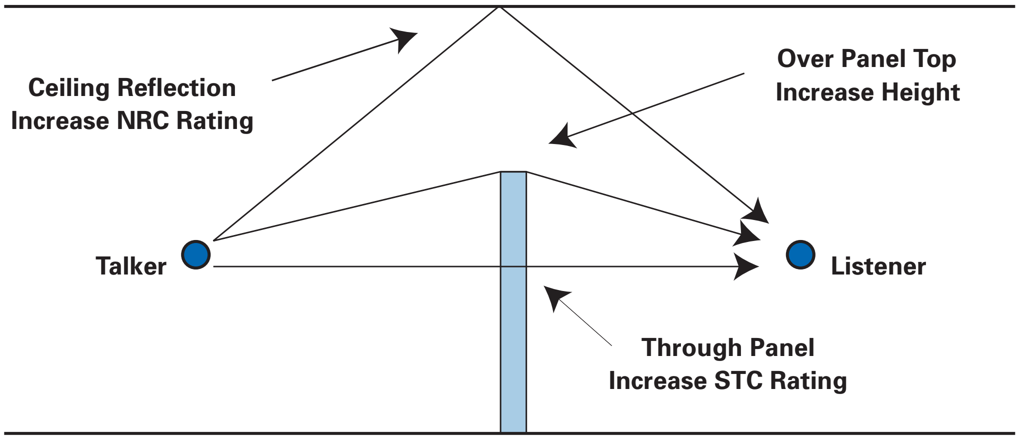


Figure 3-1

Experience has suggested that three of these paths are most important. However, the sum of the other paths can be important at times. ***Figure 3-1*** shows the three.

3.1.1.1 *Transmission Loss Path*

Because people are generally close to each other in open offices, the panel system has to successfully block speech transmitted through it. Unfortunately, most panel systems are sold on the basis of their sound absorption rating (Noise Reduction Coefficient-NRC) rather than their ability to block sound transmission (Sound Transmission Class-STC). STC is the important rating. A high NRC, but low STC, panel will not block much speech.

3.1.1.2 *Reflection Path*

If one visualizes the surfaces in an open office as mirrors, it is easy to imagine the large number of fellow workers to be seen in the ceiling reflection. Since speech will reflect from that surface in a similar fashion, the sound absorption rating (NRC) of ceilings is most important.

3.1.1.3 *Diffraction Path*

Unlike light, sound waves will bend (diffract) significantly around objects. Since most well designed offices have reasonably enclosed workstations, the most important diffraction path is the top of the panel separating the talker from the listener. Panel height is most important for this path. For non-enclosing workstations, diffraction around panel sides can be significant.

Which of these paths has the least loss and so contributes least to creating privacy? Which is the *critical path*? Like a leaky pail, the weakest path dominates and transmits the most speech. Failure to understand this concept has resulted in what may be called *acoustical overkill*. For example, an office designer, thinking that sound absorption is the only important factor, will specify a high-performing and expensive ceiling material; despite the fact that the panel heights are so low that workers are in view of each other. The ceiling could be open to the sky so no sound is reflected, and still there would be no improvement in privacy. This leads to the most important design rule for speech privacy:

The critical sound path in an office design must be identified and, when necessary, its performance must be improved first.

This rule might be called *balancing performance*. When necessary, the sound attenuation of the critical path must be increased until another path is found to be critical, or the desired privacy is achieved. In this way the performance of each of the structural factors is improved until all the factors have equal privacy performance. Most often this minimizes costs. We use "when necessary" here to point out that only a certain amount of sound attenuation is necessary to permit sound masking levels to be within the acceptable range.

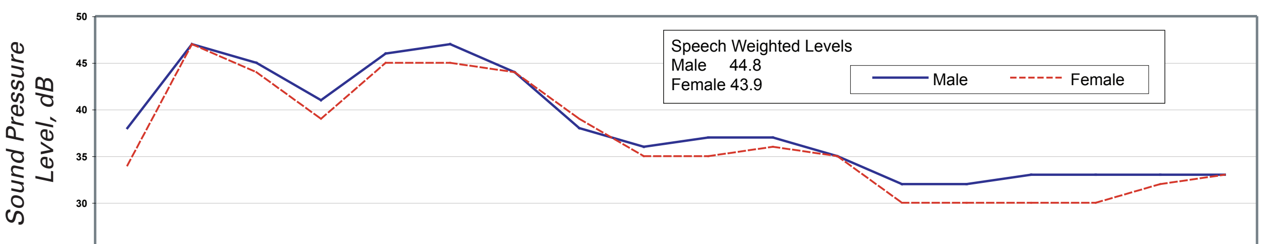
3.1.2 Sound Sources and Paths

Each of the sound paths is discussed in greater detail below to show their relative importance in increasing the sound attenuation between a talker and a listener.

3.1.2.1 Distance

The greater the separation of persons, the more privacy they have from each other but the greater the expense (floor area) to provide that privacy. As space costs have risen, people density has increased also. The common rule for assessing the influence of distance is called the *inverse square law*, where the sound level decreases by 6 dB for every doubling of distance. By this rule, moving two people from 6 to 12 feet apart would increase the Speech Weighted Loss by 6 dB, a significant improvement. Unfortunately, the next 6 dB improvement requires a new distance of 24 feet! This rule, however, applies only for a space in which there are no reflecting surfaces. Tests have shown that in a room with no, or low, panels, just a carpet and a mineral tile ceiling, the sound level reduction from 6 feet to 12 feet is closer to 5 dB. As a result, the use of distance as a privacy tool is not as beneficial as one might expect. The spacing of persons in an open office should have little impact on sound masking system design.

Casual Voice Spectra



	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000
Male	38	47	45	41	46	47	44	38	36	37	37	35	32	32	33	33	33	33
Female	34	47	44	39	45	45	44	39	35	35	36	35	30	30	30	30	32	33

One-Third Octave Band Center Frequency, Hz

Figure 3-2

3.1.2.2 Talker Sex

Figure 3-2 compares the casual voice spectra of men and women [53]. Although the female voice has less bass, the voice spectrum ratings (See Appendix A) are so close there is essentially no difference between them. The particular characteristics of a person's voice seem to be more significant than their sex. Therefore, for a masking system designer, speaker layouts do not need to take the sex of the office worker into account.

3.1.2.3 Talker Voice Level

The level of a talker's voice has significant influence on the level of speech received by a listener. ASTM [1] has defined two levels of speech, *normal* and *raised*. ANSI [16] has defined four levels: *normal, raised, loud,* and *shout*. The most common level in open offices is the "normal" voice. Occasionally a raised voice occurs during heated discussions. For sound masking systems, the normal male voice is a reasonable design objective, but it is important for the designer to determine whether the office has *loud talkers* and to identify any rooms used for *conflict resolution* where the raised voice level is more applicable. The standards suggest that raised voice levels are about 5-7 dB higher.

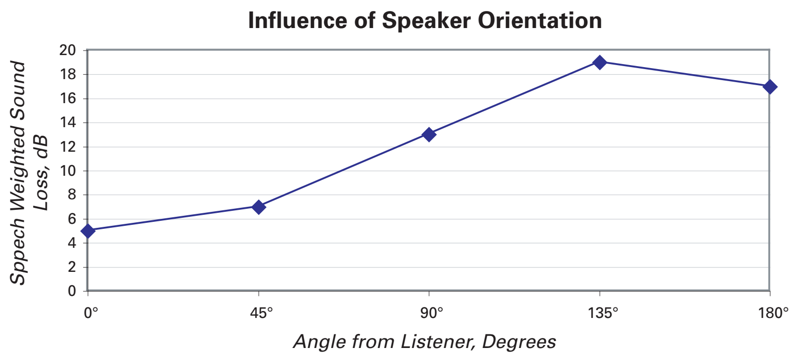


Figure 3-3

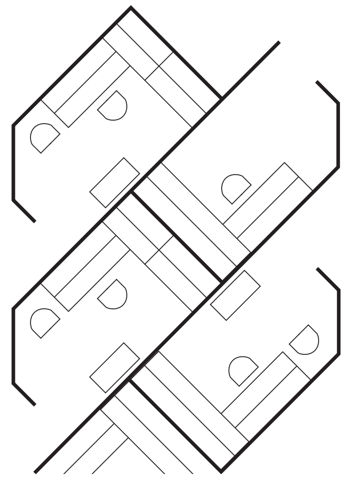


Figure 3-4

3.1.2.4 Talker Direction

The human voice is very directional. How a person is situated in the workstation is determined by the layout, but the designer seldom takes advantage of this fact to enhance privacy. ***Figure 3-3*** shows the Speech Weighted Loss for two people separated by 6 feet in an office *without* any separating panels. Obviously, there is great benefit in orienting people so they do *not* face each other. Even a 90 degree turn creates about an 8 dB improvement in privacy. Since the masking system designer has no say over the placement of people, it is best to presume the persons in adjacent workstations are facing each other (worst-case).

There are a number of workstation layouts where employee direction is set beneficially. For workstations in a row, seating the employees facing at right angles to each other gives a significant improvement in privacy. ***Figure 3-4*** shows a workstation arrangement that takes advantage of voice directivity.

3.1.3 Structural Elements

Each of the three important sound paths has a different acoustical mechanism, but all result in a sound loss of some magnitude. They add in parallel, i.e., the path with the least sound loss dominates the overall loss, much like resistors in parallel.

3.1.3.1 Ceilings

The important characteristics of any ceiling are its height and sound absorption. For suspended ceilings, the presence of items with other characteristics, such as light fixtures is important. ***Figure 3-5*** shows the influence of suspended ceiling height on the speech reflected from it for various values of NRC. If the ceiling reflected path is critical, two advantages can accrue for the masking system designer. High ceilings increase sound attenuation, so sound masking levels can be lower. Also, the greater room volume increases the diffuseness of the masking (improved acceptability).

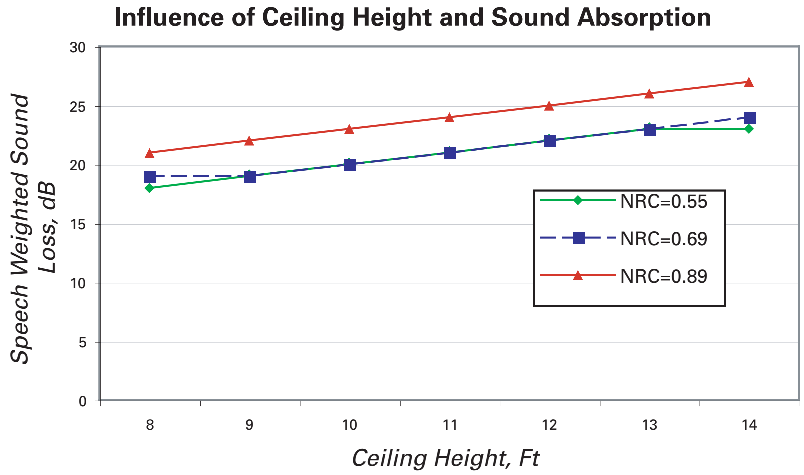


Figure 3-5

Masking in rooms with twelve foot high ceilings is almost always found acceptable to workers. Suspended ceilings with high NRC permit the sound masking levels to be reduced if the ceiling path is critical. High NRC ceilings are most often made of fiberglass (yellow) as opposed to mineral fiber (gray). For the office designer, when the ceiling path is important and the ceiling height is twelve feet or more, a less expensive ceiling material (mineral tile) may be used in place of the more expensive fiberglass materials.

3.1.3.2 Light Fixtures

Ceiling and panel mounted light fixtures can be disastrous in certain circumstances, as can air diffusers mounted on metal sheets of ceiling panel size. If ceiling or panel lights are placed in line between two persons and halfway between them, the reflection can be so strong that *all other* privacy improvements are wasted expense. ***Table 3-1*** shows what happens to the ceiling reflection in terms of Speech Weighted Loss, again for the worst-case situation.

Ceiling NRC	**0.55**		**0.91**	
Condition	None	Fixture	None	Fixture
Flat-Lenses	17	15	26	15
Parabolic-Lenses	17	16	26	16
Pendant	17	17	26	26

Table 3-1

Flat and parabolic fixtures have very high sound reflectance. The table shows that the degradation is not as important for the standard mineral tile but considering the expense associated with a fiberglass tile; these light fixtures can destroy the value of that expense if improperly placed. The pendant light fixture scatters the sound reflection so there is little degradation. When they are used, the suspended ceiling is generally higher than nine feet, another benefit for sound masking. It is important to note that these negative comments apply only to a small percentage of workstations, but they can be a source of complaints from those individuals and the masking system might be considered “not working” as a result. When checking the functioning of a masking system, it is worthwhile to observe, and report, light fixture positions that can severely reduce the benefits of masking.

3.1.3.3 Panel STC

The Sound Transmission Class rates the ability of a panel to block sound (not necessarily speech) passing directly *through* it. The higher the STC rating the more privacy is afforded by that path, but how much is necessary considering other paths? Analysis was made on the worst-case situation. ***Table 3-2*** shows the Speech Weighted Loss using a mineral tile ceiling (NRC=0.55) for several STC ratings and panel heights. The floor had a wear-resistant carpet and all surrounding panels were of the same height.

STC	48″	54″	60″	66″	72″	80″
11	8	10	11	12	12	12
18	9	12	15	17	17	18
25	10	12	15	17	18	19
34	10	12	15	18	18	20

Table 3-2

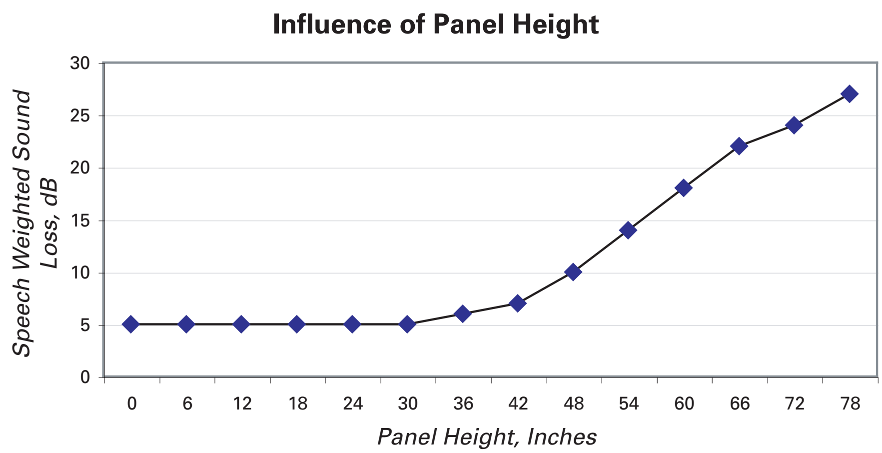


Figure 3-6

The precision of these data is not high since most manufacturers do not provide 1/3 octave band transmission loss data. In spite of this, it is clear that panel STC is not a factor for panels 54 inches high or less, since the diffraction path, which is now a nearly direct path, is the critical path. For the minimum acceptable Privacy Index for Normal Privacy (80), the Speech Weighted Loss should be 16 or above (See Estimated Privacy Index in Appendix A). The panels should be at least 60 inches high and STC ratings should be 20 or greater.

3.1.3.4 Panel Height

Speech can bend (diffract) over the top of a separating panel to reach a listener. ***Figure 3-6*** shows the influence of panel height on Speech Weighted Loss for the worst-case. It is clear that there is a critical height below which panel height offers no benefit. Note that this graph relates only to the diffraction sound loss of a panel, excluding contributions from other factors such as STC or ceiling NRC. Many call centers and other offices have panel heights in the range of 48 inches. The sound loss under these conditions is so small that reasonable sound masking levels will not guarantee Universal Privacy. One must resort to the concepts of Partial Privacy (2.1).

NRC	48″	54″	60″	66″	72″	80″
0.10	9.6	12.1	15.0	17.4	18.1	19.2
0.80	9.6	12.2	15.1	17.5	18.2	19.4

Table 3-3

3.1.3.5 Panel NRC

As noted earlier, panel systems with high NRC ratings have been sold under the mistaken impression that sound absorbing materials alone provide better privacy. ***Table 3-3*** shows the Speech Weighted Loss for several panel heights for the worst-case. There were two panel systems both with STC values of 25 but one was a steel sided panel (NRC 0.10) with negligible sound absorption and the other was made of fiberglass with a porous cloth cover (NRC 0.80). One additional decimal place is shown in the table to indicate that panel absorption was detectable, but negligible. The sound reflected from the separating panel goes in the opposite direction from the listener and the added distance of the sound reflected from the surrounding panels greatly reduces their influence. Since most workstations have personal decorations that reduce the effectiveness of the sound absorbing materials, there is no reason to limit their use for acoustical reasons.

3.1.3.6 Carpeting

Carpets have negligible influence on improving privacy when there are furniture panel systems in place, even those whose bottoms are slightly raised from the floor. However, carpets are necessary to reduce the sounds of footfalls; sound masking is marginally effective in covering these sounds if there is no carpet. Carpets are necessary in areas that have no panels or sound absorbing materials to reduce reverberation and create a sense of quiet.

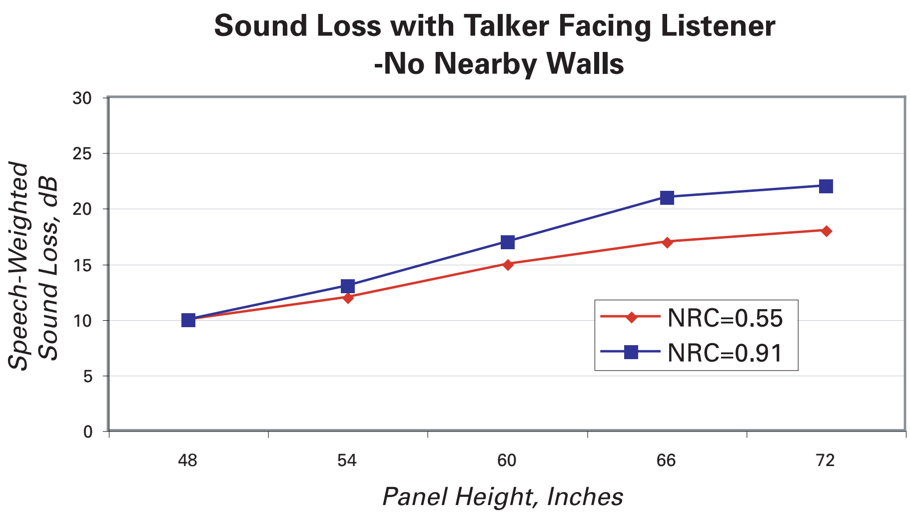


Figure 3-7

3.1.4 Combining the Factors

Several typical situations are addressed to show how all the factors add up to an overall Speech Weighted Loss.

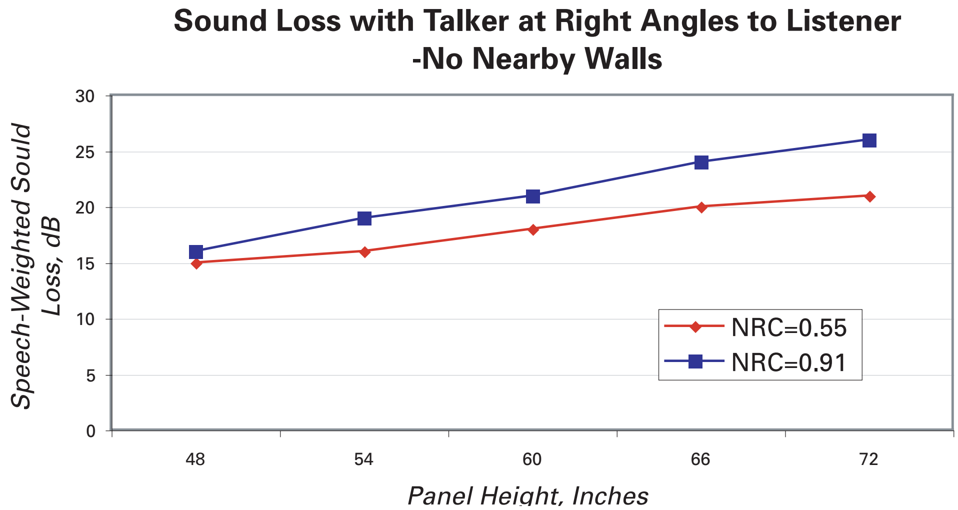


Figure 3-8

3.1.4.1 Workstations away from Walls

Figures 3-7 and **3-8** show The Speech Weighted Loss for seated persons in two 7 by 7 foot workstations, each 3 feet from the separating panel. The panel STC was 24. In **Figure 3-7**, the talker is facing the listener (worst-case) and in **Figure 3-8**, the talker is at right angles to the listener. Two types of ceilings are shown, the standard mineral tile (NRC 0.55) found in most offices and the better performing fiberglass tile (NRC 0.91). It is clear that when the talker is facing the listener and the panel heights are less than 60”, no benefit is derived from adding the more expensive ceiling tile, but there is about a 3 dB improvement when higher panels are used. This improvement translates to 3 dB less masking or 9 PI points of improvement.

When the talker is at right angles to the listener, the loss is higher for all panel heights. The better performing ceiling provides about a 3 dB improvement even for panels 54” or higher. Is the additional ceiling expense applicable to all configurations?

3.1.4.2 Workstations against Walls/Windows

When workstations are near walls or windows there is an additional amount of sound reflection. Often there are multiple reflections including those from panels other than the separating panel, the ceiling, and the floor. They only contribute cumulatively to diminish the sound loss because their path lengths are longer. **Figures 3-9** and **3-10** show the Speech Weighted Loss associated with a talker in a corner workstation (typical of managers), while the listener's workstation is along one wall. The talker and listener are seated, each 3 feet from the separating panel, Again both workstations are 7 x 7 feet and the panel STC=24, so the wall behind the talker is 4 feet away. In **Figure 3-9**, the talker is facing the listener while in **Figure 3-10** the talker is facing the side wall. Wall reflections have greatest influence on high panels where their contribution is greater.

Sound Loss wth Talker Facing Listener
Corner Workstation

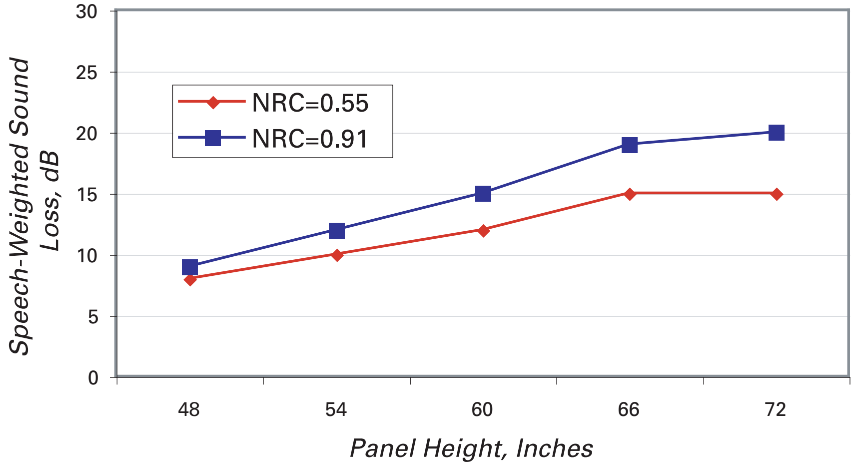


Figure 3-9

Sound Loss with Talker at Right Angles to Listener
Corner Workstation

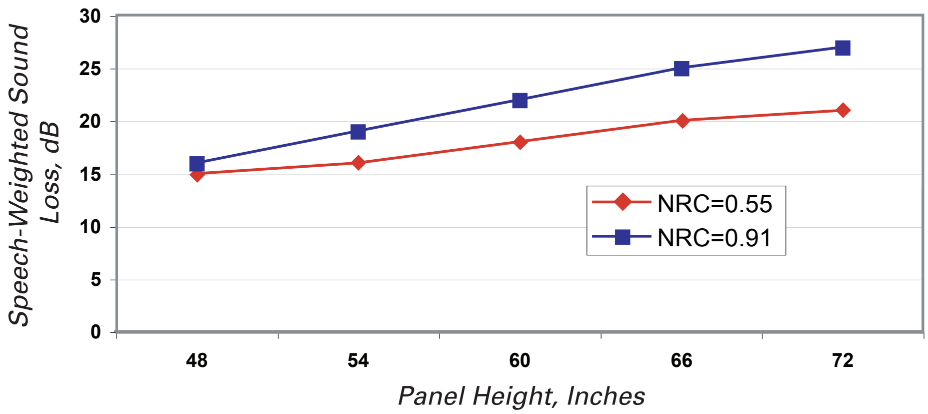


Figure 3-10

3.1.5 Creating Privacy with Sound Masking

The two dynamic factors that influence privacy need to be considered.

3.1.5.1 Speech Level

Studies have shown that there are really two levels of speech that occur usually in an open office: the so-called "normal" voice, and the "raised" voice (2.3, 3.1.2.3). Lowered voice levels are generally restricted to personal phone calls. Experience has shown that people will control their level of speech in a work environment so that use of the normal voice is valid. ASTM [1] has published the peak spectrum of both these levels for use in calculating AI, so it is possible to use these data for privacy modeling or calculations from measured data in existing offices without the need for speech tests.

3.1.5.2 Background Level

In most offices, the background level is the steady sound of the air handling system. This sound is insufficient to provide speech privacy in well-designed systems, so sound masking is normally required. Knowing how loud people talk normally and using the sound loss generated by the building structure, we can determine how much sound masking is necessary to achieve the privacy goals of the user. Normal Privacy is the goal for most open office workstations. Confidential Privacy can only be achieved with the expensive addition of high panels, ceilings with high sound absorption, and very generous spacing between occupants. Most often that is impractical both financially and physically.

3.1.6 The Masking Spectrum Dilemma

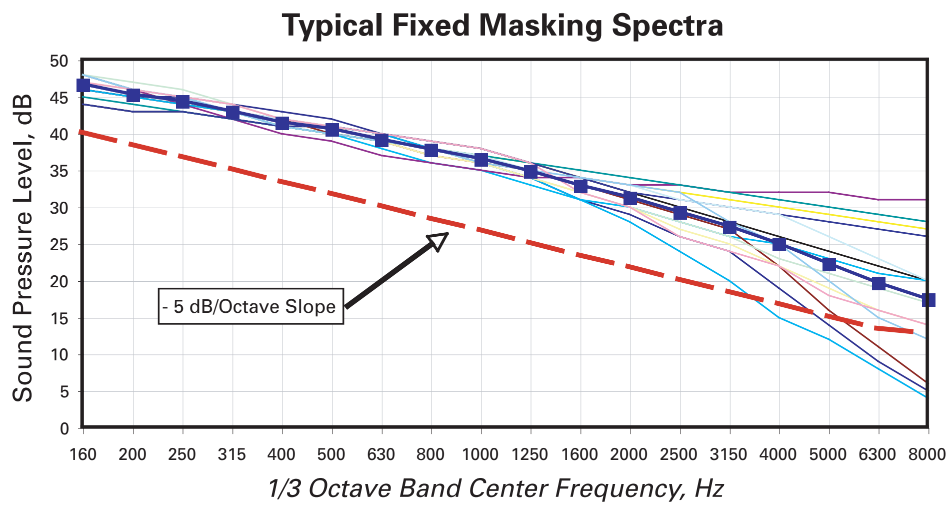


Figure 3-11

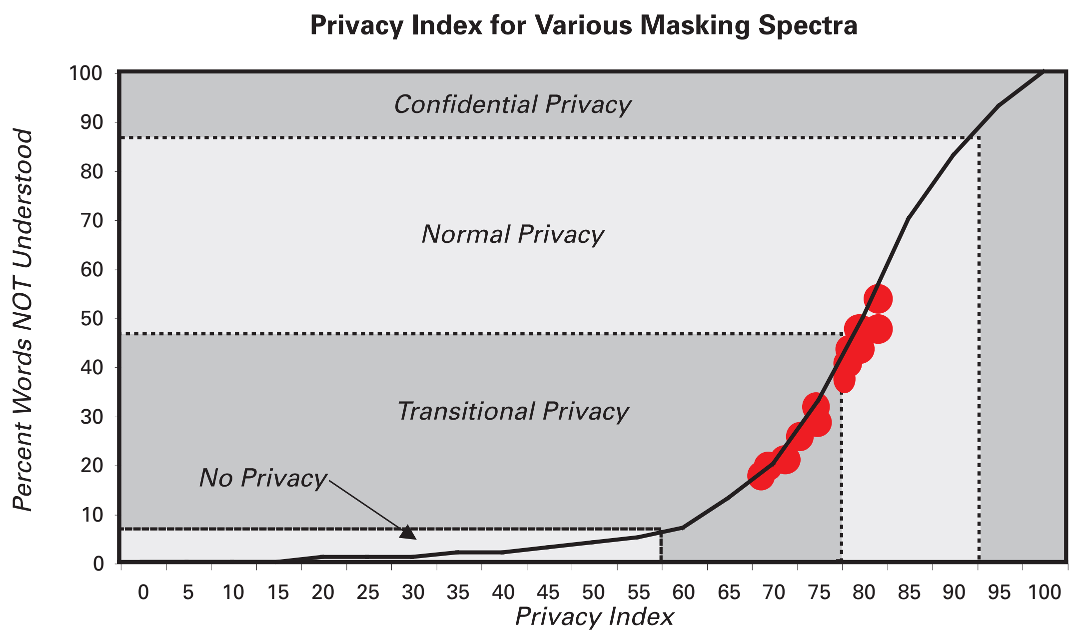


Figure 3-12

Not only is the level of the sound masking important, but the spectrum contour is important also. This is particularly true in open offices. Most standards that relate to the acceptability of a sound, suggest that sounds with more high frequency content are considered "hissy" and less desirable [17]. However, speech privacy is improved with masking sounds that contain higher frequency content. Which is more important, masking that is effective at a lower level but hissy, or masking that is not hissy but requires a higher level to be effective? Since most consultants and masking specialists have opted for the latter case, that is addressed first. ***Figure 3-11*** shows examples of several masking spectra used for open offices. It is clear that there is a difference of opinion about what is needed at high frequencies. The overall level of each has been adjusted to 47 dBA for comparison purposes, but it is not necessarily the overall level needed in every case. The heavy line with data points is the average spectrum and the dashed line is a spectrum that decreases at 5 dB/octave, the so-called "neutral contour" [17]. They compare rather closely except at high frequencies. The wide divergence of all the spectra at higher frequencies may be the result of field measurements where low panels or highly reflective ceilings require more high frequency content to provide privacy.

Figure 3-12 shows the privacy results for each of the spectra shown in ***Figure 3-11*** for an open office workstation with 66 inch high panels and the worst-case situation. One spectrum provided a Privacy Index of 73 while another provided a Privacy Index of 85; a wide and very significant difference in performance. A general rule for sound masking near this range of Privacy Index is that an increase of 3 PI points is achieved with 1 dB increase of sound masking (2.5). The poorest spectrum required a level 4 dBA higher to provide the same speech privacy as the best performing spectrum. The following rule must be taken into account when choosing the masking spectrum contour for an open office:

The masking spectrum contour is very important in open offices.

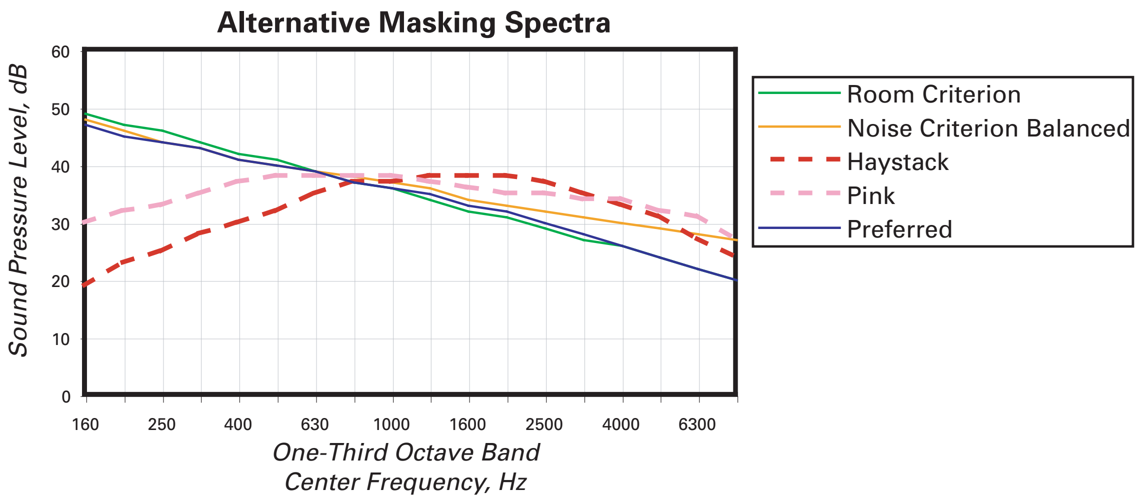


Figure 3-13

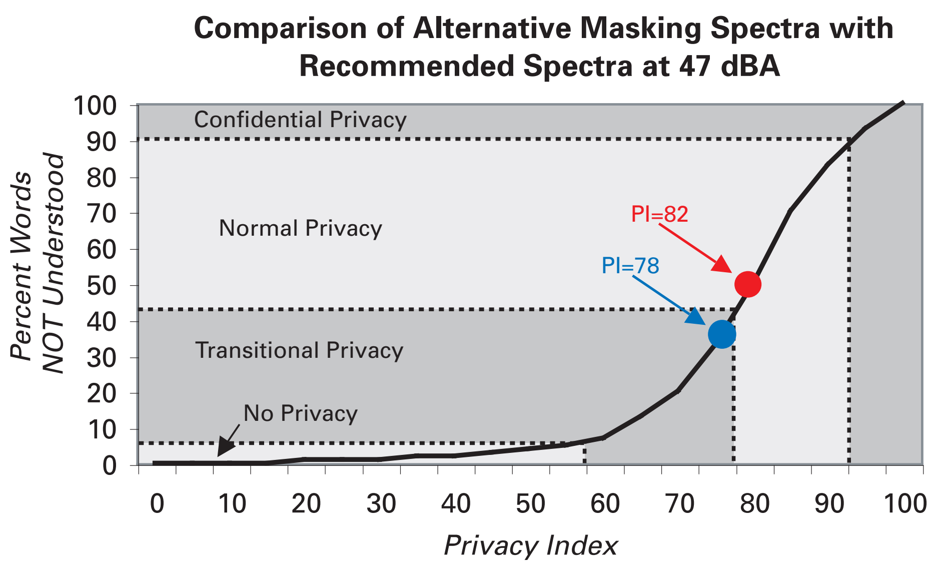


Figure 3-14

Unfortunately, there is more to masking than privacy; there is acceptability. One manufacturer has suggested that a hissy spectrum at lower level is more important to acceptability than a non-hissy spectrum at higher level. ***Figure 3-13*** shows two alternative masking contours that are at variance with those shown above. The more peaked dashed contour is the so-called "haystack" spectrum that has been used on panel-mounted maskers. The flatter dashed contour is more like a pink noise contour and is used in some face-down suspended ceiling maskers. Two of the solid line contours are found in a standard [17]; they are "neutral": contours and are used here as a reference for acceptability. For neutral contours, the standard states: "there were no complaints of rumble or hiss. The levels of 40 to 50 dBA were rated 'acceptable'. The third solid line contour is the average spectrum from ***Figure 3-11*** and matches closely with the recommended neutral contours. If one uses the standards, the two alternative contours clearly would be labeled "hissy". Tests by the National Research Council of Canada agree with this finding [63].

Figure 3-14 compares the performance of the alternative spectra with the average from ***Figure 3-11***. The worst-case situation was used; it had a separating panel 66 inches high (STC=25), a high performance mineral tile suspended ceiling, and a masking level of 47 dBA. The pink-like contour yielded PI=82 while the haystack contour yielded PI=81. The average contour yielded PI=78. The average contour has to be between 1 and 2 dB higher to achieve the same PI as the alternative spectra. The additional high frequency sound at the key speech intelligibility frequencies provides the difference between them.

The results suggest that a number of masking spectra can provide speech privacy. It becomes a trade-off between performance (overall level and spectrum contour) and acceptability. As so eloquently expressed by one company president, it is a balance between "works great, sounds lousy", and "works lousy, sounds great". Based on these results, it appears that spectra that roll off about 5 dB per octave are to be preferred despite the fact that slightly higher overall levels are required. Since the exact spectrum contour is very important in open offices, it is the high frequency content that makes the difference (***Figure 3-12***).

3.1.7 Universal Privacy with Sound Masking

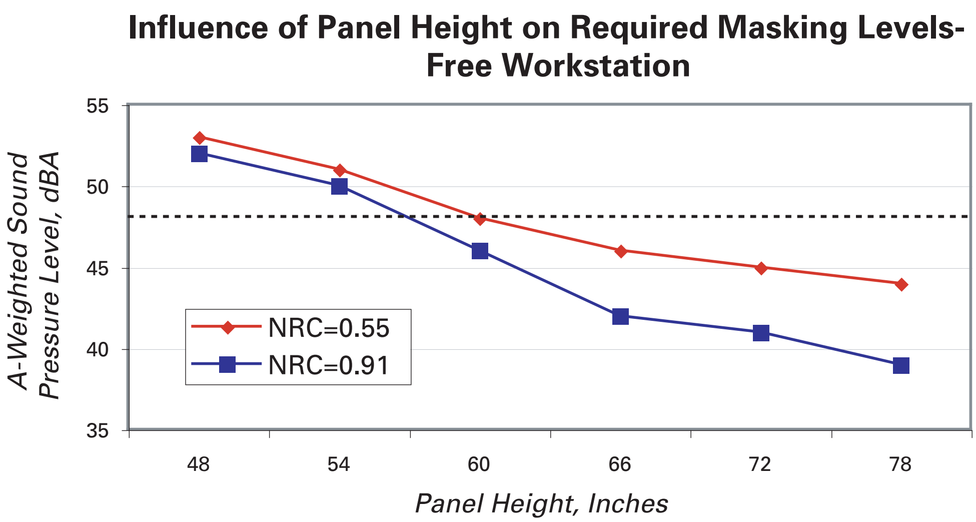


Figure 3-15

We look at two common occurrences: an open workstation away from reflecting walls and a corner workstation both for the worst-case situation. The panel STC = 25 and the panel NRC is .65, typical values for enclosing workstations. A-weighted levels are used, since they are common as overall descriptors. The standard mineral tile is again compared with the high performance fiberglass tile, for several panel heights.

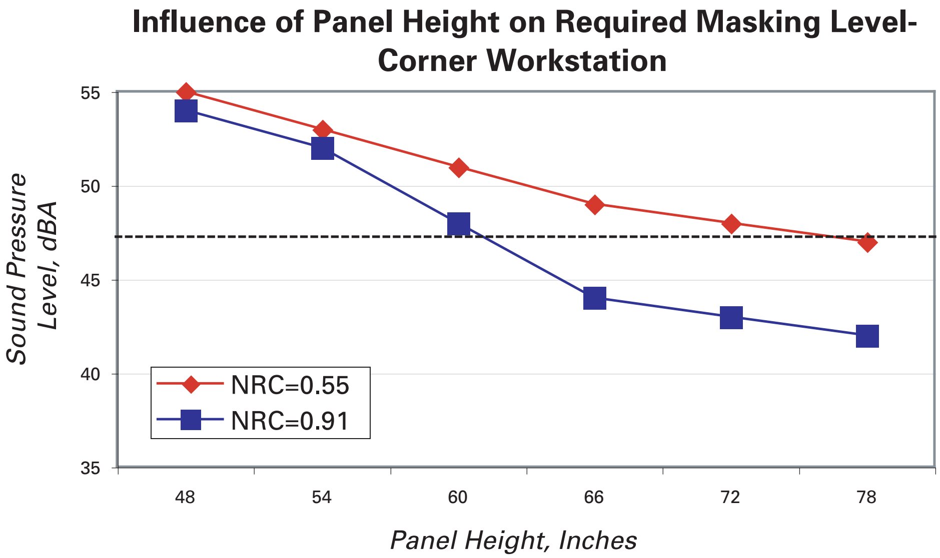


Figure 3-16

Figure 3-15 shows the sound masking required to achieve Universal Normal Privacy (PI=80) in a workstation with no surrounding wall or windows. The dashed line suggests a level (48 dBA) above which the masking might be unacceptable to most occupants. For panel heights of 60 inches or higher, mineral tile ceilings can be used with reasonable levels of sound masking. Higher NRC ceilings, of course, permit lower levels of masking. For panels lower than 60 inches, the use of highly absorptive fiberglass ceilings create extra cost, but no improvement. It is clear that Universal Normal Privacy cannot be achieved for these panel heights, and one must resort to the concept of Partial Privacy (3.1.9).

Figure 3-16 shows the results for a corner workstation where the wall reflections decrease the sound loss and so more masking is required to achieve Normal Privacy. Comparison of the figures shows that the required levels are about 2-3 dB higher due to these additional reflections. To achieve Universal Normal Privacy for a panel height of 60 inches a fiberglass ceiling tile is required. For higher panel heights, a high performance mineral tile (NRC=0.75 or greater) is acceptable. For panel heights less than 60 inches, high NRC ceilings provide no benefit. It is clear that Universal Normal Privacy cannot be achieved for these panel heights and one must resort to the concept of Partial Privacy (3.1.9).

It should be noted that a PI of 80 is the lower limit for Normal Privacy. GSA/PBS [15] suggested that an AI=0.11 (PI=89) would satisfy most occupants. Unfortunately, this would require a 3 dB increase in masking level, with the potential for loss of acceptability. As a result, the above comments should be interpreted as the *minimum* requirements for panel height and ceiling type.

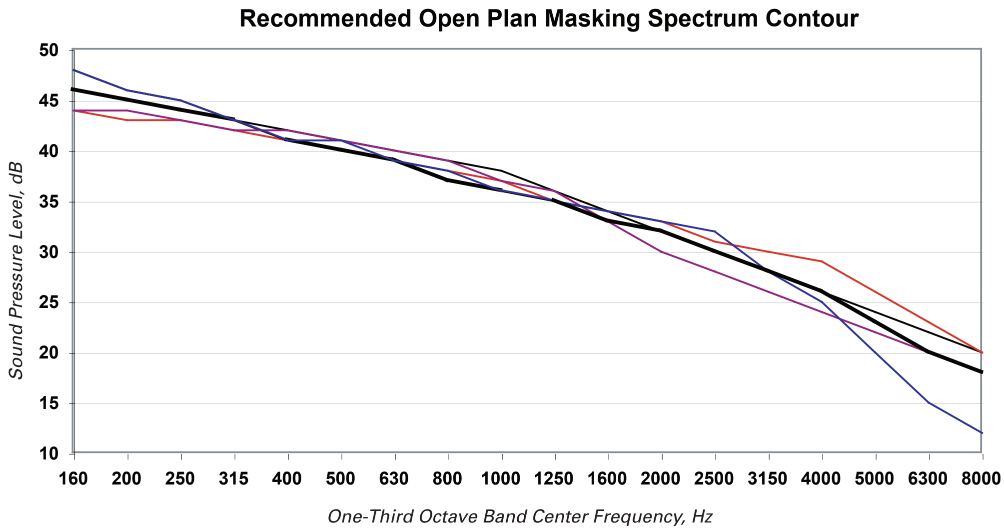


Figure 3-17

Since there are a number of masking spectra available, what is the most effective one? For two workstation configurations, there were four spectra that yielded the desired degree of privacy with the minimum sound injection (excluding the alternative spectra). They are shown in ***Figure 3-17***.

The average of the spectra is given in ***Table 3-4*** and is the recommended spectrum contour for use in open plan offices *when specific analysis cannot be made.* The contour is consistent with that recommended by the National Research Council, Canada [63, 64]. Please note that the spectrum has been normalized to 47 dBA.

Frequency	160	200	250	315	400	500	630	800	1000
Level, dB	46	45	44	43	41	40	39	37	36
Frequency	1250	1600	2000	2500	3150	4000	5000	6300	8000
Level, dB	35	33	32	30	28	26	23	20	18

Table 3-4

Panel Height, Inches	Masking Level, dBA
Less than 60	48
Near 60	47
Near 66	46
Near 72	45
Near 80	44

Table 3-5

The actual recommended level is based on the panel heights shown in ***Table 3-5***. In practice, the spectrum can be set at 47 dBA and then adjusted with either an amplifier or zone controls.

These levels will not produce Universal Privacy for low panel heights as noted above; the concept of Partial Privacy must be introduced (3.1.9).

3.1.8 The Total Masking Spectrum

Masking spectra are designed primarily for speech privacy so only the speech range of frequencies is important, but what a person hears and evaluates is the entire sound spectrum, which is the masking and, most often, the air handling sound. This has impact on masking system design as well as on occupant response. ***Figure 3-18*** shows how both spectra create that environment.

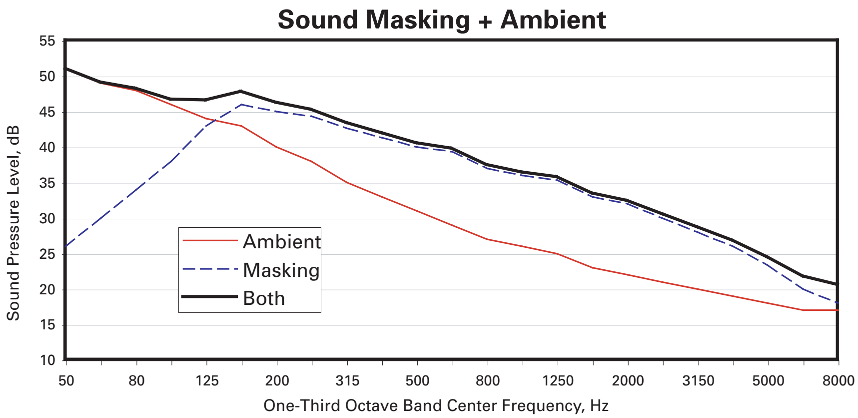


Figure 3-18

The spectrum of a well-designed air handling system generally creates significant low frequency sound but is deficient at the higher frequencies. Sound masking covers the higher, speech frequencies, but is deficient, most often, at frequencies below 160 Hz. The two spectra added together generate a spectrum that is more like that in the ANSI standard [17]. There may be a small dip in the spectrum around 100 Hz which has no influence on speech privacy and is seldom noticed by occupants. When the air handling system is off, this low frequency sound is missing but has no impact on speech privacy. If the air handling system is not designed well, the low frequency noise level is much higher, resulting in a negative response to rumble, which often is attributed erroneously to masking system malfunction. When offices are examined for sound masking, it is important that the presence of excessive air handling noise be detected.

3.1.9 Partial Privacy with Sound Masking

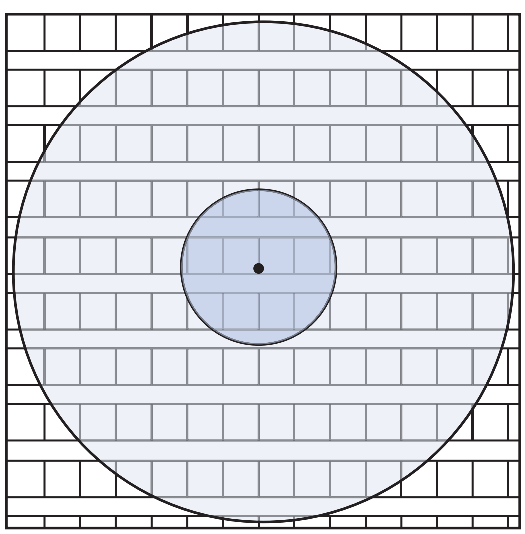


Figure 3-19

Noting that Universal Normal Privacy is not achievable at reasonable levels of sound masking for low panel heights, one might infer that masking is not useful under those conditions. That is not the case. The most common example of offices with low panels is the *call center*. Typically, panels are 48 inches high there. Is there any benefit in using masking for that situation? ***Figure 3-19*** shows what is called the ***Radius of Distraction***. This radius is the distance beyond which persons have Normal Privacy from the person talking. In this example, the workstations are 7 by 7 feet, the panels are 48 inches high, the unmasked level was 38 dBA and the masked level was 48 dBA. The large radius (46 ft) is the distance associated with the unmasked condition while the smaller radius (15 ft) is for the masked condition. Since a person's speech is directional (3.1.2.4) the actual shape is not a circle, but since we have no control over that direction, a circle handles the worst case. This result was developed with modeling software using the expected sound decay in open offices. Since it did not take into account the diffraction effect of multiple panels, the result is considered conservative. Over 80 people might have been distracted by the talker without masking, but only 8 people would have been distracted with masking; a huge improvement. Obviously, not all offices are this large so the ratio is generally smaller. Less obvious is the fact that each person is within the Radius of Distraction of numerous talkers, so there are multiple benefits in reducing that distance.

Sound masking in call centers has an additional benefit. The customer on the receiving end of the call is not aware of the conversations of the other employees, thus preserving confidentiality that is critical for medical related conversations. Also, it eliminates the "boiler shop" atmosphere sensed by a prospective customer in sales messages.

3.1.10 Making Sound Masking Work

Since masking is only one tool in creating speech privacy in an office, the other factors must have some minimum requirements to ensure that excessive masking levels are not needed.

To achieve Universal Normal Privacy in open offices with reasonable sound masking levels, panel heights 60 inches or higher are recommended. ***Table 3-6*** lists some critical characteristics necessary to achieve reasonable degrees of privacy and masking levels. Note that panel NRC is not listed. The masking spectrum contour used was the one recommended in a previous section (3.1.7) and 47 dBA is considered a widely accepted level.

Panel Height Inches	Minimum Panel STC	Ceiling NRC	Masking Level dBA	Privacy Index
54 or lower	None	0.55 to 0.65	48	Partial Only
60	20	0.55 to 0.65	47	75
60	20	0.88 to 095	47	81
66	24	0.55 to 0.65	47	81
66	24	0.88 to 0.95	45 to 47	82 to 90
72	24	0.55 to 0.65	43 to 46	80 to 85
72	24	0.88 to 0.95	43 to 46	80 to 93
80	24	0.55 to 0.65	42 to 45	80 to 88
80	24	0.88 to 0.95	41 to 45	80 to 93

Table 3-6

For panels less than 60 inches high, Partial Privacy is the best that can be achieved with a Radius of Distraction on the order of 15 to 20 feet.

For panels 60 inches high, highly absorbing ceiling tiles are recommended if Universal Normal Privacy is to be achieved at reasonable masking levels. To achieve this degree of privacy with standard mineral tiles, a level of 48 dBA is needed.

For panels 66 inches high, Universal Normal Privacy can just be achieved with a standard mineral tile. High performing mineral, or fiberglass, tiles would yield better privacy or permit lower masking levels.

For panels 72 inches high or higher, satisfactory Universal Normal Privacy can be achieved with standard mineral tiles and reasonable masking levels. The addition of high performing mineral, or fiberglass, tiles would put the listener well into the Normal Privacy degree or would permit lower masking levels.

The masking system designer should note that the worst-case situation was used to derive these results, which may result in providing masking levels higher than needed. See the section on handling temporal aspects (2.7). Offsetting this advantage is the fact that a PI of 80 is the *minimum* acceptable value for Normal Privacy and many workers expect better privacy.

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3.1.11 Other Applications

3.1.11.1 Privacy from Traffic Noise

Noise from exterior traffic can be an annoyance factor in some open offices. As a vehicle passes by a window, there is an angle, the coincidence angle, at which there is virtually no sound attenuation, creating a noticeable change in the sound level experienced by the occupant. Sound masking used for speech privacy will diminish the negative effects of that sound. This is especially relevant near elevated roadways, and airports.

3.1.11.2 Jury Masking

Judges have applied sound masking techniques in courtrooms. When it is necessary to call attorneys to the bench for a private talk, the jury is instructed not to listen (good luck, your honor). Having the jury leave the courtroom is impractical. Adding sound masking to the jury box to make these talks unintelligible has now been instituted widely. Achieving Confidential Privacy in a totally open space is difficult at acceptable sound masking levels. Further, many courtrooms are in older, more reverberant, rooms with high ceilings. Modern courtrooms have lowered suspended ceilings with acoustical tiles. They are less reverberant, but the ceiling reflection path is shorter. Thus the problem exists in both types of courtrooms.

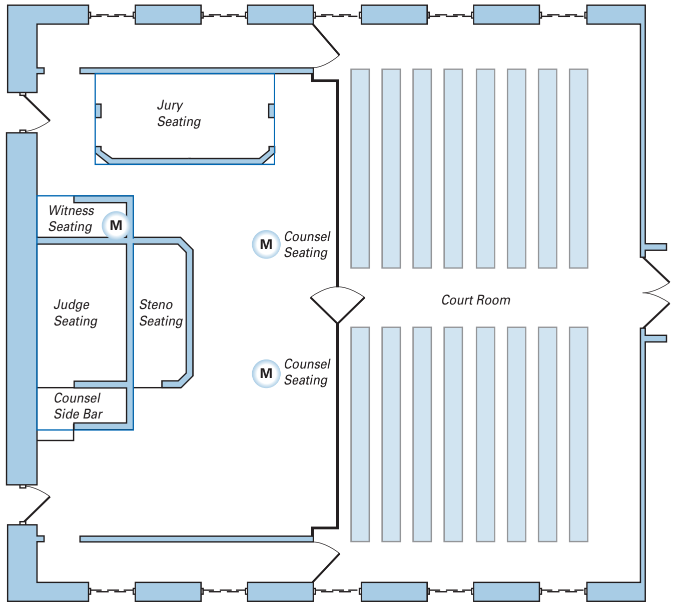


Figure 3-20

Figure 3-20 shows an older style courtroom, in which a two-row jury box is on the judge's left and the position of the attorneys for conversations with the judge are on his right. Because of the high ceiling, sound masking speakers were placed along the low barrier that separates the jury from the courtroom proper and faced toward the jurors. The judge had an On/Off switch to activate the system when desired; jury acceptance was not an issue.

The judge was not facing the jurors so, although he was closer to the jury (12 feet), voice directivity effects reduced intelligibility somewhat. On the other hand, the counsel attorneys were further (19 feet), but faced more toward the jury. Given the geometry of the situation with normal voice levels, the required sound masking level at the first row of the jury was 48 dBA when the recommended spectrum was used. It was necessary to raise the level to 52 dBA when the attorneys spoke to the judge at normal levels. This latter level is not acceptable in normal offices, but fortunately, the time period for masking is relatively short. In most cases, lowered voices are used so the high level of masking was excessive, but prudent.

3.1.11.3 Constant Sounds

Although most masking is used to diminish the disturbances caused by transient sounds (speech, activity, traffic), it can be used to reduce, or even eliminate, the disturbance caused by steady sounds. Examples are light ballast hum in offices and the higher harmonics of power transformer noise.

3.1.12 Handling the Spatial Aspects of Privacy

Since the building structural elements are under the control of the architect or interior designer, this section addresses how the variations of that structure influence the use of sound masking. The general approach is to first define privacy groups in general terms. Those areas that want only masking must be separated from those that wish added signals such as paging or music and from those areas where privacy is not needed. Next, it is best to separate groups by administrative functions; sales areas require different degrees of privacy than clerical or technical areas. Further division may be required based on how these groups physically relate to each other. Areas with suspended ceilings should be separated from areas with "clouds" (discontinuous suspended ceilings) and from areas with no suspended ceiling. Closed offices and other closed rooms must be separated from open offices (closed rooms are discussed in section 3.2). Within any group it is likely that there are workstations with individuals doing similar tasks and with similar structural characteristics, such as panel height or workstation area. Managers in the same area may have higher panels and be located either in corners or along walls. In that case, it is advisable to create a subgroup. All of these privacy groups are defined for sound masking purposes as *zones* (6.1.9).

Since a particular office facility is likely to have a wide variety of physical structure that influences privacy, it is likely that zoning for uniformity of speech privacy would require a range of sound masking levels and spectra. Modern masking systems are capable of handling this need, but abrupt changes in masking levels between adjacent zones can create negative response. Experience has suggested that the best method of addressing spatial uniformity is to incorporate an adequate number of zones each with a reasonably uniform privacy requirement and have the connection between zones smooth any differences between them. It is called Soundscaping (6.3.1).

There are some exceptions to the spatial uniformity of level required within zones. Standing talkers, talkers with loud voices, listeners with a hearing loss, or persons that are visually handicapped, all create variations in privacy requirements. In almost all masking systems the level from individual masking speakers can be adjusted within a zone to partially accommodate these persons.

3.1.13 Handling the Temporal Aspects of Privacy

There are several important reasons for control of the time factor. The first, of course, is to maintain a constant degree of privacy throughout the workday. Employees in less occupied offices (mostly during early evening hours) have a greater need for community than privacy (1.8), so masking levels should be reduced. Security personnel do not want privacy when making rounds at night or on weekends, so masking should be low at those times. When addressing the worse-case situation, it was implicitly assumed that the talker was speaking all the time. Although no studies have determined how many distractions, or how often they must occur, or how loud they need to be, to create annoyance and complaints, it is abundantly clear that the time factor plays a key role in the development of annoyance and subsequent loss of productivity. How is it to be handled?

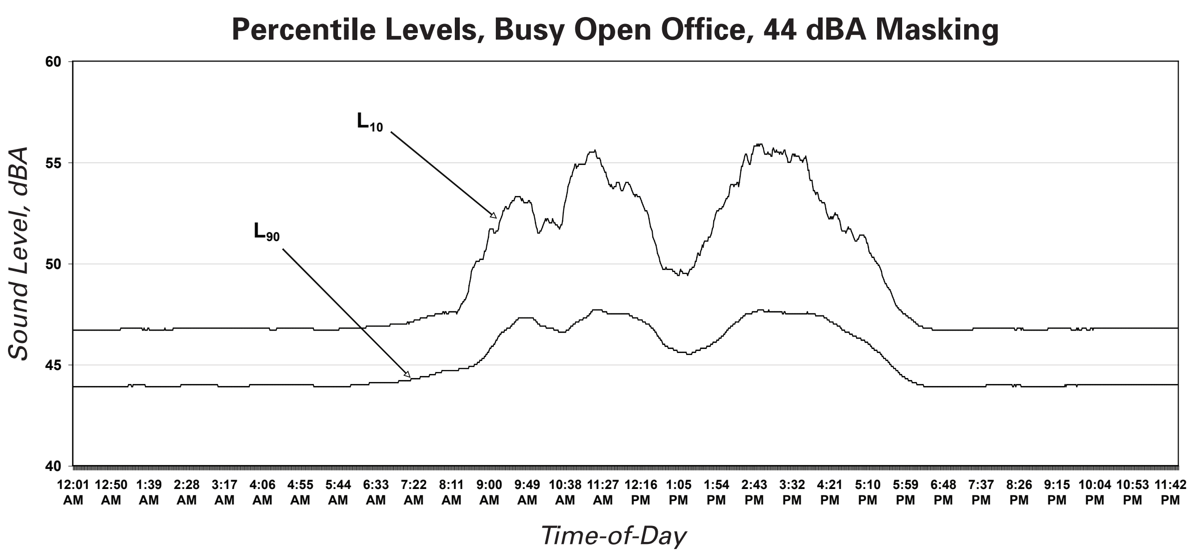


Figure 3-21

Many modern masking systems are capable of controlling masking levels. If there are defined, and relatively permanent, changes in activity levels, or changes in the structural elements related to privacy, such as new ceilings or furniture, manual level adjustments in a zone can be made. Because of the relative sensitivity of privacy to masking level, such changes must be made in small steps. There are attenuators that permit small controlled changes that can be used by an owner without negatively influencing system operation (5.4.5). When speech or other noise levels are lower, or less frequent, than those for which the design was made, the masking can be reduced; this increases acceptance without degrading privacy. Most often it is the variation of activity sound levels during the workday that require control. Some systems have an advanced function with which it is possible to program the masking level as a function of time-of-day and day-of-week (5.5.1). This function is adequate for overall temporal control in that it can handle known variations of activity during a workday, a weekend, or a holiday. A more advanced function is now available in which the system senses the activity sound levels in real time and automatically adjusts the masking level to maintain privacy (5.5.3). How is this done?

When transient sounds above the background impinge on office occupants, the level, duration, and information content, contribute to distraction. The cumulative effect of distractions is to create annoyance, possibly complaints and loss of productivity. It would be beneficial if the masking system could minimize the potential for distractions. Since masking levels have an upper limit of acceptability, and a lower limit of effectiveness, controls must contain masking levels within these limits. These limits are set on programmed level controls based on estimates of activity sounds during the workday. How can the system detect and adapt to activity sounds in real time?

The best descriptors of transient sound are the percentile levels (A.5). The tenth percentile level (L_{10}, the level exceeded 10 percent of the time) is used most often as a descriptor of transient sounds and the ninety-ninth percentile (L_{99}) is used as a descriptor of the background (or sound masking) level [23]. For use in an office, it is best to use running percentile levels over relatively short time periods. ***Figure 3-21*** shows an example of percentile levels for a busy open office over a twenty-four hour period. Prior to, and after, working hours the levels are constant suggesting there is little activity and little need for sound masking. During the workday the transient levels can be quite high (except for lunch hour) suggesting the need for sound masking.

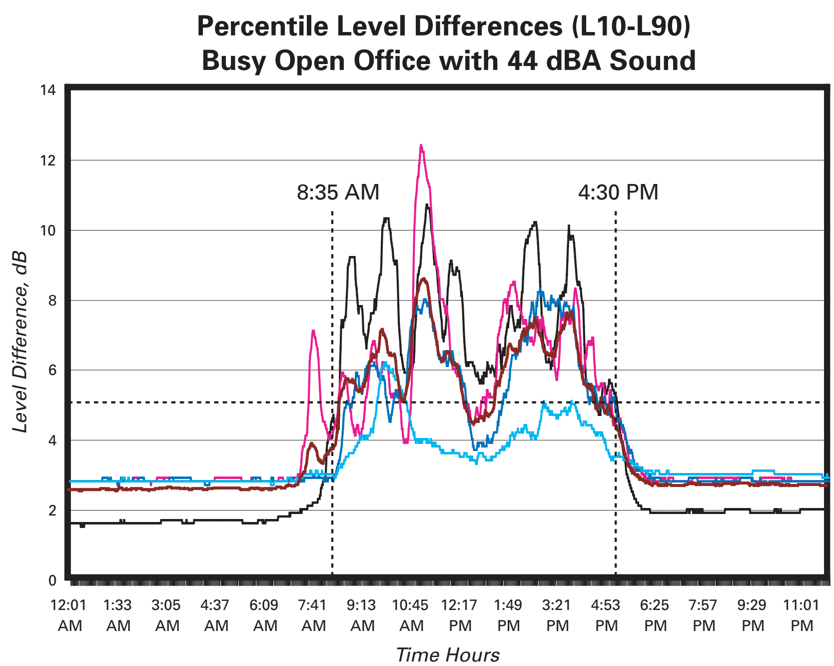


Figure 3-22

To look at how high the masking should be, the temporal data from a number of days were averaged (heavy line) and the difference between the two percentile levels is shown in ***Figure 3-22***. The figure shows a horizontal dashed line at a Difference Level (LD=L_{10}-L_{90}) of 5 dB. Experience suggests that the potential for distraction needs to be addressed when that approximate difference is exceeded. This example is for an office with a masking level set at 44 dBA. The area between the average L_{10} curve and the LD line is the cumulative effect of distraction. It occurred between 8:35 AM and 4:30 PM and higher masking levels during that period would have been beneficial.

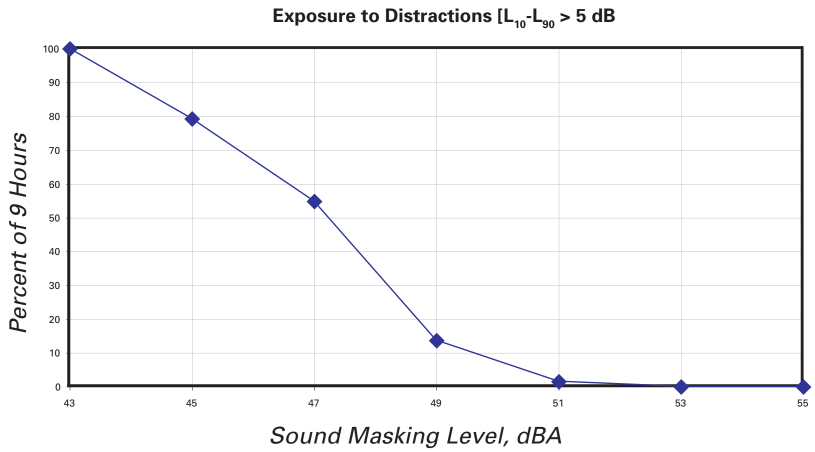


Figure 3-23

Figure 3-23 shows the total exposure time as a percentage of the workday for several levels of sound masking. Levels of 45 dBA and above provide a significant reduction in the amount of time one is exposed to distractions. Raising the level from 44 to 47 dBA would have provided a 63% reduction in exposure. Looking at the time of exposure alone, does not take into account the severity of that exposure. Using a metric such as dB-Minutes, (similar to that used by the Occupational Safety and Health Administration for hearing loss) would add in that factor.

Masking Level, dBA	43	45	47	49	51	53	55
Exposure Time, Minutes	540	428	296	74	8	0	0
Total Exposure, dB-Minutes	2178	598	341	43	1	0	0
Average Exposure Level, dBA	4.0	1.4	1.2	0.6	0.1	0.0	0.0

Table 3-7

Figure 3-24 shows the same data in terms of dB-Minutes. Although the percentage of time a listener would be exposed to distractions was significant at 45 dBA, this graph indicates that the severity of that exposure would be greatly reduced. This figure also shows how important it is to set the masking level properly, and that a predetermined fixed level based on tradition may be inadequate. ***Table 3-7*** compares these two ways of looking at transients. Raising the masking level from 43 dB to 45 dB reduces exposure time only slightly, but reduces the severity of the distraction significantly. To better appreciate this, an exposure level was created that was the average exposure over the workday. The average exposure is reduced from 4 dB to 1.4 dB by increasing the masking level by only 2 dB. Adding another 2 dB produces only minor improvement. It should be clear that too little masking can result in much distraction, and too much masking will provide little additional benefit while increasing the likelihood of not being accepted.

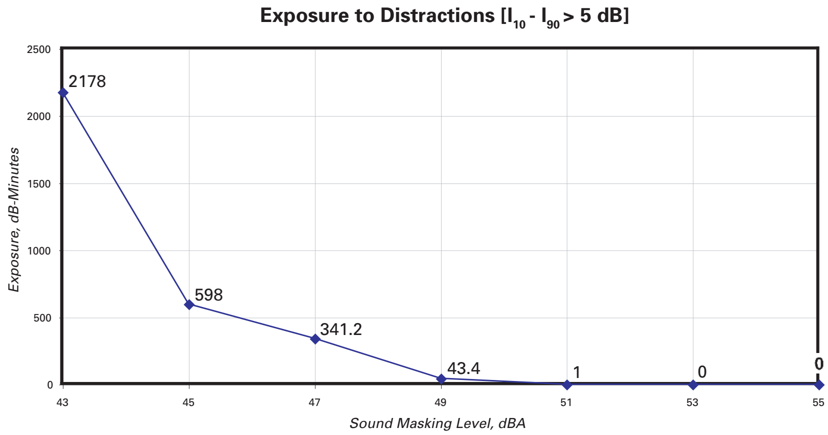


Figure 3-24

There are several more points associated with the time factor. First, since the disturbance potential varies throughout the day, the masking level should track it (5.5.3). In the absence of such tracking, and with the inability to predict the magnitude of transient sounds, it is best to initiate a masking system at a low level and then slowly raise it until the privacy objectives are met. This suggests use of an initial ramp function that can raise levels slowly but automatically (5.5.2).

While it is tempting to develop an exposure metric in dB-minutes to emulate the OSHA regulations, such a metric disregards the information content, which is an equally important factor. Since the level statistics vary based on room activity, only research will be able to provide any useful guidance for implementing it.

3.2 Privacy in Closed Rooms

There are three uses for closed rooms in commercial facilities that are important. The first is a closed office with one occupant and the second is a conference room with several occupants. In both cases, communication in the room is important and Confidential Privacy from persons outside is desired. The third is a former closed office that has been converted to a multi-person open office. In this case, the occupants wish, at least, Normal Privacy from each other. The former cases are addressed in this section, the latter case is addressed elsewhere (6.1.4).

3.2.1 The Problem

Because closed offices most often provide a high degree of visual privacy, it is often assumed that they have high degrees of speech privacy. Unfortunately, there are a number of factors that make this assumption invalid. Prevailing social customs keep office doors open for easy accessibility; closing the door results in the belief that outsiders are being excluded from interesting conversations. Modern construction techniques have lightened walls to control costs making the walls more sound transparent. Having an open plenum above the suspended ceiling as a low cost return air duct further increases the sound transparency of the office. Early on, fiberglass ceilings were used in closed offices under the erroneous assumption that if they were good in open offices, they must be good in closed ones. That assumption made matters even worse, but that error has been corrected.

3.2.2 The Construction Solution

Constructing a closed office for speech privacy makes use of only one factor in the speech privacy equation: the sound attenuation. This solution is a *static* one, i.e., once the building is built, it has fixed acoustical properties. The other two factors, voice levels and masking levels, are *dynamic*, i.e., they change from minute to minute. A heated discussion occurring in a closed office designed for normal speech levels will lose its privacy just when it is needed most. Often speakerphones are used in closed offices and, as with most audio equipment, they are set too loud. In rented offices, where wall construction is the lightest, confidentiality is lost when the air handling system is turned off in evening hours. These comments show the fundamental weakness of the construction-only solution. This is not to say that the building structure is unimportant, but rather that its properties should be integrated with the other factors in the privacy equation. The most important sound paths are shown in ***Figure 3-25***.

In the vertical plane, the wall (or door) and ceiling plenum are the important factors, while in the horizontal plane; the side wall/windows may play a role.

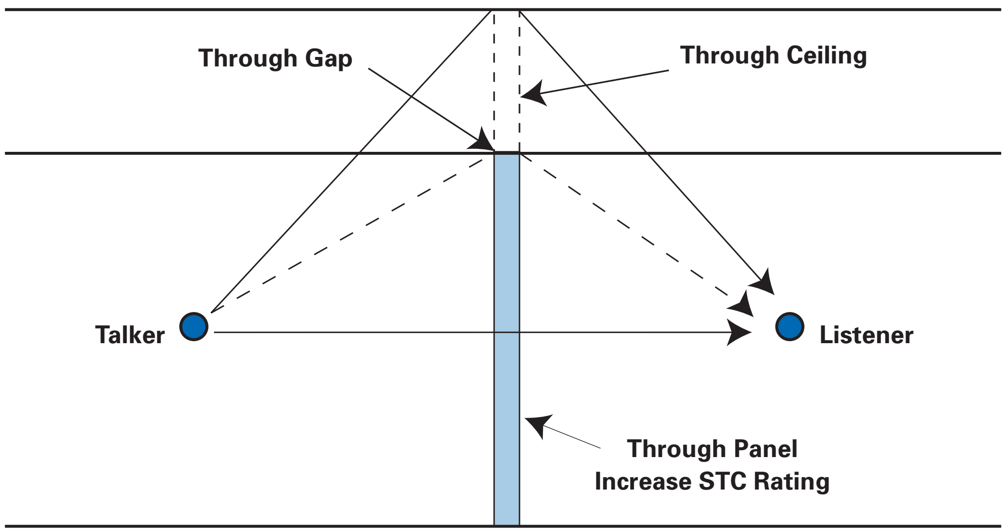


Figure 3-25

3.2.2.1 Walls

The standard approach to increasing the sound attenuation of a wall is to specify a wall with a high STC rating. Although the higher the better, the higher the costlier, and how much is good enough to guarantee privacy? STC is a laboratory rating in which the best possible performance of the wall is obtained (A.1.1). Applying the Speech Weighted Loss rating (A.1.6) to the data used for STC shows that most common partitions may have about 3 dB more attenuation of speech than the STC rating suggests. However, field installation always degrades tested performance, so that small benefit is not realized. There are a number of reasons for decreased performance. The first concerns sound passing through the wall itself. If construction is poorly done, it may have extra transmission paths not tested for in the laboratory. The others can be grouped into what is called *flanking paths*. Figure 2-1 shows some examples. Floors, or suspended ceilings, that are not flat and level result in gaps. Doors in a wall will reduce a wall's attenuation, particularly if it is poorly seated and has gaps. A continuous ceiling plenum can contribute significantly to weakening the wall's performance. The safe approach for a designer is STC overkill, with a resultant cost overkill. As in open offices, we are dealing with parallel paths, the weakest of which dominates the sound attenuation. Acoustical consultants will estimate the weaknesses of various flanking paths and recommend improvements that will permit the wall performance to come close to that specified by the STC rating. A common rule-of-thumb is that the performance of an installed wall will have a field STC (which includes all other paths) that is 5 points less.

3.2.2.2 Doors

An open door permits conversation to be heard immediately outside, but if it opens on a corridor, speech reflected from the wall may be understood in the next office if that door is also open. The standard solution for privacy is the best one: close the door. In some cases, expensive doors have been purchased that have gaskets to prevent sound leaks around the edges. Experience has shown that a normal *solid core* door will create sufficient sound attenuation when coupled with sound masking.

3.2.2.3 Windows

Persons in closed offices typically demand, and get, windows. Buildings whose curtain walls have windows may have a pane that is common to two offices. The usual fix is to have foam fill the gap between wall and window. Foam is not particularly effective. Worse though is the fact that conversations excite window vibrations that will completely bypass the wall, resulting in more sound transparency. If this condition cannot be avoided, care must be taken in the design of the sound masking system and the location of occupants.

3.2.2.4 Ceiling Plenum

If the surrounding walls extend to the structural ceiling and the return air is ducted, the plenum path is generally of no concern. The exception occurs with large ducts that have no insulation and large diffusers in contiguous rooms. In most offices, the ceiling plenum is open and continuous to permit return airflow without a duct. This path is of concern. There are several structural solutions, not all of which are successful. Walls can be raised to the structural ceiling but with an opening for return air. A lined stub duct should be inserted in that case. Walls can be raised 6 to 12 inches above the suspended ceiling line. The continuity of the suspended ceiling is interrupted, causing additional construction costs, but the potential gap at the suspended ceiling is eliminated. In most buildings, the wall terminates at the suspended ceiling, so there is a path from room-to-room through the plenum as well as through any gaps. Often this sound path is not recognized until after the rooms are occupied, so fiberglass batts are thrown into the ceiling plenum as a low cost fix that is totally ineffective. Other practitioners have hung lead sheets in the plenum as a retrofit improvement. They work, they are quite expensive, difficult to install, and interfere with return airflow. Again, all of these fixes are static.

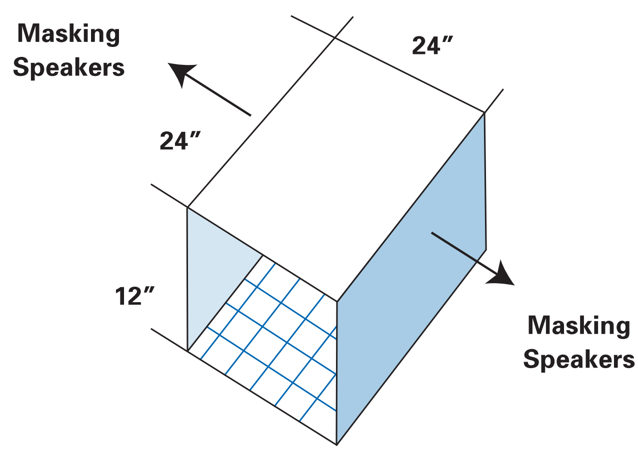


Figure 3-26

3.2.2.5 Return Air Grilles.

If the return air system uses an open plenum, the return air grilles are potential transmission paths for speech as well as plenum sound masking. . The construction solution is to add a short muffler. This adds installation and operating costs since it increases system pressure drop and changes the airflow balance in the building. ***Figure 3-26*** shows a simple and inexpensive solution using duct sheet metal. They can be fabricated in any local sheet metal shop as needed. Since most offices occur in a row, the masking speakers will also appear in a row, so by orienting the opening at ninety degrees to that row, speech privacy between offices is improved and no excess masking sound penetrates into the offices.

3.2.3 Speech Weighted Ratings

The Ceiling Attenuation Class (CAC) was developed for rating the sound passing through an open ceiling plenum between two closed offices (A.1.5). This rating is speech weighted so is very useful.

Sound Transmission Class (STC) and Noise Isolation Class (NIC) are used as sound attenuation ratings for walls (A1.1, A1.1.2). STC is a rating for a wall partition under laboratory conditions, while NIC is a similar rating but with a reduced frequency range. Neither is speech weighted. How can these ratings be used to estimate the speech loss between offices?

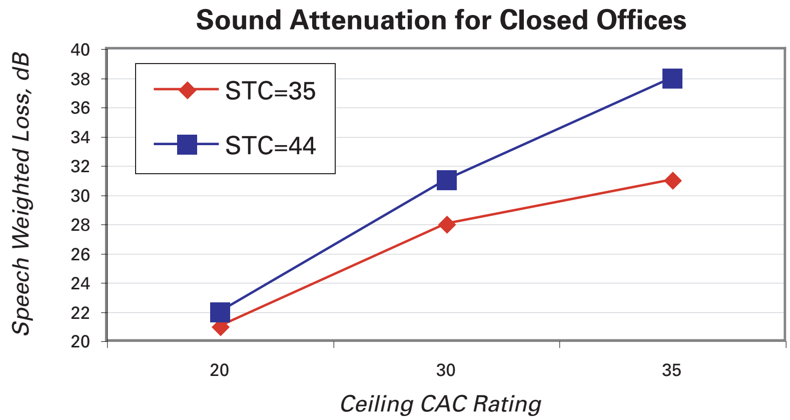


Figure 3-27

Calculations have been made converting the rating data to Speech Weighted Loss. ***Figure 3-27*** shows the expected Speech Weighted Loss for walls of typical closed offices with an open plenum above. The STC rating was degraded to account for flanking paths. The lower value of STC applies mostly to what is referred to as "spec" offices where low cost rental space is obtained. It is clear that the CAC rating of the ceiling plays a major role. Values of CAC near 20 apply to fiberglass ceilings that work well in open offices because of their high sound absorption, but are disasters in closed offices. The CAC rating of the ceiling is an important factor for design of closed offices

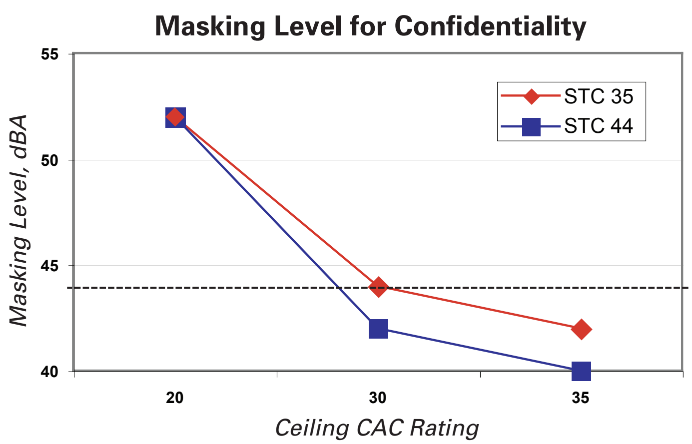


Figure 3-28

The approximate level of sound masking required to provide Confidential Privacy for these cases is given in ***Figure 3-28***. The dashed line represents the recommended maximum masking level for closed offices. It is clear that sound masking will *not* be acceptable for low CAC ceilings such as fiberglass. The CAC ratings of ceilings should be 30 or greater with 35 being preferred; and ceilings with this rating are commonly available. One interesting result is that sound masking can be used effectively in offices with the least expensive walls.

Since persons in closed offices want confidentiality from outsiders, the listeners are those outside and it is there that the masking must be applied (6.1.1). If the outside area includes other closed offices, then the levels noted above apply in those offices also. If the outside area is an open office, or corridor, the levels needed for the open areas should be applied. (3.1.6). Those levels will provide increased privacy since they will be higher.

3.2.4 Making Sound Masking Work

It is necessary to have minimum characteristics of the building structure in order to avoid having excessive masking levels in a closed office. Recommended ratings for closed offices are shown in ***Table 3-8***. See 3.2.2 for grille covers.

Item	Recommendation
Wall STC	45
Wall NRC	Not important
Ceiling CAC	30 or higher
Door STC	Solid Core Door
Return Air Grilles	Center in Room

Table 3-8

The sound level in closed offices must be lower due to expectations of a quieter environment, but also because the sound attenuation between offices is considerably greater. For the construction recommended in ***Table 3-8*** the masking spectrum shown in ***Table 3-9*** is appropriate. The levels shown at frequencies above 3150 Hz are generally at or below the unmasked background level, so may not be achievable.

Frequency	160	200	250	315	400	500	630	800	1000
Level, dB	41	40	40	39	38	37	35	33	31
Frequency	1250	1600	2000	2500	3150	4000	5000	6300	8000
Level, dB	29	26	24	22	20	17	15	12	10

Table 3-9

3.2.5 Other Applications

3.2.5.1 Home Environment

There are a number of noise problems in homes, the worst ones occurring when one is trying to sleep. Research on community noise done by the author on behalf of the Environmental Protection Agency showed the most pervasive noise sources in residential areas were barking dogs, and their noise is great cause for complaint but a weak prod for enforcement. The next most pervasive sources are emergency vehicle sirens. A test in Boulder, Colorado showed that siren use could be safely restricted to intersections, greatly reducing the impact. Unfortunately, listeners wrongly interpret the noise as necessary so complaints are not made, and insurance companies mandate continual use, so the test did not survive. In large urban areas, road, helicopter, and airport noise are a large problem. Internal noises can cause annoyance; faucet drips, snoring and sleep apnea are common examples

In most of these cases, very little can be done to reduce source levels. One means of alleviation is to use noise-canceling earphones. They work well but are not easily accepted in the home and are uncomfortable for sleeping. Fans had been used in years past in southern climates to mask external sounds. They have a tonal characteristic and create fairly high levels, but users surprisingly habituated to them.

Small electronic maskers are commercially available now and can be made to work well for the above situations. The author has used one in his home for many years to eliminate the distraction of exterior nighttime noises while sleeping. It does not work well for a snoring partner in the same bed, but it does block household sounds. Masking has been used in dining rooms when entertaining in order to block the noise of children playing elsewhere in the home.

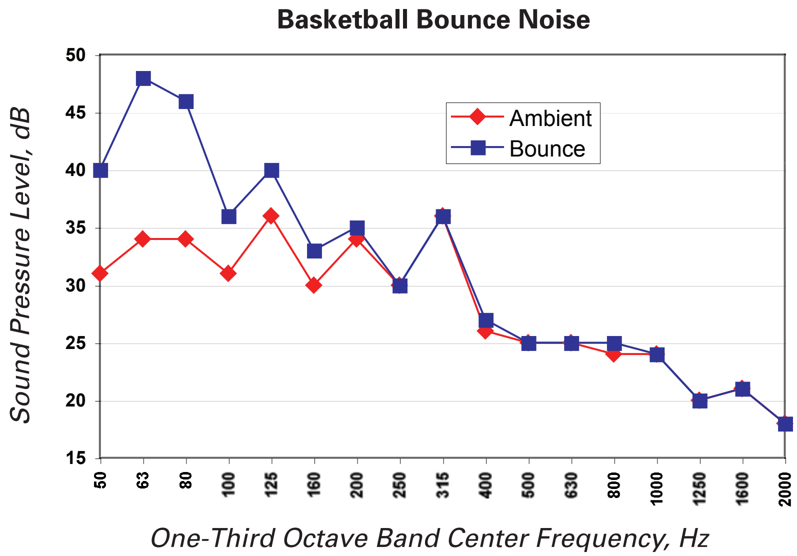


Figure 3-29

3.2.5.2 Impact Sounds

An unusual application was to protect a medical suite from the impact sounds created by ball bounces in a basketball court *directly above*! ***Figure 3-29*** shows the frequency spectrum in the room below. The sounds were low frequency and of much higher level than the existing background (34 dBA). Since most masking speakers do not generate significant sound below 125 Hz, a sub-woofer speaker was recommended; it had the frequency response needed to mask the bounce sounds.

3.2.5.3 Condominiums and Apartments

Occupants are physically close but socially separate. Any noise intrusions are poorly accepted. The construction solution is generally applied, but is successful only when extremely high STC values are specified. One poor design is to put the living room of one unit contiguous with the bedroom of another. Since many of these units have interior air handling systems, it is surprising that sound masking has not been used. This author's own interest in sound masking originated with such a situation. A self-contained masking system was placed in the air duct that distributed both the heat and the masking throughout the condominium. A 5 dBA rise in level was sufficient to block out sounds from neighbors as well as from outside when the windows were closed. The occupant did not notice the masking; the spectrum was shaped to match the sound of the air handling system. The ratio of the cost of structural improvements to solve this problem to sound masking costs was 100 to 1.

3.3 Modeling Speech Privacy

Often a person is asked to install a sound masking system with little knowledge of the factors that will control how much masking is required or even whether it will work acceptably. Prospective customers seldom appreciate the factors that control speech privacy and, as a result, have unrealistic expectations. These two factors have caused a bad name for sound masking and for the installer (privacy complaints are *always* the fault of the sound masking). Even if an installer wanted to predict speech privacy, he would find it virtually impossible to calculate, and arduous to measure (if an existing facility). The discussion in the previous sections provides some general guidance that helps to avoid problems. However, complaints are specific to a geometry, so a software program was written that analyzes a wide variety of office designs in order to permit the masking system designer to decide whether, or how much, masking is needed. The program is discussed in this section.

Speech privacy can be determined in *existing* offices with extensive measurements. Unfortunately, these determinations may reveal deficiencies that are too costly to correct. Although software modeling can be used to quantify deficiencies in existing offices, it is best used to determine speech privacy in *planned* offices so errors can be avoided. Because of the geometric complexity of an office, particularly an open office, modeling tends to be the best approach to removing much of the guesswork.

Acoustical modeling of offices must use the three key factors that determine speech privacy. For the voice factor, it is necessary to take into account both normal and raised levels. Fortunately, most people control their voice levels so that the voice spectra in standards may be used [1]. If the model is applied to an existing office, sound attenuation measurements can be made to improve the accuracy of the results. For other cases, the software must have a database of the acoustical properties of ceilings, furniture systems, walls, and carpets in order to determine the sound attenuation. With these two key factors calculated, a masking spectrum can be designed to provide the desired speech privacy.

Acoustical modeling does have some simplifications that can limit the accuracy of results:

1. The model is restricted to speech privacy where the relationship between physical factors and human response are well documented.

2. Sound attenuation analysis should take into account both amplitude and phase (time delay) for each path. This would require solution of the acoustical wave equation as well as knowing the phase shifts that occur on reflection from, and transmission through, various materials; a nearly impossible task. Present analysis does not take into account phase shifts and presumes that each path is incoherent with the others, so the sound attenuation at each frequency for each path can be added in a mean square sense to create a cumulative sound attenuation spectrum. As a result, modeling cannot be totally correct, but field measurements suggest that this weakness is not a serious handicap.

3. Voice characteristics are complex. For example, some persons are known to have voices that "carry." Field measurements of voice spectra are not always in agreement, nor do the voice spectra in the two standards agree [1,16]. The ASTM standard [1] is used and has two categories of voice level, normal and raised. It is impractical to test each and every person's voice in an office environment, so the voice spectra in the standards are used in modeling. The directivity of the human voice is fairly strong and

must be taken into account; however, data are averages. For modeling, the horizontal direction of speech can be accounted for, but it is reasonable to assume people speak horizontally.

4. One-third octave band analysis is preferred, but the acoustical properties of office materials are often provided as a one-number rating (STC, CAC, NRC) or at best as a one-octave band spectrum. One-third octave band transmission loss spectra are available for most wall and ceiling ratings. If not, one-third octave band spectra must be synthesized, using the data that are available. For STC, the ratings provide the best that one can achieve (A.1.1). But how much degradation of the rating is necessary to match with reality? A default degradation factor that can be adjusted for specific situations is required and one must be supplied in any software. For CAC (A.1.5), the measurement procedure is for worst-case situations, so although a default degradation factor is needed, it is likely to be small. For NRC (A.1.3), the number is rounded to the nearest 0.05. At high absorption that can mean a variation of several dB. The sound absorption for the rating is determined for random incidence sound. In the open office, the incidence is at a specific angle (specular reflection) resulting in unknown differences. The rating method for NRC also allows for numbers greater than 1 (the physical limit) and a correction formula is needed to bring the high absorption values back to reality. How can a realistic sound attenuation by reflection in one-third octave bands be determined from a one number rating or from one octave band absorption coefficients? For ceilings, there are two types of materials, mineral fiber and fiberglass and generally, there are one-octave band spectra available. So it is possible to synthesize reasonable one-third octave band spectra. For mineral tile materials, the absorption coefficients are sufficiently low that errors associated with conversion to sound attenuation will be small. Furniture manufacturers are reluctant to provide more than NRC ratings for their products, but fortunately, the absorption characteristics of panels play a small role in speech privacy in well-designed offices.

5. The theory of sound diffraction over a single finite height barrier is reasonably well known (Maekawa equation) and is used successfully in many practical situations. There is no comparable theory for the reflection from a single finite height barrier. Fortunately, in the office environment, the reflected path length from talker to listener via panels is sufficiently long that there are no major contributions to weakening the sound transmission loss. The diffraction theory applies to barriers with no flat surface (ceiling) above them. If the gap between the ceiling and the panel top in open offices is large, the error calculating diffraction is likely to be small. When the gap is closed (closed office), the diffraction path disappears. There is no correction formula that connects the two extremes.

6. For closed offices, the sound transmission path from a talker in one room to a return air grille, through the ceiling plenum, to another return air grille, and then to a listener in an adjacent room is quite important and quite complex. Experimental results are needed for that case. Fortunately, this problem can be bypassed by use of sound attenuators on the grilles.

7. Reflection from ceiling light fixtures is complex and can only be approximated from field measurements.

8. For closed offices, the influence of various ceiling heights and ceiling plenum depths on the ceiling plenum path (CAC) can only be approximated. The extension of partitions above the suspended ceiling up to the structural ceiling has an unknown influence on the sound transmission loss.

Despite these limitations, experience has suggested that the program described below is sufficiently accurate to prevent egregious errors in the design of a sound masking system.

3.3.1 Storing Physical Attributes of the Space

The program contains a database of the acoustical characteristics of products commonly used in offices. Since the published data are continually changing, the data must be considered representative and may not be specific to the current product. If new data are published, the user can add it to the database. A sample screen is shown in ***Figure 3-30***. Data for suspended ceiling materials are given in one-octave band absorption coefficients for the NRC and CAC ratings. There are some data for suspended ceilings in one-third octave bands for both sound absorption coefficients and two-room sound transmission losses. Transmission loss data for walls are given in one-third octave bands. Data for open office furniture products are given as one-number ratings (NRC and STC).

Product data change continually, so the user must update the information. The supplied data is likely out of date and must be interpreted as representative only. Records can be added and modified. Since the data used in any design can be saved, the user is cautioned not to delete any record that he has used or saved.

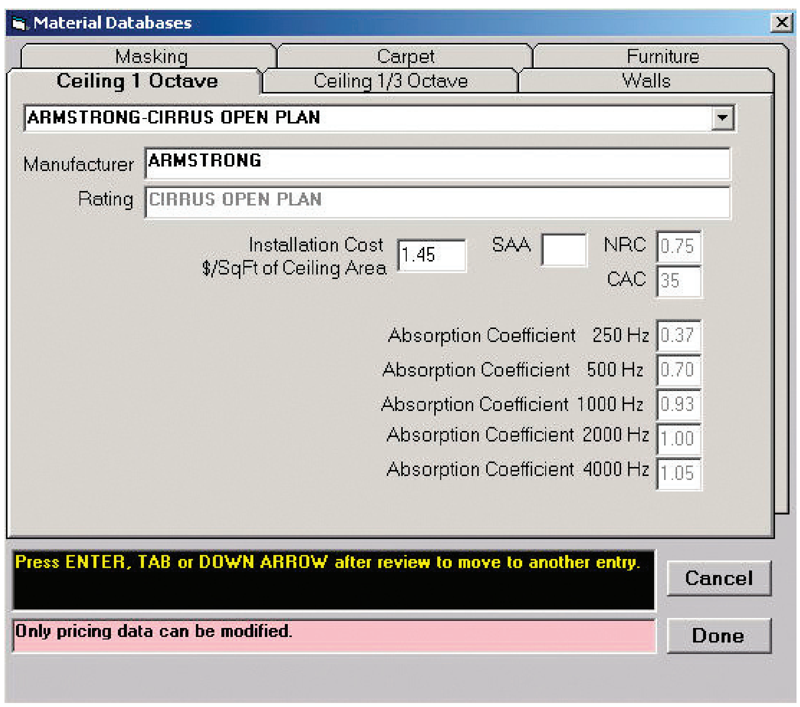


Figure 3-30

3.3.2 Storing Representative Masking Spectra

The overall level and contour of the masking spectrum plays an important role in both the privacy achieved and in creating acceptability. Since there is no magic spectrum for all cases, the program includes a number of spectrum types. A representative screen is shown in ***Figure 3-31***. These spectra are recommended by manufacturers, researchers, consultants, or are listed in standards. The user can modify any entry or add a new one.

In some specifications, the masking spectrum is given in one-octave bands; these can be entered and the program will modify it to a one-third octave spectrum. For comparison purposes, all spectra can, and should, be set at the same overall A-Weighted level. Later, any or all of these spectra can be used to evaluate speech privacy.

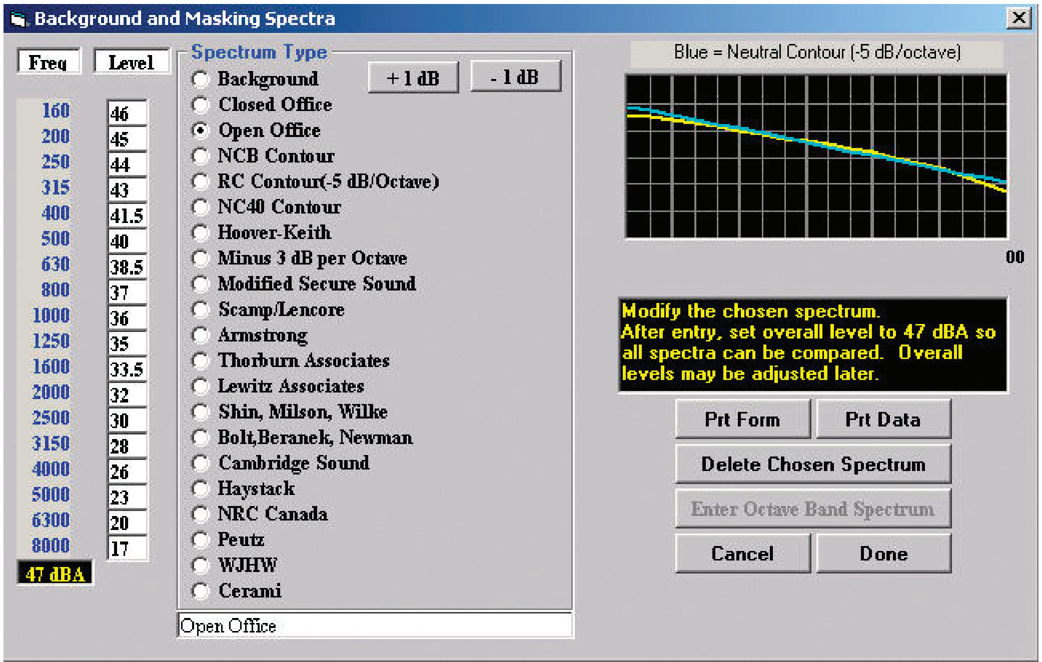


Figure 3-31

3.3.3 Modeling the Space

Speech privacy must be analyzed between two individuals, a talker and a listener, in either open or closed offices. A database contains default initial values for many of the geometric properties of the office; these values can be changed at any time. The user can choose between twelve common office arrangements. Any of the seven vertical surfaces involved can be made into a furniture panel, a wall, a furniture panel backed by a wall, or nothing.

The other design possibilities are as follows:

1. Vary the suspended ceiling height.

2. Vary the structural ceiling height.

3. Add or remove the suspended ceiling.

4. Add or remove walls bounding an open office workstation. They can be walls or windows.

5. Vary each of the furniture panel heights independently to construct a number of designs.

6. Add clear panels of any height above the furniture panels. Each clear panel can be varied independently.

7. Add return air grilles in closed offices and position them arbitrarily.

8. Add a ceiling light fixture in open offices. There are three types of light fixtures available. The fixture can be placed anywhere within the two offices.

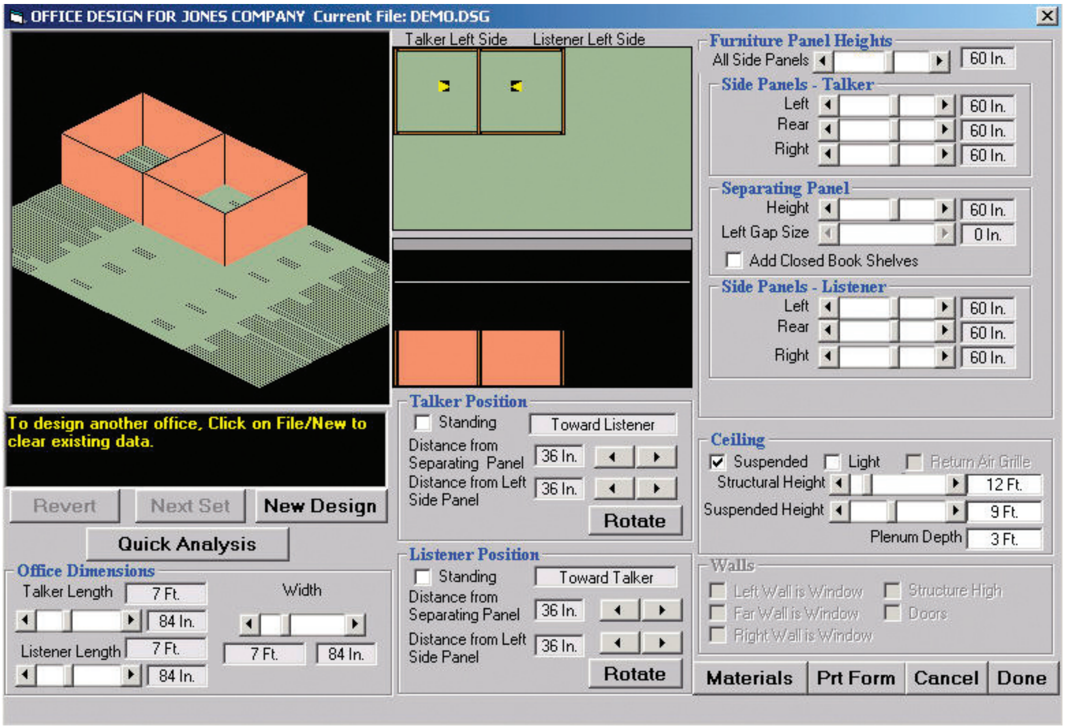


Figure 3-32

9. Add bookshelves to the separating panel in open offices. A small improvement in privacy occurs for seated persons.

10. Place the talker and listener at any point within their respective offices. They can be rotated in 45-degree increments to face in any of eight directions.

11. Vary the size of both offices within reasonable limits.

12. Place and position open or closed doors in either of the closed offices.

13. Add a sound reflecting hallway wall for closed offices.

14. For open office furniture panels, gaps can be placed at the ends of the panel that separates the occupants. This can be expanded to study the diffraction around the side of freestanding panels.

15. The materials used for the design can be chosen from the database.

3.3.4 Modeling the Sound Attenuation

Once the office is designed, the sound attenuation for that configuration needs to be estimated. The program contains forty-six possible sound paths, some including double and triple reflections. It permits the user to sum all paths together to provide an overall result. It will provide a list of important paths with the weakest (critical) path at the top. In this context, "critical" means the path that would need improvement first if the design does not provide the desired privacy. Any path can be evaluated independently, and the individual Speech Weighted Loss and sound attenuation spectrum is shown and compared overall. The user can determine Speech Weighted Loss for all suspended ceilings in the one-octave band database, so their performance can be compared. The same can be done with the furniture panels in the database for an open office. This is useful to determine the best material, if an improvement is required; however, material changes must be made in the model design module. A typical screen is shown in ***Figure 3-33***.

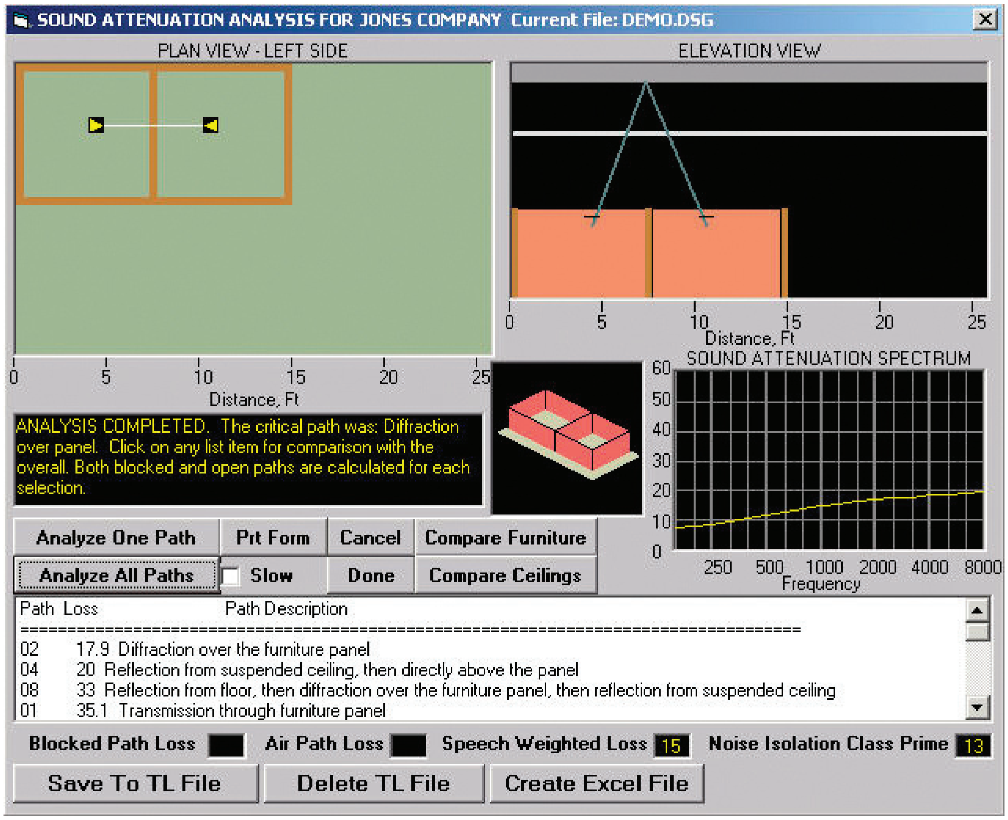


Figure 3-33

The most important number is the Speech Weighted Loss (A.1.6). For each type of reflection there is an open-air path and a path through a material. If the path is relevant, individual analyses may show two SL values, one for each path type. The overall SL will be reported as well as the NIC' rating for open office or NIC for closed offices.

3.3.5 Modeling the Sound Masking

Once the sound attenuation is estimated, the object is to add the sound masking, if needed, to provide the listener with the desired degree of speech privacy. The direction a person speaks was chosen in the design phase, but how loud they talk remains to be determined. Some data on male and female voice spectra are included for lowered, normal and raised voices. The voice data from ASTM have been used [1]. Lowered (casual) voice spectra have been added and are derived from field measurements. Estimates of the existing background spectrum are needed as a starting point for the design of a masking spectrum. A representative screen is shown in ***Figure 3-34***.

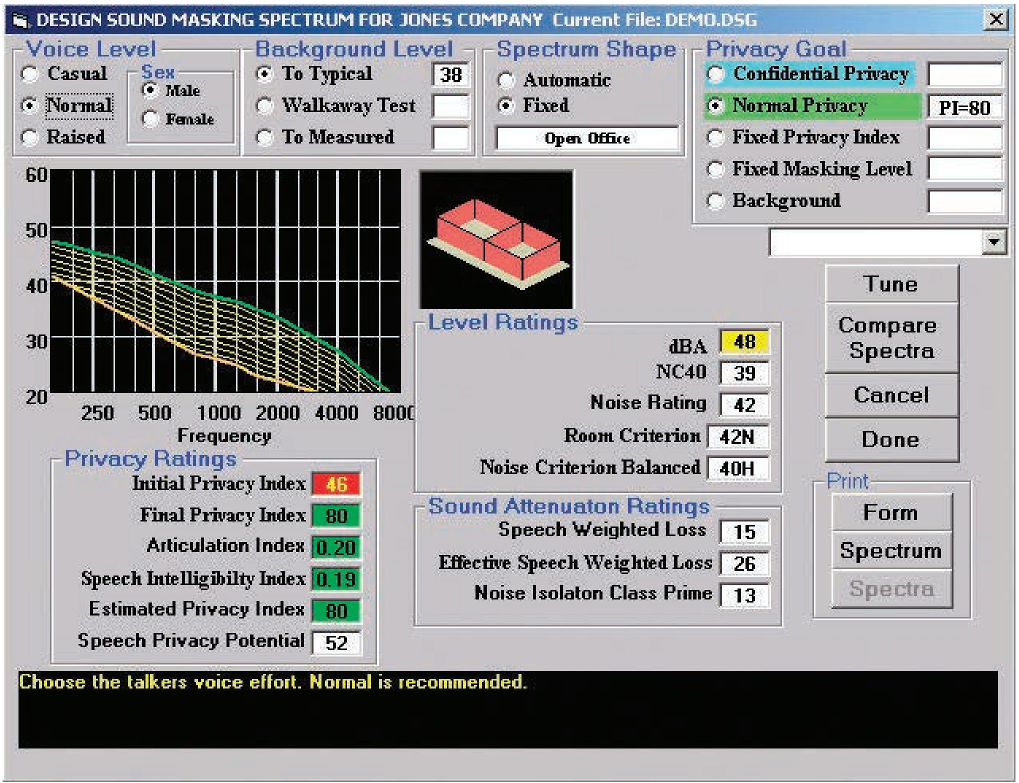


Figure 3-34

The purpose, of course, is to determine if masking is needed and, if so, how much over the background sound it should be. A typical A-Weighted level of the unmasked condition can be the starting condition. For existing offices, the background may be estimated and used as the starting condition by use of the Walkway test (Appendix B), or a measured value can be added. Normally, the background spectrum is sufficiently below the final masking spectrum, so the exact spectrum is not crucial. If it were, it would be necessary to modify the default background spectrum in the masking spectrum database to one that is more representative of the actual environment. As noted above, the choice of masking spectrum contour can be very important, particularly in open offices. The user can choose to have the program develop a masking spectrum or choose a masking spectrum from the database. In the latter case, the spectrum contour is maintained, but the level is adjusted to meet requirements. There are two goals for the equalization: to a specific Privacy Index, or to a specific A-Weighted masking level. The latter is used only when it is not possible to achieve the desired degree of privacy with a reasonable masking level.

When setting the masking, the program will create a masking spectrum sequentially from the background level until the design goal is met. ***Figure 3-34*** shows a number of the resultant ratings. The final spectrum will be shown graphically and can be printed. Since it is not always possible to predict the best masking spectrum for a given situation, every fixed contour masking spectrum in the database can be evaluated automatically and comparative results displayed, from which the desired spectrum can be chosen.

3.3.6 Additional Results for Open Offices

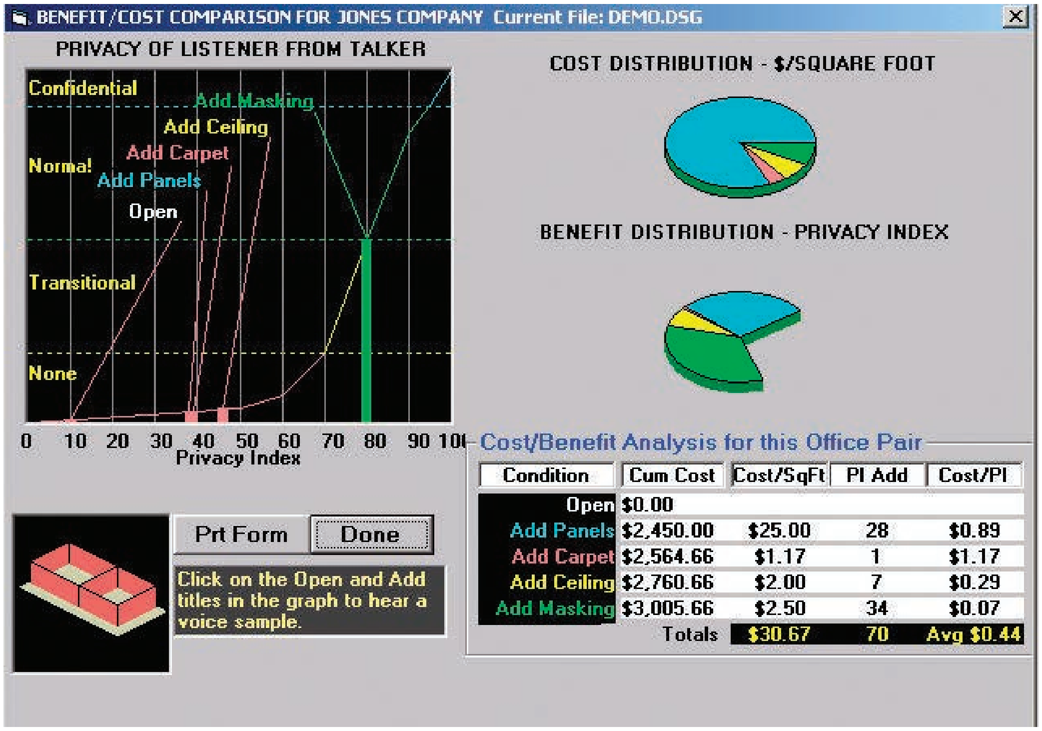


Figure 3-35

A privacy analysis module is available that shows the Privacy Index contour and the various points in it as an open office workstation is constructed. The graph in ***Figure 3-35*** shows the importance of the relative contributions of the major design factors: panels, carpet, ceiling, and masking. Carpets are not significant contributions to speech privacy in open offices. Since few persons can translate such a graph into a meaningful sense of privacy, a sample of speech for each PI can be played by clicking on the title of each.

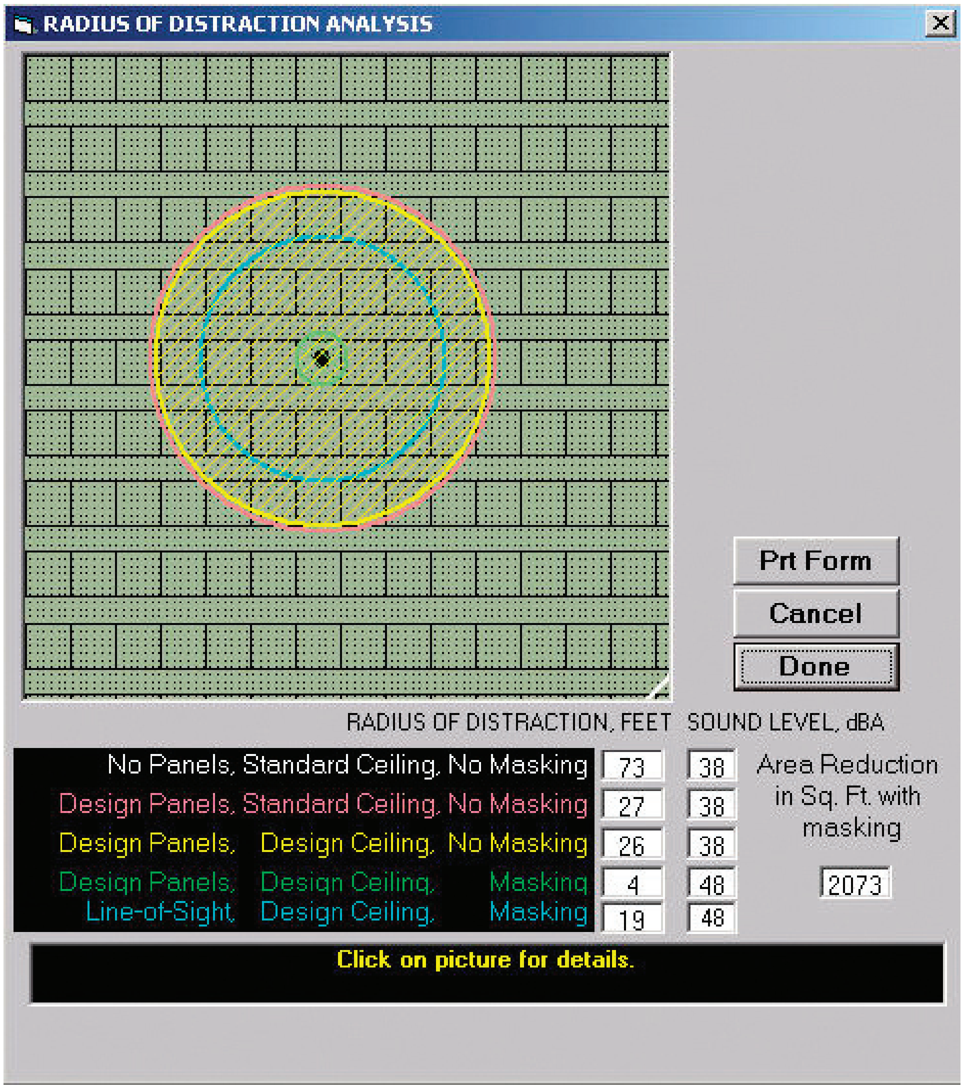
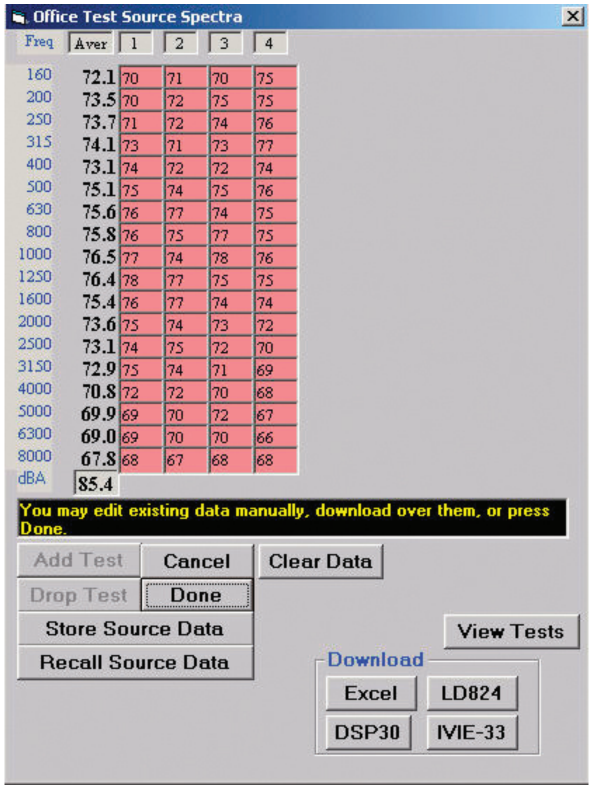


Figure 3-36

When Universal Privacy cannot be achieved, particularly in call centers where panels are low, the concept of **Radius of Distraction** needs to be invoked. An array of workstations is shown in ***Figure 3-36***. The distance at which Normal Privacy starts for each step in the design is tabulated and drawn as a circle or arc. The number of people removed from distracting speech by the talker can be deduced from the area between the initial and final circles or arcs.

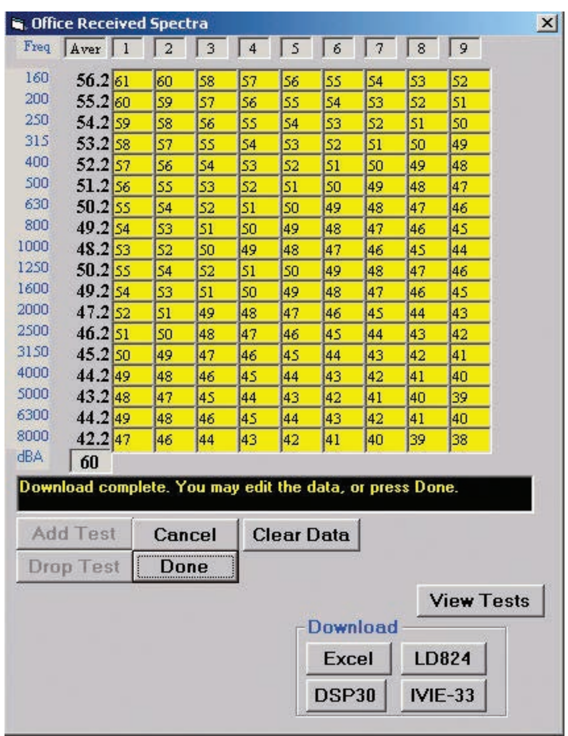
3.3.7 Calculating Speech Privacy from Measured Sound Attenuation



Freq	Aver	1	2	3	4
160	72.1	70	71	70	75
200	73.5	70	72	75	75
250	73.7	71	72	74	76
315	74.1	73	71	73	77
400	73.1	74	72	72	74
500	75.1	75	74	75	76
630	75.6	76	77	74	75
800	75.8	76	75	77	75
1000	76.5	77	74	78	76
1250	76.4	78	77	75	75
1600	75.4	76	77	74	74
2000	73.6	75	74	73	72
2500	73.1	74	75	72	70
3150	72.9	75	74	71	69
4000	70.8	72	72	70	68
5000	69.9	69	70	72	67
6300	69.0	69	70	70	66
8000	67.8	68	67	68	68
dBA	85.4				

Figure 3-37

It is necessary to first measure the spectrum of the test sound source, followed by measurements of received levels caused by that source. Finally, the masking spectrum must be determined in order to achieve the desired degree of privacy.



Freq	Aver	1	2	3	4	5	6	7	8	9
160	56.2	61	60	58	57	56	55	54	53	52
200	55.2	60	59	57	56	55	54	53	52	51
250	54.2	59	58	56	55	54	53	52	51	50
315	53.2	58	57	55	54	53	52	51	50	49
400	52.2	57	56	54	53	52	51	50	49	48
500	51.2	56	55	53	52	51	50	49	48	47
630	50.2	55	54	52	51	50	49	48	47	46
800	49.2	54	53	51	50	49	48	47	46	45
1000	48.2	53	52	50	49	48	47	46	45	44
1250	50.2	55	54	52	51	50	49	48	47	46
1600	49.2	54	53	51	50	49	48	47	46	45
2000	47.2	52	51	49	48	47	46	45	44	43
2500	46.2	51	50	48	47	46	45	44	43	42
3150	45.2	50	49	47	46	45	44	43	42	41
4000	44.2	49	48	46	45	44	43	42	41	40
5000	43.2	48	47	45	44	43	42	41	40	39
6300	44.2	49	48	46	45	44	43	42	41	40
8000	42.2	47	46	44	43	42	41	40	39	38
dBA	60									

Figure 3-38

3.3.7.1 Test Source.

It is reasonable to assume that the persons speaking are seated, so the test source should be 48 inches high and faced horizontally. The directional characteristics of the source should be as near to that of the human voice as possible. It is recommended that test levels at 39 inches horizontal distance be above 80 dBA, since tests may be performed in closed offices. While it is desirable to make the tests in an anechoic chamber to eliminate reflection effects, it is seldom practical to do so. A simple field procedure is to find an area that is at least ten feet from a vertical reflecting surfaces and is carpeted. There will be a floor reflection near 100 Hz that will cause a dip in the spectrum, but that is below the speech intelligibility range. The influence of this reflection is reduced by the increased path length, the floor absorption, and the directivity of the source. A series of measurements can be made by moving and rotating the source randomly. Energy averaging of the measurements will smooth out the spectrum and provide the test source spectrum. The data should be measured in one-third octave bands and can be downloaded from the meters noted in ***Figure 3-37***.

Since this source may be used for future tests, the spectrum can be stored and recalled at any time.

The value of each measurement can be determined by pressing **View Tests.** If it appears that one test is erroneous, it can be deleted by pressing **Drop Test**.

Press **Done** to save the data into the project file.

3.3.7.2 Received Spectra.

The test source should operate at the estimated position of the person talking and faced in the appropriate direction. It is recommended that "appropriate" be the worst-case scenario with the talker facing the listener. Up to ten received measurements may be made. Using the same process as for the test source, the data may be downloaded to the software as shown in ***Figure 3-38***.

Press **View Tests** to shown each specific measurement spectrum and the Speech Weighted Loss for it

3.3.7.3 Masking Spectrum.

Next a masking spectrum is determined for these tests. Since masking is an area event the masking spectrum is determined using the arithmetic average of the received tests. The procedure is similar to that in Sections 7.3 and 7.4, except that the speech privacy for each and every test can be viewed to determine which ones may be deficient.

CHAPTER 4
PRIVACY IN MEDICAL FACILITIES

For over forty years, persons involved in medicine, researchers, doctors, nurses, and patients, have written innumerable articles on the negative effect of hospital noise on both nurses and patients. Yet very little has been done to solve the problem beyond administrative controls (please talk quietly, do not page so often), which are of limited effectiveness. The passage of federal legislation, which includes requirements for speech privacy associated with medical information, has provided an unprecedented opportunity to solve both the disturbance and privacy problems. In this chapter, we show how tools used to solve speech privacy problems in other applications can be used to solve the medical facility noise problem as well.

4.1 Federal Regulations

The Congress of the United States has passed the Health Insurance Portability and Accountability Act (HIPAA) into law [26]. It mandates that individually identifiable patient health information be protected. Although written and computer files are obviously to be protected, verbal information must also be protected. "Covered entities" (those who must comply with the law) must make *reasonable* efforts to safeguard patient information from being overheard. The law itself gives no specific guidance on how this is to be accomplished, but a document released by the Department of Health and Human Services provides some clarification [28]. It includes, as part of the protection, the phrase "health information whether it is on paper, in computers, or communicated orally". The Office of Civil Rights also has published a document on this issue [29], stating that the law does *not* require retrofitting spaces, such as soundproofing of rooms, in order to comply. Again, the bias toward the structural solution is showing. This effectively rules out one of the three privacy factors (2.3) and limits solutions to the other two factors: low level speech (administrative controls) or higher background levels (masking). Eventually these requirements will be decided in court. As a result, many medical facilities have already realized that compliance is wise and have begun retrofitting their facilities.

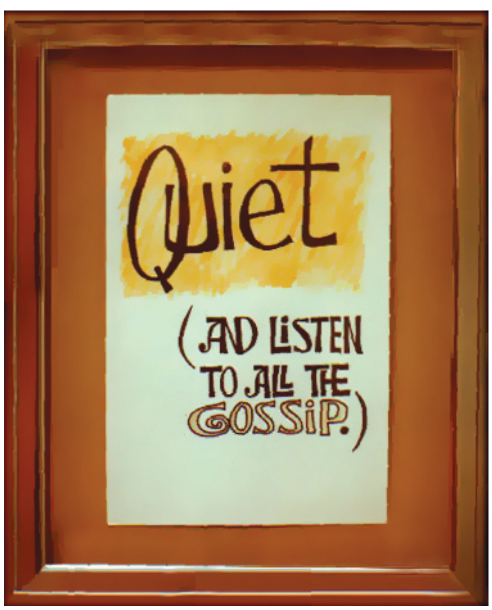


Figure 4-1

4.2 The Noise Problem

For a number of years, noise in hospitals has been a problem, in part because of the need to have all surfaces hard and cleanable. A large number of measurements and reports in prestigious journals, as far back as 1963 in the United States and other countries, testify to the seriousness of the problem [27-47]. The primary problem from the patient's viewpoint has been the distraction and annoyance caused by the noise of people, which results in less rest, poorer sleep, and possibly longer recuperation time. The increased socialization now permitted in hospitals, as well as the increased use of medical machinery, has exacerbated the problem. The standard attempt at a solution has been administrative controls, as exemplified by ***Figure 4-1***.

An extensive survey by the Public Health Service in 1963 [31] showed that patients interviewed were frequently disturbed by speech and distress sounds, some of which were caused by the staff during night hours. Other studies concerned the interference of noise with sleep and recuperation. Particular sounds that caused awakening (mostly during evening hours) are shown in ***Table 4-1***. It is no surprise that the first item was the most disturbing.

Patients in distress
Staff conversations in corridors
Telephones
Arrival of patients
Activity noise in corridors
Dropped objects

Table 4-1

A study by Haslam [35] confirmed these results and indicated that over 70% of patients suffered from excessive noise. Several studies have shown that exterior noise can be a problem also. The noise from heavy traffic on local streets as well as ambulance and helicopter arrivals can penetrate patient's rooms. The World Health Organization recommends that nighttime levels not exceed 35 dBA. Other organizations recommend similar levels. In another study, Griffin recommended that "average" sound levels be kept below 45 dB, but she pointed out that higher maximum levels could be tolerated if the ambient level is *not* very low. Meeting such stringent level requirements are impossible, they would cause ceasing of all activity. Even libraries are noisier than that.

A study by Schieber [40] found that the amount and rate of increase in the sound level from the constant background was the main contributor to full awakening, or changes in the stage of sleep. ***He determined that the magnitude of the change in level, regardless of its median value, was more significant than the level of a steady sound of the same median value.*** This conclusion was supported by an Environmental Protection Agency document [25]. Suter [65] expanded this finding by stating "it is clear that intermittent and impulsive noise is more disturbing than continuous noise of equivalent energy, and that ***meaningful sounds are more likely to produce sleep disruption than sounds with neutral content***." The difference between the ambient and the single event levels should not exceed 8-10 dB. It is the difference between the maximum level and the steady background level that is the important factor. As was discussed in earlier chapters, if that background level is very high, noise reduction such as sound absorption and attenuation must occur.

Many articles have missed these crucial observations, but rather concerned themselves only with maximum levels. In keeping with this major point, one must look at the fluctuations of sound in a hospital environment and some measurements have been made. The descriptor of this is the Percentile Level (A.5). An example of sound levels taken in a hospital corridor without sound masking is shown in ***Figure 4-2***. These data were collected in an older hospital in which all the surfaces were sound reflective, representing the worst-case scenario. On occasion, the sound level increased above 60 dBA; one percent of the time the increase was 24 dB from nighttime background levels (the ninetieth percentile level); enough to awaken anyone. Extremes such as this do not occur in patient rooms. It is clear that the quest for quiet is achieved less than 50 percent of the time.

4.3 Hospitals

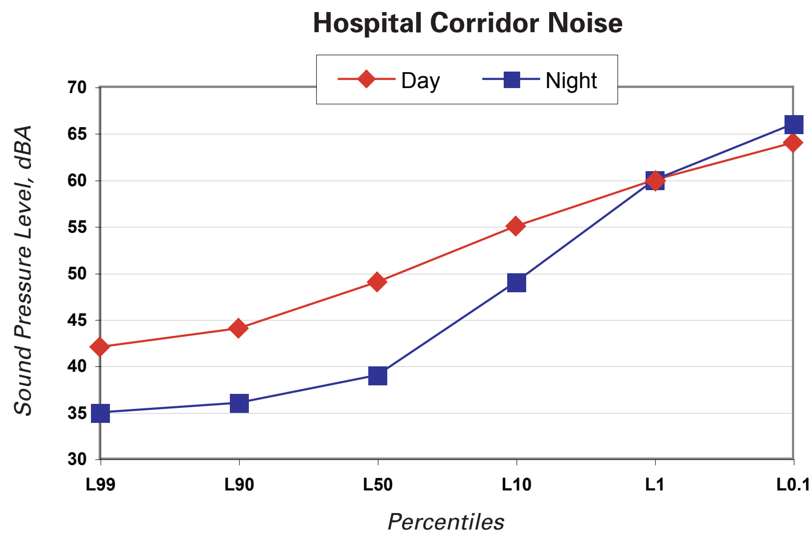


Figure 4-2

It is clear from earlier chapters that the primary function of sound masking is to bury unwanted sounds in a steady sound, reducing the fluctuations that disturb patient rest and sleep. Application of sound masking to hospitals can solve two problems; the regulatory one associated with HIPAA and the one dealing with patient rest and recuperation. Earlier chapters have shown that sound masking can provide the Confidential Privacy required by HIPAA in most cases. Since masking also reduces the range of sound levels experienced by patients, there also would be a large reduction in patient disturbances from all types of sounds, not just speech.

Topf (47) found that personal sound masking was found to be effective; others have reported a lack of success. Based on the fact that many studies of hospital noise have applied high levels of “white noise” as the testing spectrum, it is not surprising that these tests were not successful. Also, personal masking implies the use of headphones that, over time, are rejected by most people. The proper method of application of sound masking in medical facilities can be derived from the cumulative experience in commercial offices.

4.3.1 Patient Rooms

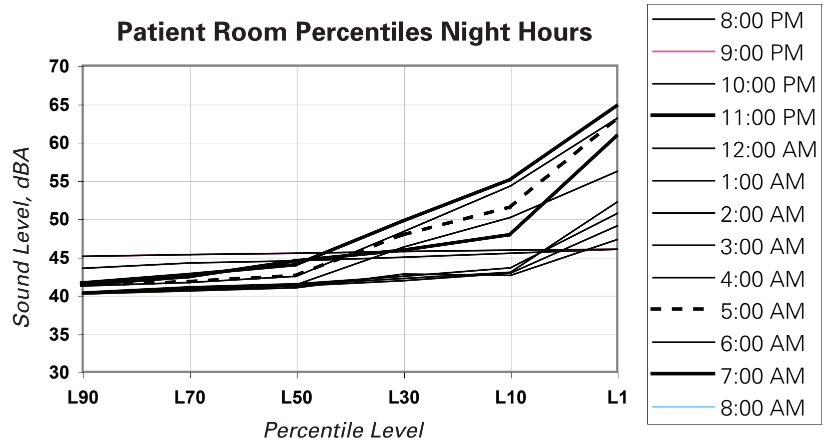


Figure 4-3

They must be protected from both hallway sounds and those external to the building. It appears to be common practice in hospitals to keep the doors to patient rooms open, exacerbating the problem. Some data have been collected on nighttime levels in a single patient room. ***Figure 4-3*** shows percentile levels in hourly periods from 8 PM to 8 AM. The noise floor was near 40 dBA and was created by the air handling system. It was broadband and constant. If we use the criterion for potential distraction and annoyance as the Level Difference (A.5), the results can be presented in a more informative way as shown in ***Figure 4-5***. The periods of activity during the night hours were related mostly to noise emanating from the corridor and less so from nurse visits to the patient. The early morning activity was caused mainly by activity within the room (doctor and nurse visits). It is clear that the level variations during some hourly periods were sufficient to awaken the patient. For a situation like this, with a noise floor of 40 dBA, what reduction in potential annoyance would occur if the background sound level were increased with sound masking? ***Figure 4-4*** shows the approximate influence of sound masking on these data when averaged over the twelve-hour nighttime period. Even modest levels of masking (45 dBA) create significant reductions in the potential distraction.

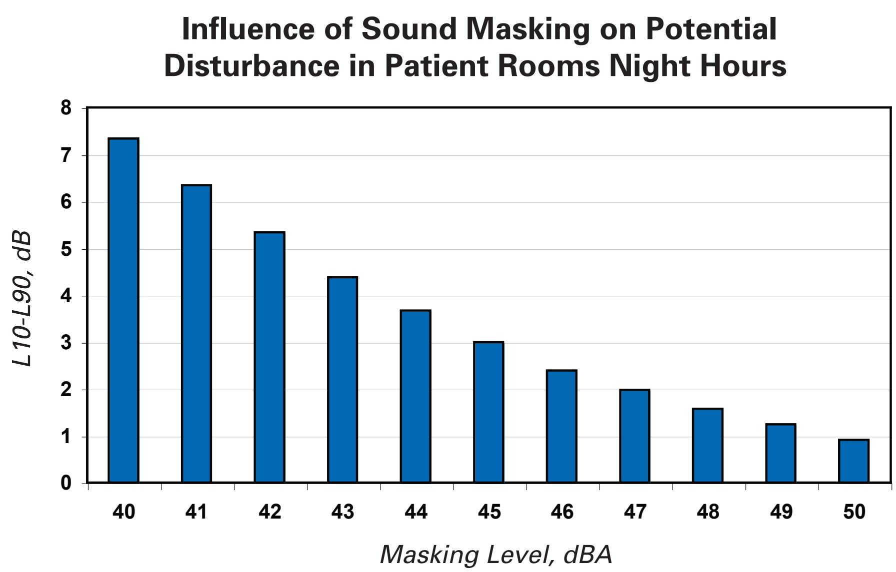


Figure 4-4

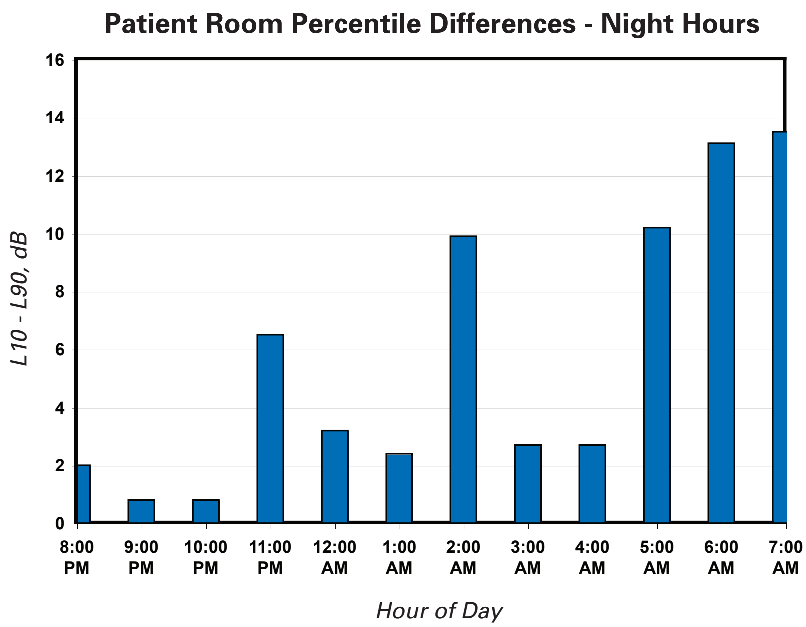


Figure 4-5

Because of the close proximity of patients in multiple occupancy rooms, masking cannot protect doctor/patient conversations. Masking cannot prevent the sound from one patient's television set from being heard by the other patient. Some hospitals have a small speaker next to the patient's head so levels can be set low to avoid disturbing the other patient. Speakers inside pillows have been proposed. The data presented in the previous figures did not include any exterior noise, such as helicopter and traffic noise, but masking should alleviate the impact from those sources also.

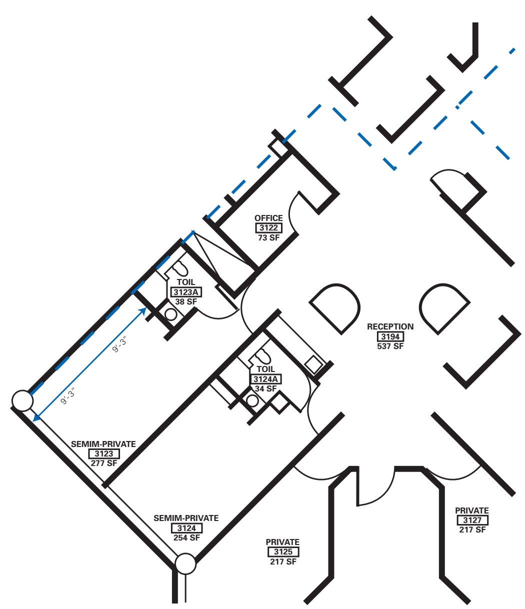


Figure 4-6

Fortunately, patient rooms in modern hospitals have suspended ceilings above which a masking speaker can be placed. In other cases, innovative installation may be required to meet Design Rule Two (6.1.1). A masking system was installed on one floor of a hospital. One masker was placed above the suspended ceiling in each room and one was placed in the corridor outside the room. The geometry is shown in ***Figure 4-6***; the rooms were 13 by 37 feet with two beds. The masking level in the patient rooms was set at 42 dBA with a sound spectrum typical of that used in closed offices, while the masking outside the rooms was set at 47 dBA with a sound spectrum typical of that used in open offices. Both objective and subjective tests of speech privacy were made with doors open. Patients could not understand conversations outside the room, nor could persons outside the room understand conversations within the room. As an acceptance test, the masking level in the patient rooms was slowly raised. Comments about the sound by the patients began to occur between 46 and 47 dBA, suggesting that might be an upper limit for acceptability.

4.3.2 Corridors and Nursing Areas

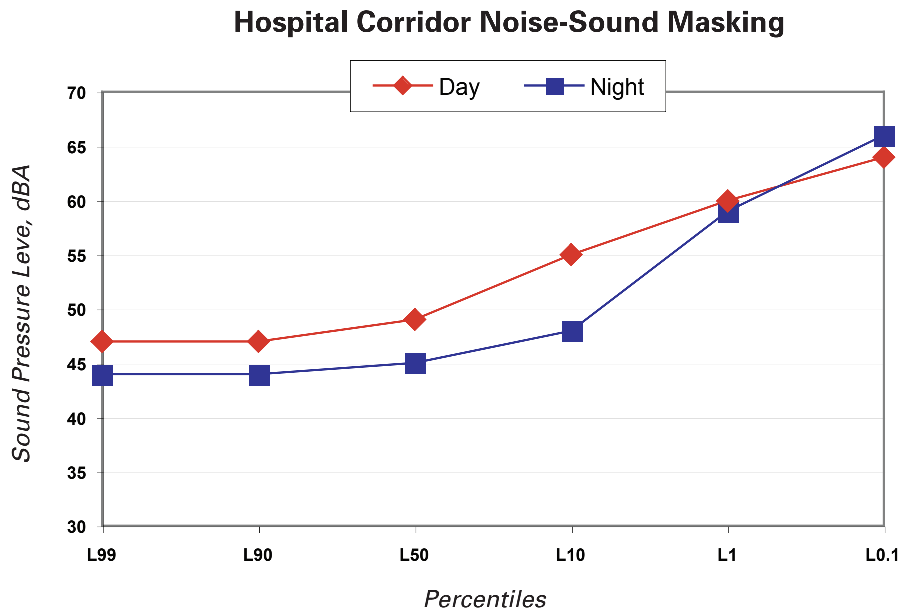


Figure 4-7

Masking has been used in corridors to block speech and other sounds from one patient room to another as a low cost alternative to providing each room with masking. The primary value however is to provide confidentiality of conversations within patient rooms from those persons outside. Levels similar to those used in commercial open offices can be used for this purpose. The data from ***Figure 4-2*** were adjusted to add sound masking in order to demonstrate the reduction in distraction that would occur in corridors. This is shown in ***Figure 4-7***. The most intrusive sounds (those occurring one percent of the time) were reduced by 8 dB. This improvement is significant and the improvement is even better in patient rooms. This result does point out the fact that sound masking is not a cure-all, but must be used in conjunction with other sound attenuating factors.

4.4 Nursing Homes

Suter [65] noted that older people are more likely to have their sleep disturbed than younger people and they are more likely to be awakened in the early hours of the morning. Sanders [66] noted that only modest increases of sound level (6 dB or more) in nursing homes were a significant factor in awakening residents. The use of sound masking in these facilities would appear to be beneficial to the residents.

4.5 Medical Suites

Included in this category are physician's offices, medical laboratories, clinics, and on-site employee medical suites. Most suites are rented in standard buildings where the ceiling plenum is continuous, acting as a duct for air returning to the air supply system. Further, the walls are of light construction permitting speech to pass through them. Experience has shown that confidentiality is not achieved in examination rooms under these circumstances. Patients seated in a waiting area generally can understand patients at the sign-in window. One erroneous structural solution is to create a glass window with a small circular hole for conversations with the staff. People naturally speak louder under these conditions and the sound reflection from the window itself further exacerbates the problem. Many doctors have installed masking systems, even before the passage of HIPAA. The addition has been shown to be of considerably less cost than structural solutions and are effective in creating the needed confidentiality at low masking levels.

4.6 Pharmacies

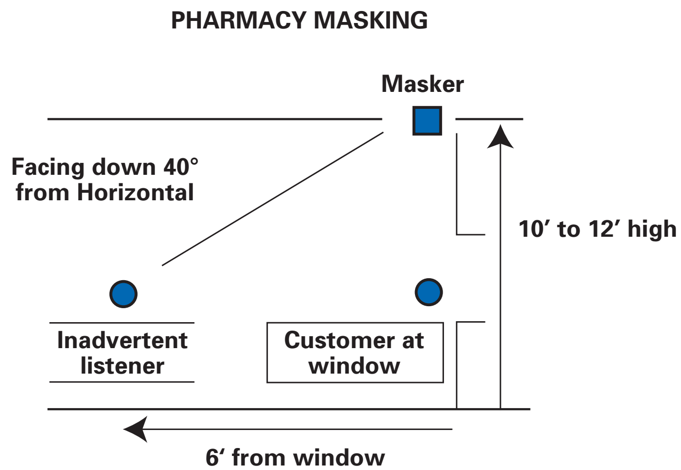


Figure 4-8

Pharmacies have a situation similar to the window in a doctor's office in that a number of people may have oral access to the conversation at the window. Again, a plate glass window is not the solution. In keeping with the bias toward structural solutions, many pharmacies have placed a yellow line at a distance from the counters, as is done at immigration windows, to maintain a distance from the person being helped. Aside from spatial constraints, the author has found that in *all* pharmacies using this method that he has visited, the conversations were clearly intelligible at the specified distance. At what distance should the line be placed? A study by the author has shown that a low level masking speaker immediately above the window, either in a suspended ceiling or on the wall above the window can be used to define a practical distance, such as shown in ***Figure 4-8***. When there is a high or no suspended ceiling, a self contained masker, as is used in distributed masking systems, should be installed between 10 and 12 feet above the floor and directly above the opening with the speaker axis pointed downward 40 degrees from the horizontal (it is pointed at a position 6 feet from the window and 5½ feet high (standing adult height). With the patient talking toward the opening, Confidential Privacy (PI>=95), is achieved with about 46 to 48 dBA. With masking, a yellow line (arc) at a distance of six feet is practical. Without masking, the line must be at least 10 to 12 feet from the window.

4.7 Psychiatrist's Offices

Psychiatrists have suggested that the use of masking *within* the counseling room has a calming effect on patients. One noted that the presence of the masking gave the patient a sense of privacy from any relatives in the waiting room and that made it easier to speak about problems. The patient was unaware that the masking in the waiting room was providing the needed confidentiality. The other use of masking is these offices is similar to those in doctor's offices (4.5).

4.8 Medical Providers

Included in this category are Public Health authorities, life insurers, billing agencies, and service organizations. Most of these have facilities much like standard office settings, with both closed on open areas. As a result, they can be handled in the same way as noted in earlier chapters. In many open areas, customer support personnel use telephones continuously. This case is similar to call centers where the primary object is to prevent one customer listening to a support person from understanding the conversation of a nearby support person talking to another customer. Sound masking has been used for many years to solve this problem.

CHAPTER 5

MASKING SYSTEM EQUIPMENT

This chapter discusses desired features of sound masking equipment, and shows examples of some existing equipment. The choice of specific equipment in the design is given in Chapter 6 and its use in providing privacy is given in Chapter 7.

5.1 Components of the System

A sound masking system is composed of just a few fundamental components.

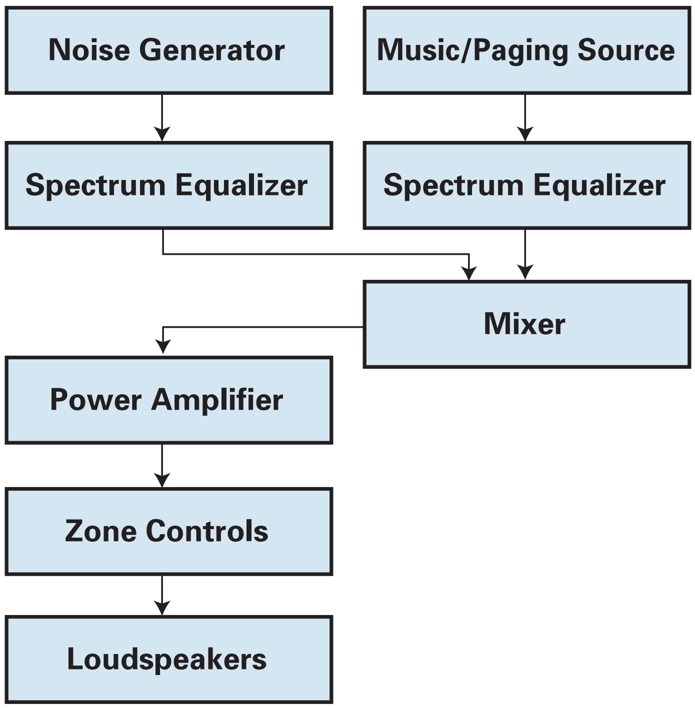


Figure 5-1

5.1.1 Masking Generators

Masking generators are sources of random broadband electrical noise. Some generators have two, or more, independent sources; others have only one source that is split into two channels, one channel being time delayed to create incoherence between them. Either type is acceptable. Some generators create both pink and white noise. Pink noise is used for most applications. One type of source is a shift register that processes zeros and ones (digital) to create randomly spaced square waves that result in a seemingly random signal (5.2.1). These sources will repeat the same sequence after a period so are in a sense deterministic. The cycle time in modern digital sources is sufficiently long that it is impossible for a listener to detect the repetition. Another type creates a true random signal (analog) by extreme amplification of natural electrical noise (5.2.2). Listening tests have shown that it is not possible for a listener to tell the difference between them. Although, earlier the analog source was preferred, the popularity of "digital" has made the digital sources acceptable. Most masking generators have digital sources.

There are products where the generator is a plug-in module for a power amplifier. The compact size is advantageous for small systems.

5.1.2 Spectrum Equalizers

Sound with a white or pink spectrum is not acceptable to persons exposed to it, so the electrical signal must be adjusted to meet the masking spectrum requirements of the listener and the environment into which it is sent. Setting a masking spectrum shape is called equalization and is discussed in Chapter 7. The equipment should have a variable frequency high pass (low cut) filter to eliminate electrical signals at frequencies below those that the chosen loudspeaker can handle. It should also have a variable frequency low pass (high cut) filter that reduces the high frequency content. This latter filter broadly shapes the masking signal. Both of these filters should have variable cutoff slopes in terms of dB/octave. Finally, the equipment should have a ⅓ octave band equalizer that covers at least the speech band of frequencies. It is recommended that the equipment have two or more channels of equalization since there are numerous applications where different equalization is required. Most modern generators have these filters incorporated into the same cabinet as the source.

Some masking systems have been designed only for open offices and have only a fixed spectrum contour. This reduces manufacturing costs but limits the utility of the system since one spectrum does not apply to all situations (3.1.6).

5.1.3 Mixers

The purpose of a mixer is to permit signals to be added and mixed with the sound masking. Then the system will have several audio functions, making it more cost effective. Both paging and music are mixed successfully with sound masking. The superior uniformity of a masking system results in superior uniformity of the paging and music. The mixer is integrated into the cabinet of many generators, but separate mixers can also be used. **NOTE**: All added signals *must* be equalized separately prior to mixing with an equalized masking signal.

5.1.4 Power Amplifiers

The purpose of an amplifier is to provide the necessary power to drive the loudspeakers. Because of the widespread use of two, or more, channel generators and the common availability of stereo amplifiers, two channel power amplifiers are recommended. They are advantageous for systems that require incoherence between adjacent speakers (6.4.13). Amplifiers with analog volume controls on the rear panel are strongly recommended. The small rotation of an analog control can detune all the speakers fed by that amplifier, requiring complete re-equalization. If an analog volume control must be on the front panel, the knob must be removed after equalization or a cover placed over it.

5.1.5 Zone Controls

The purpose of a zone control is to set the overall level of the speakers connected to it. On large systems, multiple zone controls are connected to the output of each amplifier so that large capacity amplifiers can be used, but reasonably sized zones can be used (6.1.9). On small systems, the analog volume control on the amplifier can be used as a zone control, so a separate control is not necessary. If an analog control must be on the front panel, the knob must be removed after equalization or a cover placed over it.

5.1.6 Loudspeakers

The loudspeaker converts the electrical signal to sound. The conversion of the electrical spectrum to a sound spectrum is determined not only by the response characteristics of the speaker but also the acoustical impedance into which the speaker looks. With the evolution of high displacement cones, a large back box volume, although advantageous, becomes less important. The frequency response must cover at least the speech intelligibility range (3.1.4). To avoid series/parallel designs (6.4.2) they should have a step down transformer to be part of a 25 Volt or 70 Volt system. Since most transformers have multiple windings, it is advantageous to have the wiring lead to an external control so that output levels of individual speakers can be set easily and independently. Rewiring a speaker to handle unexpected conditions can be costly. To meet codes, it is advantageous for the zone wiring to be able to be placed within the speaker cabinet. The connector through which the wire is led should fit to conduit, as several jurisdictions require it. To reduce installation time, the speaker should have a built-in mounting bracket. Anyone that has had to connect several chains to form that bracket appreciates the convenience.

5.2 Types of Masking Sounds

Generators can create a variety of masking sounds, but not all of them are effective in providing privacy.

5.2.1 Digital Broadband Noise

The source of digital broadband noise is a shift register that is seeded randomly so that a sequence of zeroes and ones are created in random order as a Poisson process. Since the register has finite length, the signal is actually deterministic as it repeats at some cycle time. Fortunately, modern devices have repeat times that are sufficiently long so that it is not possible for a listener to detect the repeat. Because it is deterministic, it is often referred to as *pseudo-random*. Most modern masking generators are of this type.

5.2.2 Analog Broadband Noise

Analog broadband noise is the highly amplified self-noise of an electronic component. Statistically it is a truly steady state (stationary) noise with a Gaussian amplitude distribution. Some sources, particularly for home use, create this type of noise mechanically with a small fan. In the early development of digital sources, it was possible to distinguish the difference between an analog and a digital source, but that is no longer the case. Because analog sources require high amplification, they must be carefully screened from unwanted external signals. Some products contain this type of source.

5.2.3 Non-Stationary Broadband Noise

Non-stationary noise is created by a multiplicity of noise sources. The spectrum and overall level of each source is varied and then they are mixed. These sources are used to inhibit the recovery of signals, such as speech buried in background sound. This type of noise source is used for secure applications and its use is discussed in Chapter 8.

5.2.4 Environmental Sounds

Figure 5-2

These sources are mostly digital records of the sounds of surf, wind, or even heart beats. To recreate the sense of surf or wind, the level and spectrum must vary with time, making them adaptable for home or personal, but not commercial, use. ***Figure 5-2*** shows an early masking system, circa 1960, where the signal choices were either white noise, modified white noise, surf, or rain. Interestingly, the sound was radiated from a speaker located on the underside of the unit to make the source less noticeable.

5.2.5 Music

The purpose of masking is to provide privacy, but the purpose of music is to create a pleasant atmosphere. Can music provide privacy and can music co-exist with masking? The level of music at any frequency varies continuously and may not cover all speech frequencies, so it is not a good signal for creating privacy. Further, music conveys information, so that it calls attention to itself and, as a result, may generate annoyance or complaints, not good for a masking signal. However, music can be successfully used as an *adjunct* to masking (6.1.6).

5.2.6 Simulated Speech (Voice Babble)

Figure 5-3

Can voice babble be used as a masking signal? ***Figure 5-3*** shows an example of an existing product. It is possible to add a number of sinusoids of various frequencies to create a sound equivalent to the babble of voices such as might be heard in the lobby of a theater at intermission time. It also can be generated by recording an actual voice and switching the phonemes associated with that voice. One positive aspect is the human sounding characteristic, which can enhance the sense of community (1.8). However, it has limitations. It must have a broad enough range of frequencies to provide privacy. The apparent cacophony of voices can be very distracting for those doing complex tasks, so levels must not be intrusive. Since people naturally tend to search for information in the babble, it can be a cause of distraction. Voice babble can create a false sense of community and then annoyance when the listener discovers there are actually only a few people present. Voice babble is totally unacceptable to security personnel touring an office after working hours.

It is probably safe to say that the value of voice babble as sound masking has yet to be established. Voice babble in a *fully occupied* office may be a beneficial adjunct to random sound to assist in enhancing the sense of community.

The product shown in the figure was intended for use by a person desiring confidentiality. Apparently, it is used near the talker, not the listener (6.1.1).

5.3 Types of Systems

There are two basic system types; centralized, where all controls are centralized, and distributed, where each speaker is an entire system. There are some hybrid systems that have some features of both.

5.3.1 Centralized Systems

5.3.1.1 Description

All components, except for the loudspeakers, are located centrally, typically in a rack cabinet. All audio functions (sound masking, paging, or music) are generated and controlled from this central location. The audio signals are then distributed to the loudspeakers where they are converted to sound. The AC power to run the system is fed to the centralized location, which typically is a telephone or computer room.

5.3.1.2 Advantages

The primary advantage of centralized systems is that they can meet the high standards of the American National Standards Institute (ANSI), the American Society of Testing and Materials (ASTM), and the International Standards Organization (ISO). ANSI S3.5-1969 [12] and ANSI S3.5-1997 [16] define speech intelligibility (Articulation Index and Speech Intelligibility Index) in one-third octave bands. ASTM E-1374 [9] recommends that sound masking systems use the Articulation Index (Privacy Index) as a metric for determining speech privacy (A.3.1, A.3.3), and one-third octave bands for setting the masking spectrum. Both ASTM E1110-1994 [6] and ISO 532-1975 [62] also require that one-third octave bands be used in order to properly evaluate the loudness of masking sound.

Centralized systems can have a number of important functions that are not readily available in distributed systems:

1. The owner has control of the system.
2. The masking can be equalized precisely in one-third octave bands.
3. The system can incorporate music and paging for very little additional cost. These functions are equalized separately.
4. The system can have advanced functions (5.5).
5. The equalization settings can be downloaded on most generators to archive the data for possible re-equalization or for use on other projects.
6. The system can be liberally zoned, giving the owner detailed control over the system. The owner can then accommodate the preferences of various work groups without affecting others.
7. The system is more cost effective than a distributed system for almost all projects.

Other advantages gained by having all the equipment and controls being at one location:

1. It is easy and convenient to make changes to masking, paging, or music levels.

2. It is easy to equalize the system to meet the requirements of the standards.

3. Inspection and maintenance of equipment is straightforward.

4. The centralized components of the system can be moved to another location quickly and inexpensively.

5. Only one AC power source is required.

Masking levels at any location can be set in three ways:

1. The sound level and spectrum for the entire system (masking, paging, music) can be set at the central location.

2. The sound level for each defined area or work function (zone) can be set at the central location.

3. The level of each speaker can be set at each speaker.

5.3.1.3 Disadvantages

1. Masking generator failure will cause the entire system to fail. Experience with commercially available generators has shown that failure rates are miniscule. If a two, or more, channel generator is used, a spare generator will be available.

2. Custom design is required so an experienced installer is needed. Design software now available minimizes this potential disadvantage. Some major manufacturers now offer training programs.

3. Centralized cabinets occupy space. Use of compact equipment and wall cabinets minimizes this disadvantage.

4. System expansion may require more centralized equipment. Over sizing the cabinet minimizes this disadvantage.

5.3.2 Distributed Systems

5.3.2.1 Description

This type of system has all of its maskers distributed throughout the masked area. Each masker is a complete system (generator, equalizer, power amplifier, and loudspeaker); it is called a "*self-contained masker*". Since each masker must be fed power, AC power must be distributed from a centralized location to the area masked and then converted to DC to power the units. A centralized source of paging or music must distribute the signals to each masker; thus requiring a second wiring system.

5.3.2.2 Advantages

1. Each masker *can* be individually equalized to provide almost individual sound masking.

2. Masker failure affects only a small area.

3. It is a simple system to design.

4. No floor space is used.

5. It is infinitely expandable.

5.3.2.2 Disadvantages

1. The owner has no control over the system.

2. Each masker *must* be individually equalized, making it nearly impossible to equalize a large system with various privacy needs. An attempt to minimize this disadvantage is to set the controls on each masker identically before installation, but then the requirements for different areas cannot be met.

3. The system does not meet the standards, so equalization is not precise.

4. The system requires multiple AC power outlets that feed multiple AC/DC converters. Installation of this wiring adds hidden costs if done by anyone other than the sound system installer.

5. A centralized system cabinet and equipment must be added if the system is to have music or paging.

6. Level changes must be made at each and every speaker. If the speakers are in a ceiling plenum or in a floor cavity, the ceiling or floor must be opened to gain access.

7. Normally, none of the advanced functions are available (5.5).

5.3.3 Hybrid Systems

These systems generally have self-contained maskers, but have centralized control of the maskers' functions, especially the overall level and, in some cases, the masking spectrum. In some systems, the power is also distributed along with control signals. Some hybrids have distributed controls for specific areas; each control is essentially a separate system so the masking spectrum and levels can be set separately.

5.3.4 Personal Systems

Figure 5-4

Figure 5-5

These systems are distinct from the others in that they are one-speaker distributed systems that are designed for home or portable use. Historically, many persons that lived in warm climates slept with a running fan. Although not an optimum masking sound, the overall level was sufficient to provide privacy from outside noises. Modern electronic systems have replaced fans. ***Figure 5-4*** shows a masker that is for personal use both commercially and privately. Many airline catalogs show maskers that can be used in the home environment to enhance both privacy and, ostensibly, sleep. They are single units that operate on either batteries or household power. They may have broadband random sound or environmental sounds, the former being preferred. ***Figure 5-5*** shows a typical catalog product.

Several attempts have been made to use personal systems in commercial facilities, particularly by employees in open offices. Some have chosen to use a radio with music as a source of entertainment as well as for privacy. Most employers prohibit radios since they distract others. Some manufacturers have made desktop maskers for use by, and under the control of, the workstation occupant. An early attempt was a masker mounted on top of a workstation panel (6.1.10.6). Unfortunately, the device had available level and spectrum controls that could be changed by two nearby individuals. This inevitably resulted in what may be called "masking wars". Maskers mounted on workstation panels have been developed, but even though they worked well, they were not acceptable to manufacturers. Some recent tests have been conducted on prototype workstation maskers (7.5.5).

5.3.5 Attributes of Successful Systems

Considering sound masking as an evolutionary process, we can list features that will allow them to adapt successfully to a changing market. A system with more of these features will survive longer. There are some systems, such as personal ones, that have limited features but survive because they have adapted to the needs of a specific market.

1. The system should be able to generate sound that masks the intelligibility of speech for the various degrees of privacy. It should also be able to mask the sound of aircraft, the sound of vehicles, the barks of dogs, the music of neighbors, and other sources of annoyance. To do this, the system must have a broad range of levels and spectra.

2. The system should be able to apply different levels and spectra at different locations. To do this, the system must have an adequate number of zones to control overall levels, and a sufficient number of masking generators to create independent masking spectra where required.

3. The system should be able to vary the masking level with time (3.1.13). To do this, the system must have a clock. It may have a programmed level control function (5.5.1) that will vary masking levels with the time-of-day and day-of–week. It may have an environmental sensor that sends level information to the system so the masking can be adjusted based on actual activity levels (5.5.3).

4. The system manufacturer should have a sufficient number of types, sizes and shapes of speakers available so it can accommodate a wide variety of applications. To do this, the system must be able to handle indoor and outdoor applications, large or small plenum ceilings, and large or small access floor cavities. Both loudspeakers and vibration devices (Chapter 8) should be available. For visible masker locations, speaker shape and color must be acceptable to the owner.

5. The sound masking must be acceptable to the listener. To accomplish this, the requirements outlined in 6.1.1 must be met, but also the person equalizing the system must know how to take into account the existing acoustical environment and the potential response of occupants to masking. There have been cases where acceptability was achieved by a mimic of local sounds, such as those of an atrium water fountain or an air diffuser. To improve acceptability of a new system, it should have a slow ramp function (5.5.2) that increases the masking level over a period of days until the desired level is achieved. Similarly, when the power is returned after a power outage, the system should increase level slowly (5.5.4).

6. The system should be truly background so as not to call attention to itself. This includes general inaccessibility to controls, spatial uniformity in commercial applications, diffuseness of the sound field, inability for listeners to locate the maskers, and slow level changes. To do this, the equipment cabinets should be lockable, maskers should be placed in the least visible locations and in locations that maximize diffuseness of the sound field.

7. A commercial system should be able to incorporate paging and music. This increases system utility and provides an economic advantage to the user. The system should be able to equalize each signal independently and be able to set relative levels between the signals.

8. A commercial system should be centrally controllable either manually or remotely. All controls must be available to the installer, a limited number of controls should be available to the owner, and none to employees. The controls available to the owner must only be those to change level. They must be stepped (not analog) and have a limited level range so the correct functioning of the system is retained. Manual controls are acceptable if the cabinet or room is lockable. A computer software interface with the controls is preferable since passwords can be used.

9. System equipment costs should be comparable to those of other sound systems. Equipment should be designed to minimize the cost of installation.

10. The system should be readily expandable. Centralized systems should have excess cabinet space, spare zone controls, and adequate power capacity. Distributed systems require only correctly located power outlets for expansion.

11. The system should be capable of providing confidentiality from both casual and deliberate listeners, where applicable, as well as freedom from distraction for other listeners.

12. The system must comply with local building codes as well as national and international standards.

5.3.6 Choice of System

The choice of a system should be based primarily on the area of coverage and secondarily on the audio functions to be included. For systems covering less than 2000 square feet, a distributed system may be the most practical, but it may not be the most cost effective. For small and large systems, the performance and cost advantages of centralized systems far outweighs those of a distributed system. Chapter 6 on design goes into considerable detail on how to choose the system.

5.4 System Equipment

In this section, a general discussion of sound masking equipment is given and some existing products are shown. Chapter 6 describes how to design with these products while Chapter 7 describes how these products are used to provide privacy.

5.4.1 Self-Contained Maskers

Figure 5-6

These units contain all the components in one cabinet. As a result, it is considered a component of a distributed system where each speaker is a separate system. The advantages and disadvantages of this equipment were discussed earlier (5.3.2). Most have accessible controls and ones that are well designed can be hung with the speaker facing in any direction. They are sufficiently small to be used in applications where the unit is simply placed under or behind an object to keep it out of sight and to create a more diffuse sound field. A typical example is shown in ***Figure 5-6***. There are two types. The one shown can be plugged directly into a 120 Volt line, while the other type requires a low voltage power supply.

5.4.2 Generators

The purpose of a generator is to create a broadband random electrical signal over the speech range of frequencies at least. The generator can create the spectrum by either analog or digital means. The quality of digital sources has improved to the point where it is difficult, if not impossible, to tell the difference between them. Most generators can create a white noise spectrum (a level increase of 3 dB/octave) or pink noise (a constant level in each octave).

It is advantageous for the generator to have at least two channels of masking, since there are many applications where two different spectra are required (6.1.6).

For large systems, the generator is housed in the same rack cabinet as the equalizer, mixer, power amplifier and zone controls.

5.4.2.1 GPN1200B

Figure 5-7

This unit is a basic masking generator that permits pink or white noise to be modified with a low pass filter and an analog volume control. Controls are on the rear panel. Because this unit does not have a one-third octave band equalizer, it is recommended that the output of this unit be passed to an external equalizer. It has no user controls on the front panel as shown in ***Figure 5-7***.

5.4.2.2 MG2500

Figure 5-8

This unit has two channels, one of which can be either a paging/music input or a masking signal. As a result, the generator can have two of the three possible audio functions: masking, paging/music, on masking + paging/music. It is rack mountable. It has a built-in compressor/limiter and incorporates low pass, high pass, and one-third octave band pass filters for both channels. When used for checkerboard wiring design (6.4.1.3), the second channel can be delayed so that the two masking signals are incoherent. All controls are through a serial port connection so there are no user controls on the front panel as shown in ***Figure 5-8***. One feature of this unit is that settings can be saved and later recalled, so a particular configuration can be uploaded to a new unit to avoid having to start from the beginning on each project.

5.4.2.3 MG3001

Figure 5-9

This unit has two channels of masking, so if paging or music is needed, a mixer must be added. It is rack mountable. It incorporates low pass, high pass, and one-third octave band pass filters. It also has two advanced features, the programmed level control (5.5.1) and the slow ramp up function (5.5.2). All controls are through a serial port connection, so there are only status indicators on the front panel as shown in ***Figure 5-9***.

5.4.2.4 ASP-MG24

Figure 5-9a

This unit has four channels of masking, and two auxiliary inputs for paging or music. The masking channels can create either pink or white noise and have low pass, high pass, and one-third octave band pass filters. The auxiliary inputs have six parametric filters. Each of these six signals can be mixed into four outputs, providing extreme versatility of audio functions. An additional module has several advanced features, the programmed level control (5.5.1), the slow ramp up function (5.5.2) and the fast ramp up function (5.5.4). Control is by software connected through either a front panel serial or USB port. All configurations can be saved to a file. Spectrum measurements that are passed through an equalization program can be downloaded into this unit so that the equalization process can be done in one step. The front panel is shown in ***Figure 5-9a***.

5.4.3 Equalizers

Figure 5-10

The purpose of an equalizer is to set the correct acoustical spectrum for the listener. It converts the pink or white noise electrical spectrum from the generator to the desired acoustical spectrum at the listener. Although equalizers have level controls, they are used primarily to provide sufficient signal to allow the amplifiers to function. The person equalizing the system must have feedback from acoustical measurements to correctly set this unit. The output of the equalizer is an electrical spectrum whose frequency contour is sent to the loudspeakers but modified in overall level by the amplifiers, zone controls or speaker taps. The loudspeaker then converts the electrical spectrum into an acoustical spectrum in the vicinity of the speaker. The contour of that acoustical spectrum is determined largely by the acoustical impedance the speaker sees at each frequency. Since the speaker can be in a number of plenum or cavity environments, the acoustical spectrum can vary strongly even with the same electrical spectrum input. After that, the acoustical spectrum at the speaker needs to be converted to the desired acoustical spectrum at the listener.

It should be clear from these considerations that for best conversion, the equalizer should have a one-third octave band equalizer. This is why ASTM standards recommend such a unit. Experience has shown that each one-third octave band should have at least a +/–12 dB range. The device should have a high pass (low cut) filter with a variable cut-off frequency and a +12 dB/octave roll off (although that is not critical). The sound output of a masking speaker begins to reduce at frequencies below 160 Hz so this filter is used to attenuate frequencies that are not converted to sound. It should have a low pass (high cut) filter with variable cut-off frequency and variable order characteristic (-6 dB/octave and –12 dB/octave). This filter can be used beneficially to keep the one-third octave band filters within their limits.

There are two types of equalizers, internal and external. ***Figure 5-10*** shows an example of an external equalizer, the Atlas Sound EQM131.

There are several ways to control an equalizer. The unit shown above has sliders for one-third octave bands, and rotary knobs for level, high and low pass filters The generators (5.4.2.2, 5.4.2.3, 5.4.2.4) utilize DSP technology and control the internal equalizer settings through a serial or USB port. Adjustments are made with a cursor on a computer screen. In one unit (5.4.2.4) the band can be set by a download from measurement software. A real time analyzer measures the existing masking spectrum and stores it to a file. That file is opened in equalization software (7.7) and compared with the desired masking spectrum. The necessary corrections are saved to a file, which is opened by the generator software, so equalization can be done in one step. A recent development is to connect the equalizer software directly to the real time analyzer, either wired or wireless, so no files need be created.

5.4.4 Amplifiers

The purpose of an amplifier in a masking system is to provide the power and set the base level going to controls downstream. Amplifiers with low impedance outputs are not recommended. Most masking systems have amplifiers with 25 or 70 Volt outputs. If the system has several channels, using a stereo amplifier reduces the weight and size of the system.

Experience has suggested some preferred features of amplifiers. Analog volume controls are best located on the back panel to reduce the possibility of the owner detuning the system with a random knob turn. Some amplifiers have front panel controls that have a cover, which is often removed by the user. Any rotation of such a control will create unknown level changes. As noted in Chapter 2 (2.5), it takes only a 1 dB change in level to change the Privacy Index by 3 points. Similarly, amplifiers with analog Bass or Treble controls on the front panel should be avoided where possible.

In small systems, it may not be feasible to use amplifiers with the above features, so a lockable cabinet is recommended.

5.4.4.1 Large System Amplifier

Figure 5-11

For large, multi-zone systems, it is recommended that the amplifier have a power rating in the hundreds of watts with no front panel controls. An amplifier suited for large systems is shown in ***Figure 5-11***. It has two channels, a cooling fan, and rear panel analog volume controls. Each channel will handle up to 350 watts or it can be bridged to 700 watts and it is rack mountable. Since it is not recommended that zones be this large, these amplifiers are used to feed zone controls.

5.4.4.2 Small System Amplifier

Figure 5-12

For small systems, power amplifiers generally have front panel controls and built-in mixers, since they are used for other purposes. They should be shelf or rack mountable. The latter case applies if protection from user tampering is needed. ***Figure 5-12*** shows an example of an all-purpose amplifier used for masking applications (AA120).

It has six inputs for mixing purposes and Bass/Treble controls. Each input has a separate volume control for each input, as well as a master level control for the mixed output. An added value of this particular unit is it can have a sound masking module inserted on the back panel (AA120M). This module generates a pink or white noise spectrum and has a low pass filter with variable cut-off frequency. The masking signal can bypass the front panel controls so the masking spectrum can be set independently of the other signals. When precise spectrum control is desired the signal from this module can be fed to an external graphic equalizer (5.4.3) and then back to the power amplifier.

5.4.5 Zone Controls

Figure 5-13

The purpose of a zone control is to adjust the level in all speakers connected to that control. For small systems with few zones, the amplifier itself is often used as the zone control . For large systems (6.1.9), it is cost effective to use controls assigned to each zone, instead of having one amplifier for each zone.

There are a number of advantages in using zone controls. They permit both installer and user to adjust levels without detuning the system. The zone control panel (Atlas ATPLATE) shown in ***Figure 5-13*** can accommodate up to six zone level controls (Atlas E-408), each with the power capacity of 100 watts (typically 100 speakers), ten steps of 1.5 dB each, giving a broad range of level control. They are relatively inexpensive so they permit the system designer to create more masking zones with little cost increase. Use of a stepped zone control with a 3 dB/Step is *not* recommended. A 3 dB change can result in a nine point change in Privacy Index (2.5). If the level is increased, this change will result in too much masking while if decreased, it will reduce the degree of privacy.

5.4.6 Speakers

The purpose of the speaker for normal masking applications (See Chapter 8 for other uses) is to convert the electrical spectrum to an acoustical spectrum in the frequency range desired for privacy. That range at least must be from 160 Hz to 8000 Hz (2.3). Many types of speakers have been used for masking applications. In distributed systems the speaker is contained in the self-contained masker and generally has less diameter than those used in centralized systems. With the advance of acoustical technology, speaker diameter and back box volume are becoming less important. Direct radiating speakers, or special use speakers, are discussed in Chapter 6 (6.1.10).

There are several recommended features of masking speakers. They should have built-in suspension brackets instead of having to be set up with several chains. The brackets should be adjustable so the speaker can be faced vertically upward, horizontally, or vertically downward. They should have a conduit connector for projects that require conduit. They should have several values of tap settings changeable with an external rotary switch. Typical values are ¼, ½, 1, 2, and 4 watts. There are a number of reasons for having this range; Soundscaping (6.3.1), zoning for small projects (6.1.9), and for use in unusual ceiling situations (6.3). An added beneficial feature is an “Off” position. This can be used for several situations, such as accommodating a person with a hearing loss or handling local complaints, and to install speakers where they are not yet needed, but will be when office changes are made.

Figure 5-14

Figure 5-15

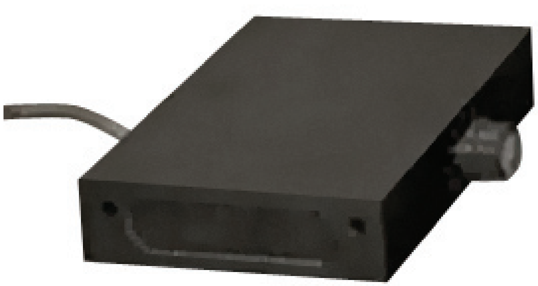


Figure 5-16

The one watt tap setting is recommended for speakers hung in a ceiling plenum or in an open ceiling. The two watt tap setting is recommended for under access floor applications. Other tap settings can be used for Soundscaping (6.3.1). ***Figure 5-14*** shows a speaker (Atlas M1000) with the recommended features. It can be used in a ceiling plenum, in an open ceiling, or in a raised floor cavity 12 inches or higher. ***Figure 5-15*** shows a speaker (Atlas M812) that can be used in a slightly smaller ceiling plenum and can be mounted directly on the ceiling grid. On occasion a suspended ceiling will be added below a concrete or gypsum board ceiling to reduce reverberation. The spacing is generally set near 4 inches to accommodate light fixtures. The cavity height of the raised access floor of one manufacturer is near 3 inches. In both cases, the speakers noted above will not fit. ***Figure 5-16*** shows a low profile speaker (Atlas M2000-LP) that was designed to fit in such small spaces. It has two speakers and is a dipole radiator.

5.4.6.1 Some Desirable Characteristics of Plenum Speakers.

There have been, and still are, a variety of plenum loudspeakers. Some of their characteristics are promoted by the manufacturer, whether important for masking or not. The speaker must generate significant sound, at least in the speech range of frequencies (160 to 8000 Hz). Speakers that radiate at lower frequencies are better since they can match the air handling system noise (3.1.8).

1. *Speaker type*. There are two types of speakers available. The most common type has either one, or two, speakers enclosed in a back box so that only the face of the speaker is exposed. Typical examples are shown in Chapter 6 (Figures 6-12 to 6-17). Another type contains two speakers facing in opposite directions horizontally and mounted on a flat plate with no back box. These do not seem to be manufactured presently.

2. *Speaker Diameter*. Most speakers are four, six, or eight inches in diameter, although eight inch is more common because their large volume keeps the cost attractive. Any of these diameters can be acceptable, if the diaphragm displacement is sufficient to generate the desired range of frequencies.

3. *Back box Volume*. Speakers with high back box volumes are often cited as necessary to improve the low frequency range of speakers. Although large volumes are better, it is not critical, as most speakers do not have Helmholtz resonances in the relevant range. Typical speakers have volumes in the range of 500 to 700 cubic inches.

4. *Internal Absorption*. Absorbing material (damping) is intended to reduce the amplitude of acoustical or vibratory resonances. Because sound masking is random, excitation of a resonance is minimal; the energy at the resonance frequency is transient. However, that is not the case for paging or music, so internal sound absorption and vibratory dampening is beneficial.

5. *Speaker Impedance*. Most masking speakers have a transformer that matches the signal on the 25V or 70V line to the 8 Ohm impedance of the speaker. Eight Ohm systems are not recommended (6.4.2). The transformer used should have several taps such as Off, ¼, ½, 1, 2 and 4 Watts. In older designs, the tap had to be chosen by the installer and hard wired, which severely reduced flexibility and added installation time. Most modern masking speakers, however, have multi-tap transformers that are connected by the manufacturer to an external rotary switch. Speakers designed this way are strongly recommended. The only limitation of such transformers is that changing one tap setting results in about a 3 dB level change. This change is courser than that desired (1.5 dB) because of its effect on

Privacy Index (2.5), which is one reason why zone controls are strongly recommended (5.4.5, 6.1.9). Having an Off position on the rotary switch has great value both in convenience and later cost savings when a space is redesigned from not needing masking to one that does. The installer merely rotates the control to activate the speaker.

5.5 Advanced System Functions

There are existing products that have one or more of the advanced functions described in this section. Some of the functions benefit the user and others benefit the installer. In the latter case, the benefit is transferred to the user by ensuring that the equalization process is less subject to errors.

5.5.1 Programmed Level Control Function (Scheduling)

As noted earlier, the need for privacy varies with time-of-day and day-of week (2.7, 3.1.13). To accommodate this requirement, an advanced system will have three controls: the start time, the end time, and the amount of level change. Newer systems permit these changes to be made at hourly increments during the 24 hour day. Each day of the week can be set differently and holidays can be included. Typical use, however, is for one level rise and one level decrease during the day such as shown in ***Figure 5-17***. The rise starts about one hour before normal working hours and the decrease starts about one hour before quitting time. The length of the rise and fall time is generally two hours.

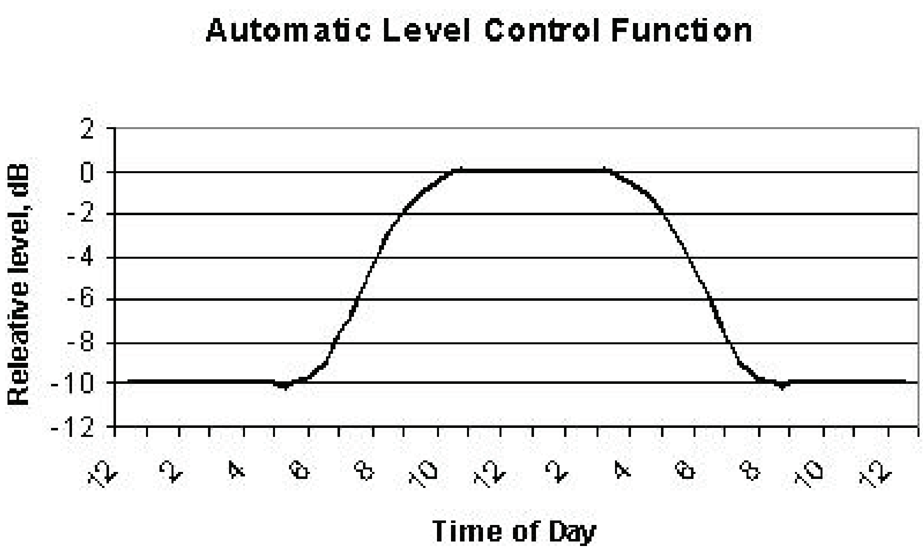


Figure 5-17

The amount of change is generally 10 dB during the workday, i.e. the rise starts 10 dB below the design level, rises to the design level (0 dB attenuation) and then drops 10 dB toward evening levels. On weekends and holidays, the population density is much less and then the change is often only 5 dB, i.e. the level rises from the –10 dB level to the –5 dB level. This feature is best implemented in DSP based systems where the required versatility is controlled by software. An early variation on this concept was to use a clock to turn the system on and off, not a good idea - too abrupt. Since both paging and music levels are above but related to sound masking, applying this function to those signals as well will keep the signal/noise ratio the same throughout the day.

The weakness of this approach is that the person setting the program schedule needs to predict what the activity levels in the office are going to be. Does one set the program for the noisiest zone, or attempt to develop an "average"? Since the social aspects of each company are different, it turns out to be an iterative process. A generator with several channels of programmed level control simplifies this problem (5.4.2.4).

5.5.2 Initial Ramp Up Function

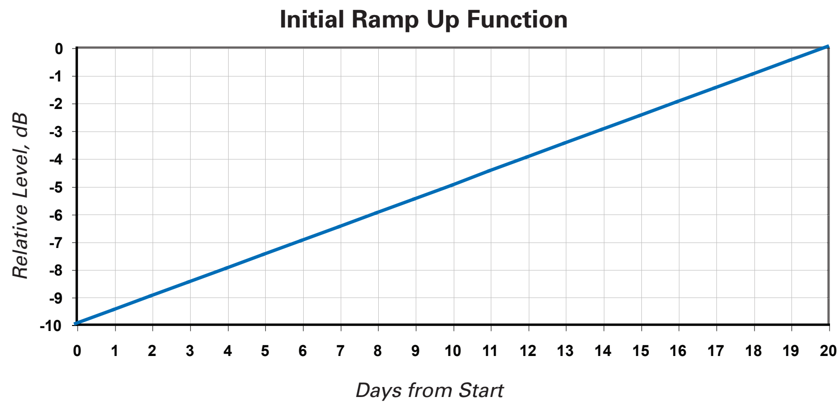


Figure 5-18

The purpose of this function is to avoid a perceived rapid increase in background sound level at the initiation of a sound masking system. There are three required inputs: the start date, the start level relative to the design level, and the number of days to the design level. In typical systems, such as shown in ***Figure 5-18***, the start date is set the day the system is equalized. The start level is recommended to be –10 dB. If used with the programmed level control function, the actual level during the day would be 10 dB below the level set by that control. For example, if the programmed level control was set to drop 10 dB during night hour and the slow ramp function was set to start at –10 dB, then the sound masking would start 20 dB below the design level at night and 10 dB below the design level during the workday. Initially, the sound masking would be inaudible during the workday and would rise slowly to the design level over the number of days entered. The number of days chosen to bring the system to design level depends on user requirements. With the recommended start level at –10 dB, 30 days is a reasonable target. This function is implemented in clock-based DSP systems where the level increments are well below the detection ability of listeners. This function is controlled by software.

5.5.3 Adaptive Function

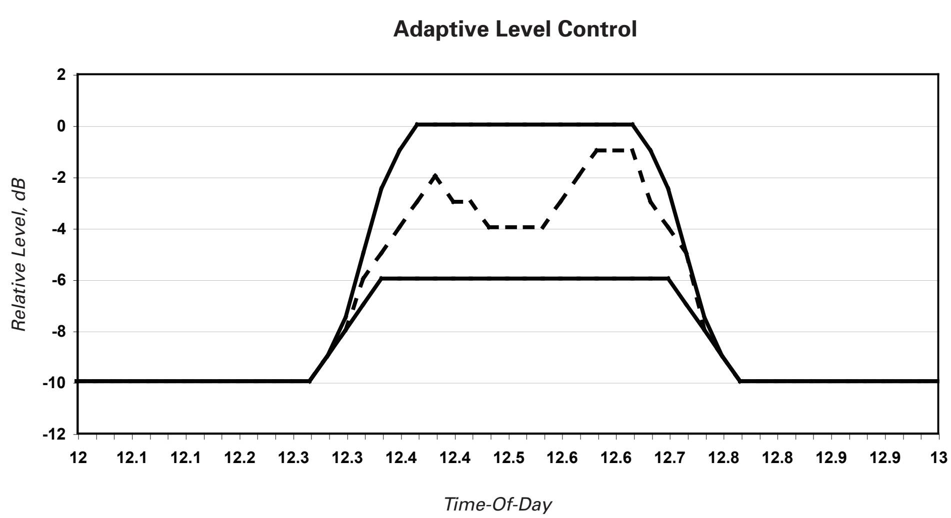


Figure 5-19

In order to set up the programmed level control function, the installer must make assumptions about activity sound levels. The purpose of this function is to sense the activity sound in real time and automatically adjust the sound masking level to maintain the desired degree of privacy. This permits the system to minimize the amount of masking whenever possible. Since part of the sound detected by the sensor is sound masking itself, processing the sound must be done in a special way to separate out the transient sounds. This is accomplished by use of percentile levels (A.5). The Percentile Level Difference (LD) is tracked as a function of time and the function acts to limit the value of that difference. Since it requires monitoring of the sound, this function would respond to *all* transient sounds, not just speech. Since there could be a high level, but no short, transient sound (vacuum cleaner), the function must have an upper limit similar to that used for the programmed level control function. Generally that upper limit should be the design level. Similarly, it should have a lower limit so that the masking does not totally disappear during the workday. Weekend daytime levels would seem reasonable to maintain a useful Radius of Distraction (3.1.9).

The response rates are critical for this function; they must be so slow listeners do not detect level changes. The running percentile levels can be calculated from a histogram with a larger number of samples to reduce the response rate. In addition, both up and down rate controls can be implemented.

One weakness of this function is that of spatial averaging. How many sensors are required in each zone to result in a good spatial average? Should the averaging be arithmetic to avoid weighting the higher inputs too heavily? Another concern about this function is the perceived ability to use the sensors as "bugging" devices by an employer. This can be overcome by converting the electrical signal to a variable DC voltage with no frequency information.

One beneficial feature of this function is that it responds to *all* transient sounds, while the programmed level control is generally based on estimates of speech activity. This makes it valuable for handling unexpected or exterior sounds, such as roadway or aircraft sounds.

5.5.4 Fast Ramp Up Function

There are occasions when the sound masking system is turned off, such as with power failures or when equipment maintenance is done. In keeping with the Second Design Rule (6.1), the masking should be as inconspicuous as possible, so rapid changes in masking level must be avoided. This function increases the masking level slowly after the power is installed or the system is turned on.

5.5.5 Simplified Equalization Function

There are two methods to do this. In each case, the process greatly shortens the equalization process. A real time analyzer measures the existing masking spectrum. In one method, the data is stored to a file and recovered by equalization software, so it can be compared with the desired spectrum. The matching process generates corrections that are then saved to a file and later recovered by the generator that sets the required adjustments, so equalization is a one step process. In another method, the data from the real time analyzer is transmitted (by wire or wireless) directly to the generator for setting the required corrections. In this case, the generator software must have a database of desired masking spectra for comparison purposes.

This function is a great benefit to the person equalizing the system; it reduces both the time spent and any errors. The limitation of this method is in collecting representative sound spectra to be processed.

5.5.6 Monitoring Function

Figure 5-20

The purpose of monitoring is to detect failures or determine output voltages of various components. There are two levels of monitoring: the first is monitoring the units in the centralized location, and the second is to monitor the speakers in the system. Response to failures can be either manual or by automatic switching from a failed unit. The latter response requires an inventory of spare equipment, which adds cost. In a centralized system, the generator output, the amplifier outputs, and the zone control outputs, can be monitored with a product such as shown in ***Figure 5-20***. Since, generator failure rates are miniscule and zone controls are passive, monitoring should be on the outputs of the amplifiers. Experience suggests that monitoring is not needed if the system is designed conservatively and the amplifiers are robust. However, in large multi-floor systems a monitoring panel can save much time during equalization. Because the failure of individual speakers is rare, monitoring them is not done usually.

One benefit of having a monitor panel is that all output voltages can be recorded from one place. If masking levels have been changed inadvertently, the outputs can be reset easily without resorting to sound level measurements.

5.5.7 Addressable Function

The advent of versatile and comprehensive hardware and software has led to the possibility of addressing each generator, zone, or speaker individually or in groups. This capability can be used to vary sound levels and even the masking spectrum. It should be possible to access a system from the internet so control can be accomplished remotely (5.5.7.1). This can also be used for audio functions other than sound masking.

5.5.7.1 Atlas VARIZONE™ System

The Varizone system is completely addressable and may be used for very large, complex systems. It is ideally suited for use in large facilities that require extreme flexibility for both paging and sound masking, such as hospitals (Chapter 4) and corporate offices.

It can accept the signal from several masking generators and can adjust each of these spectra in one-third octave bands, if needed, and so can provide several independent masking channels. These spectra can be assigned to any number of locations. If the appropriate masking generators are used, the other advanced functions can be used.

Several paging or music signals can be added, so the system can have any combination of audio functions sent to up to eight channels. Every set of two speakers can be an independent zone fed with any of the eight channels. The level in each zone can be adjusted independently. This implies that there can be half as many zones as there are speakers. The various channels can be assigned to any audio function on a time basis in any zone.

The system can have ambient sound monitoring modules, so the adaptive function (5.5.3) can be activated. It has a speaker monitoring function to detect those that fail (5.5.6).

The system can be controlled locally or through the internet, so the system can be readily adapted to changing needs and easily expanded to very large sizes.

CHAPTER 6
SYSTEM DESIGN AND INSTALLATION

6.1 Design Fundamentals

6.1.1 Two Design Rules

There are two rules for the design of a sound masking system.

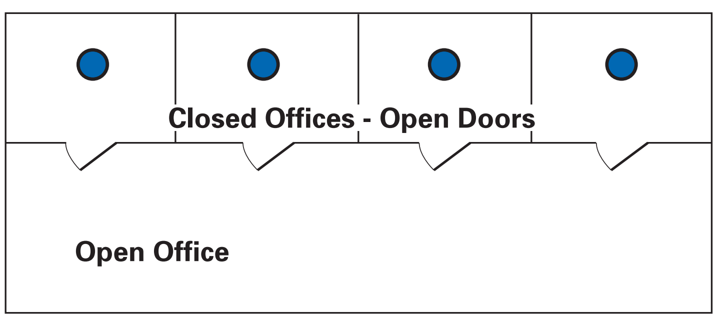
DESIGN RULE ONE

Masking should be placed at the listener.

Although it should be obvious that masking works at the listener's ear and so should be placed there, this rule is broken in far too many applications. The first task in designing a masking system is to decide what areas need privacy, and then to decide who in that area is the listener.

Most of us are familiar with films in which criminals turn on the water spigot in a men's room to protect their conversations. Managers in private offices, and even in their conference rooms, often ask for a masker to be placed *in their* room to protect their conversation from persons *outside*. Having to speak louder because of masking does absolutely nothing to protect their privacy!

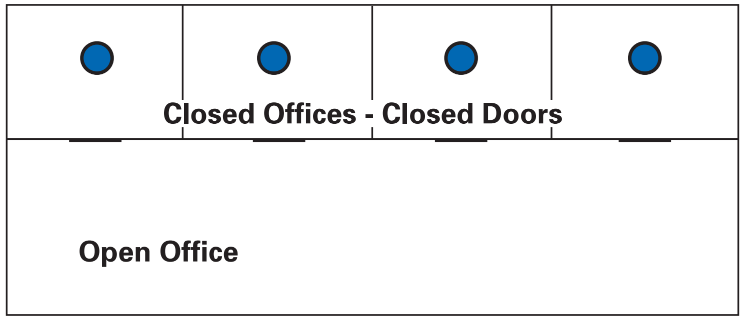
In many applications, masking is requested for areas where privacy is neither needed nor practical. Since masking is intended to create privacy, if the function of an area is communication, such as conference rooms or dispatch centers, masking should not be applied. There are marginal areas where some degree of privacy is desired but not essential, such as large cafeterias where the occupants are inadvertent listeners to those at other tables. Interaction with the customer ultimately helps to define the areas that need privacy.



The listener is in a closed office
Normal Privacy

Figure 6-1

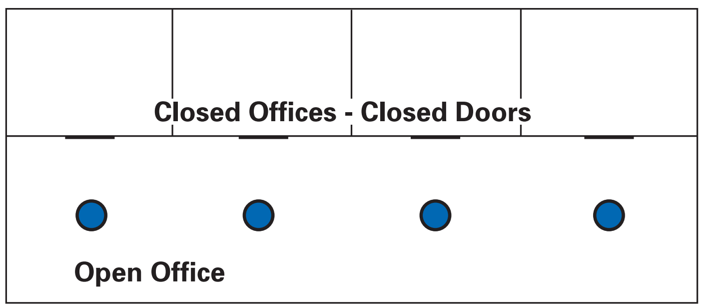
But where are the listeners? We need to find them in order to locate the masking speakers. ***Figure 6-1*** shows persons in closed offices who want freedom from distracting office sound when they have open doors. The listener is the person in the closed office so the speakers should be placed there.



The listener is in a closed office
Confidential Privacy from other Closed Offices

Figure 6-2

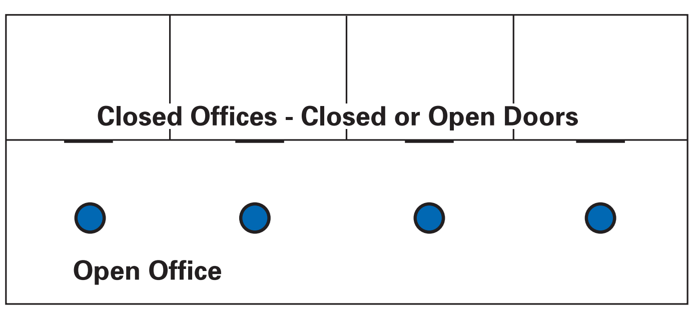
Figure 6-2 shows persons in closed offices who wish to have Confidential Privacy from persons in other closed offices. This is the situation where the ceiling plenum is open to act as a return air duct and there are return air grilles in each office. The listeners are the persons in the *other* closed offices, so the speakers should be placed in all closed offices.



The listener is in a Closed Office
Confidential Privacy from Open Office

Figure 6-3

Figure 6-3 shows persons in closed offices who want Confidential Privacy from persons in the open office. The listeners are the persons in the open office, so the speakers should be placed there.



The listener is in an Open Office
Normal Privacy from Closed and Open Office

Figure 6-4

Figure 6-4 shows persons in the open office who want Normal Privacy from persons in the closed offices (with open doors) and other persons in the open office. The listeners are all the persons in the open office, so the speakers should be placed in the open office.

One result of defining the listener is that there are two reasons for placing sound masking in closed offices. Closed offices should be zoned separately from open offices (6.1.9).

DESIGN RULE TWO

The system must be truly background by conveying as little information to the listener as possible.

This implies that the system must function without calling attention to itself. Well-designed air conditioning systems, for example, meet this requirement. If one asks an occupant whether his building has air conditioning or not, he or she would probably say "I think so, but I do not know." This is also the goal for sound masking systems. Some ways to follow this rule are:

1. All hardware should be unseen by occupants. The loudspeakers must be out of sight, or disguised when not. All control equipment should be unavailable to the occupants.

2. Levels should be spatially uniform in areas with the same work function. As a person walks through a masked area, he or she should not be aware of the presence of masking caused by level changes.

3. Temporal changes in level or spectrum, if required, should be unnoticeably gradual if done during times of occupancy.

4. In open areas, masking should cover the entire area. In an effort to save some expense, owners have requested masking sound in only those areas of an open office that they consider important for privacy. The contrast between masked and unmasked areas is very noticeable and may draw a negative response. If there is an unmasked area nearby, such as a break or mailroom, the corridor connecting them should have speakers that gradually reduce the masking level spatially. We call this "*Soundscaping*" (6.3.1). When persons pass through an abrupt change in structure, such as through a door, they will more readily accept changes in the acoustical environment, so Soundscaping is not always necessary.

5. Since the degree of privacy needs to vary during the workday, the level changes, if made automatically, should be gradual (5.5.1, 5.5.3). A corollary is that the masking should **not** be switched *off* or *on* when the space is occupied. There are some exceptions. After a period of use, switching off the system for a short time can be used to demonstrate the value of masking. Switching on can be made acceptable if the system has a slow rise function that takes several minutes to reach full level (5.5.4).

6. There is a potential for negative response if occupants can locate speakers either visually (direct radiating speakers) or by finding localized higher sound levels (hot spots).

7. Make each speaker individually adjustable (6.1.10). Since the goal of a masking system is to provide privacy without calling attention to itself, and since masking by its very nature covers a wide area, there are persons who will detect the presence of masking when others will not. Examples are the hearing impaired, those of a sensitive nature (1.13), or those who want

more privacy than the average. Locally adjustable speakers help to reduce their awareness.

8. The system should have an adequate number of zones (6.1.9). A zone controls the level of masking in an area. If one group wishes to change the masking level, other groups are not affected. A properly designed zone control (5.4.5) gives the manager a means to comply with local requirements.

9. If direct or radiating speakers must be used, every other speaker should be on a different channel of masking so there is no phase interference to call attention to the system (6.4.1.3).

6.1.2 Two Design Objectives

DESIGN OBJECTIVE ONE

The masking sound should be random and incoherent.

The word "random" eliminates speech, music, tones, or other sounds that carry information as a source of masking. When two loudspeakers radiate the identical random sound, the phase relationship of the sounds at each frequency plays a role in the addition of those sounds. Stereo systems depend on phase to create directional effects. But one objective for masking is to eliminate any phase effects. As a person passes through the midpoint between these two speakers he will hear a "swishing" of the masking. This occurs because certain frequencies will be reinforced (additive) and other frequencies will be subtracted (cancelled) during the passage. This calls attention to the presence of masking in violation of Design Rule Two and can create annoyance. This effect is sometimes called the "phase effect". It can be prominent in direct radiating speakers and in open space speakers, but is generally not noticeable for mineral ceiling panels. The cure for this is a checkerboard speaker design (6.4.1.3).

DESIGN OBJECTIVE TWO

The masking sound should create as diffuse a sound field as possible.

When people can point to the source of a sound, particularly masking, it can create a negative response. When the sound comes from many directions, it becomes impossible to isolate the source; examples are the outdoor background sound and the sound field in more reverberant areas of buildings with high ceilings. This type of sound is called "diffuse". Localizable sound masking is less acceptable than diffuse sound at the same level. How can that be achieved with sound masking? Experience has suggested that there is a hierarchy of diffuseness. The most diffuse is from speakers under a raised floor, followed by speakers in open ceiling space with a high structural ceiling (near 20 feet), followed by speakers in a ceiling plenum, followed by other indirect radiating speakers, followed by direct radiating speakers (6.1.10). When speaker location options are available, it is recommended that this hierarchy be followed.

6.1.3 Collecting Design Data

To properly design a system, two sets of data are needed: the physical structure of the project and the privacy objectives of the owner.

NOTE: Appendix B has a form that may be copied. It has a method for demonstrating lack of privacy in an existing office.

6.1.3.1 Physical Aspects

1. Obtain furniture layout drawings for open office areas. This should include the manufacturer's name, model, and the height of the panels used to separate occupants.

2. Obtain suspended ceiling reflected plans to look for return air grilles, open ceiling areas, or areas with clouds (6.3.5), including the manufacturer's name and model.

3. Obtain mechanical drawings that show ducting that may interfere with the speaker array.

4. Obtain vertical views to look for changes in structural or suspended ceiling heights.

6.1.3.2 Speaker Positioning

1. For suspended ceilings, obtain the suspended ceiling height and the plenum depth and whether there are sound absorbing materials within the plenum.

2. For access floors, obtain the cavity depth, the floor manufacturer's model and STC rating.

3. For open ceilings, obtain the height of the structural ceiling.

4. Learn the nature of the structural ceiling (for hanging speaker support wires).

5. Locate a potential central location for rack cabinet.

6. On multi-floor systems, locate vertical risers.

6.1.3.3 Open Offices

1. Panel manufacturer (for panel NRC and STC).

2. Panel heights (for sound diffraction).

3. Workstation sizes (for distance between people).

4. Proximity of walls or windows to workstations (for reflections).

5. Suspended ceiling sound absorption characteristics (NRC).

6. Whether sound absorbing materials are within the plenum.

7. Types of light fixtures, whether pendant, parabolic or flat-lensed.

6.1.3.4 Closed Offices

1. Wall sound attenuation (STC).

2. Connection of interior walls to outer walls (for sound leaks).

3. Presence and location of return air grilles (for sound leaks).

4. Solid or hollow core doors (for sound leaks).

5. In existing buildings, estimate the background sound level (to make sure that there will be a benefit when masking is added). Use a Walkaway test (Appendix B).

6.1.3.5 Social Aspects

1. Determine which areas require privacy and to what degree. Review the areas with the owner.

2. Determine the privacy objectives of the owner to ensure they are realistic.

3. Determine if paging is desired.

4. Determine if speakerphones are used in open areas.

5. Determine if any persons with a significant hearing loss, or are visually handicapped (6.1.3.7), will occupy open areas.

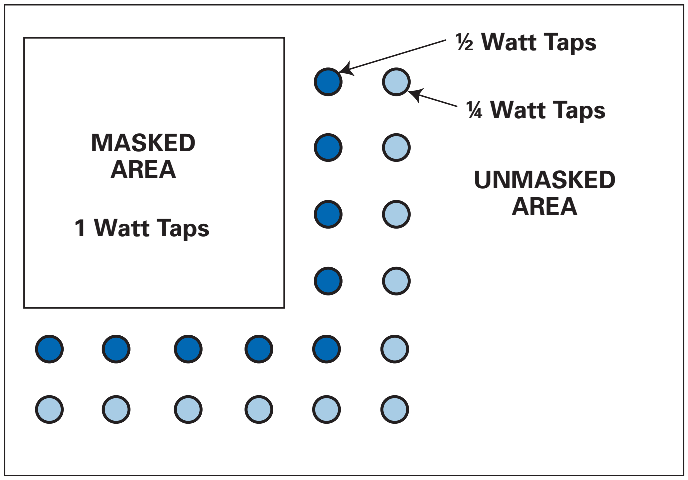
6.1.4 Pre-design Review - Things to Watch Out For

Many owners request masking without an understanding of its benefits or limitations. For example, some expect that conversations in open offices will be unheard when masking is added. It is very important both to review drawings and inspect premises to locate areas or situations where sound masking may be of no, or limited, benefit. Any limitations found should be reported immediately to the owner so there are no unrealistic expectations. A number of specific situations are discussed below.

6.1.4.1 Request to Mask Small Open Areas

Sound masking will not provide Universal Normal Privacy successfully in rooms that are smaller than about 20 feet by 20 feet when occupied by more than one person. Typically, this was a private office converted to a multi-person open office. The sound reflections from the walls are sufficiently strong that masking levels need to be objectionably high to provide any privacy. The cost of adding sound absorbing panels, to allow the masking to be lowered to reasonable levels, is prohibitive in most cases.

6.1.4.2 Request to Partially Cover Open Areas as a Demonstration



Soundscaping Partially Masked Open Areas

Figure 6-5

There may be a request to add sound masking in only one area of an open plan office, sometimes as a demonstration. The best solution is to find a smaller area and mask it completely. The next best solution is to use the concept of Soundscaping (6.3.1) to make gradual spatial changes in the sound masking level. An example is shown in ***Figure 6-5***. Two rows of speakers have been added outside the perimeter of the masked area. Usually the masked area speakers are tapped at 1 Watt. The closest row of speakers is tapped at ½ Watt (down 3 dB) and the next row is tapped at ¼ Watt (down 6 dB). This brings the level down gradually to about the existing background level.

6.1.4.3 Request for Masking in Restaurants

Restaurant designers try to create a visually interesting and energetic environment to attract customers. Generally, the design results in open spaces and acoustically hard surfaces. After the initial period of use, the owner is faced with noise complaints and looks for an inexpensive solution. Those who have heard of sound masking will request that a system be installed with the mistaken belief that it will cancel speech noise.

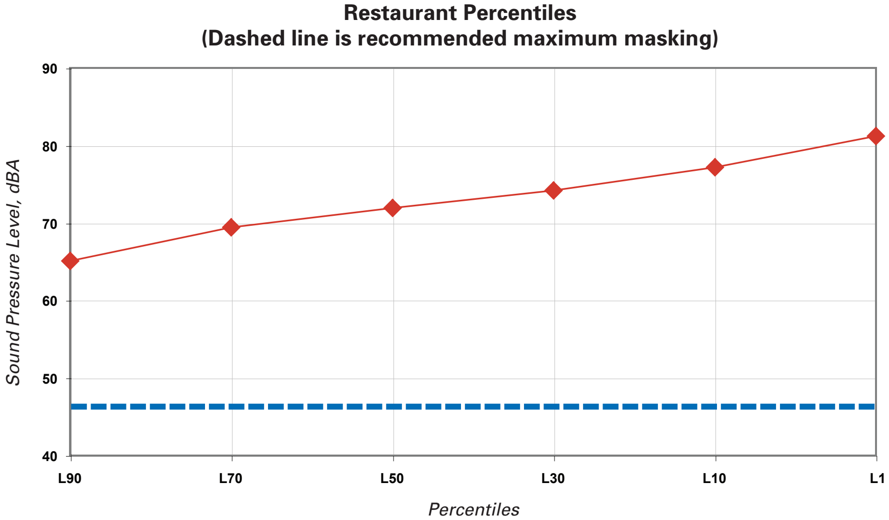


Figure 6-6

The upper contour of ***Figure 6-6*** shows the percentile level distribution (A.5) for the worst case: a fully occupied, open restaurant. The lowest level (L_{90}) is near 65 dBA. The lower contour shows the maximum recommended masking level. It is clear that the existing background level is well above the optimum level, so sound attenuation is required, not sound addition (1.1).

6.1.4.4 Masking in Corner Open Offices

In an attempt to be egalitarian, corporate centrifugal force throws corporate heavyweights to the corners of an open office. These persons expect more conversational privacy than others, but are inadvertently positioned where one would like to put a loudspeaker to maximize its coupling to the room. The reflections from the walls (often windows), and ceiling, can add from 3 to 5 dB to a person's voice level. This translates to a 9 to 15 point reduction in Privacy Index for listeners (2.5), very noticeable.

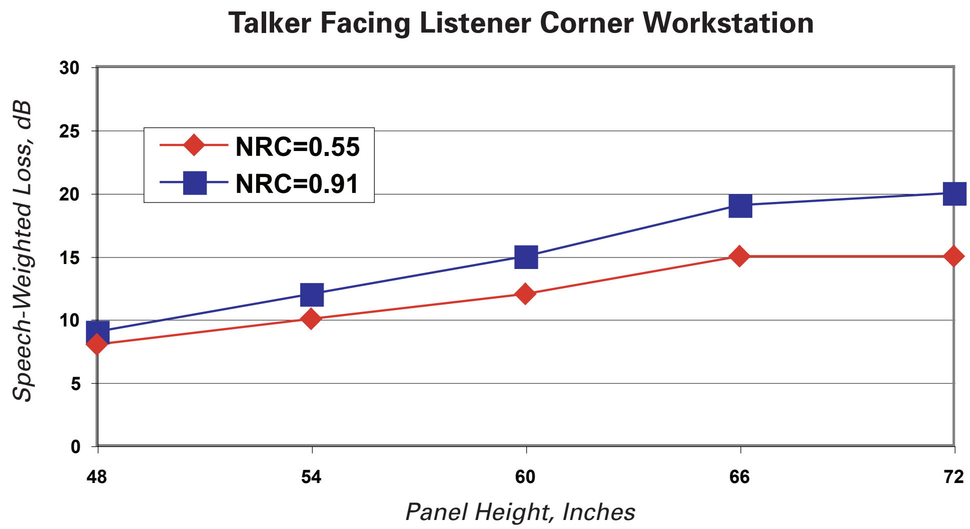


Figure 6-7

One possible accommodation would be to modify the tap settings to raise the masking in the workstations around the office. Raising the speaker tap setting one step would create a 3 dB increase for about a 9 point increase in Privacy Index to offset the reflections. Unfortunately, such a level increase may be unacceptable to the listeners. The reflections work in nearly reciprocal fashion, so the corner occupant should have higher masking also. One company placed managers in the *center* of the open area with higher panels to reduce this effect. The sound masking designer should point out that improvement will come from changes in the workstation. ***Figure 6-7*** shows the Speech-Weighted Sound Loss (SL) for a corner workstation. Since raising the masking level is not acceptable, the ceiling tiles and furniture panels must be modified. An SL greater than 16 helps to achieve Universal Normal Privacy (A.3.4). The data in the figure suggest that panels higher than 66 inches, with a fiberglass suspended ceiling (NRC=0.91), are needed to solve this problem.

6.1.4.5 Walls in Contact with Windows in Closed Offices

In some buildings, internal partitions may butt against a windowpane with the result that there are severe sound leaks between closed offices. The transmission path is vibration of the window pane, so foam caulking is ineffective. Persons sitting near these windows will have significant privacy loss that may be difficult for sound masking to overcome at reasonable levels.

6.1.4.6 Gap in Separating Panel

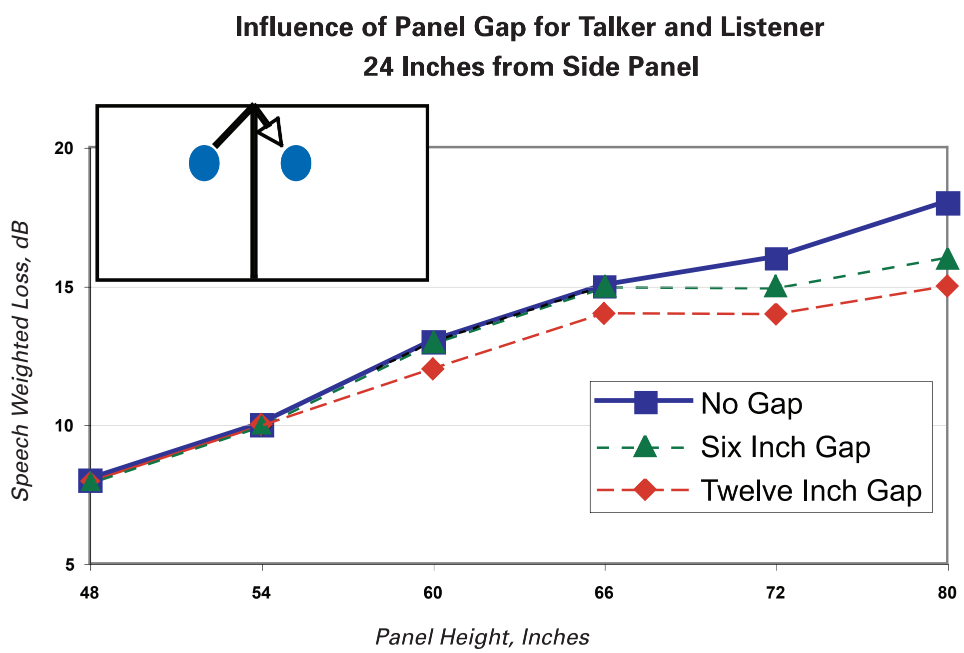


Figure 6-8

There are situations where the panel that separates two persons does not connect to the wall or to the panels against the wall. There may be a baseboard heater system along the wall or a gap to provide visual access to a window. The presence of this gap permits sound to pass around the side of the separating panel by diffraction and reflection. It has been found that when the occupants are within two feet of the side panel or wall, a significant reduction in sound attenuation can occur. ***Figure 6-8*** compares the Speech Weighted Loss without a gap to that with 6 and 12 inch gaps. Each workstation was 8 feet by 8 feet. The talker was facing the listener, 36 inches from the separating panel, but only 24 inches laterally from the side panel. The listener also was 24 inches from the side panel. A 6 inch gap becomes important for panels 72 inches or higher, while the 12 inch gap becomes important above 60 inch high panels. The sound masking designer should look for such gaps existing in workstations with panels 66 inches or higher and report to the owner that sound masking might have to be raised to unacceptable levels for persons closer to the gap than 3 feet.

6.1.4.7 Handicapped Persons

Masking systems are designed for persons with normal hearing. Persons with a hearing handicap already have more privacy than those with normal hearing. If the handicapped person is in an open office, he or she may have difficulty holding a conversation with a visitor. Furthermore, hearing aids make use of the Articulation Index contour to improve speech intelligibility, so the masking will have more hiss and thus be more annoying. The masking sound system designer should ask the owner whether such persons are in the area to be masked. If they are, there are several mitigating actions that might be taken. It is best to move that person into a closed office with no sound masking. If that is not possible, then they should be moved into an open office area separate from others and with the masking speaker turned off.

Visually handicapped persons are quite adept at using acoustical cues to help them navigate. Sound masking will mask those cues, increasing their difficulties. They should be located in areas that have no sound masking and low air handling noise.

6.1.4.8 Reverberant Rooms

Many older buildings with office size rooms are renovated to contain open areas with numerous occupants. When the walls, ceiling, and floor are very sound reflective, the probability of a successful masking system is low. Not only is the reverberant babble of voices distracting but the loss of speech between a talker and a listener is sufficiently reduced that masking levels need to be objectionably high to achieve any degree of privacy. It is best to recommend that masking *not* be used in such a room.

6.1.4.9 High Background Levels

There are situations where the background level is already high, generally caused by a noisy air handling system. Vertical ducts that bring air down to horizontal ducts cause considerable low frequency sound in localized areas. If the presence of this noise is ignored, the sound masking will be interpreted, erroneously, as being too loud. If the local supply ducts are undersized, diffuser noise in the rooms can be considerable. The masking system designer should look for these situations and report them to the owner after doing a Walkaway Test (Appendix B) to determine whether sound masking can be of any benefit.

6.1.4.10 Occupant Expectations

Although it may be possible to create a masking spectrum that provides the proper degree of privacy, it must be acceptable also. In offices where employees are very goal oriented and are well managed, the levels recommended in this manual are accepted by them. There is a trend, particularly in Europe, to comply with all employee complaints, whether reasonable or not. Unfortunately this often results in the masking level being turned down to a useless level or even turned off, depriving the non-complainers of privacy. As a result, masking is considered ineffective and the reputation of the designer is lessened. It can result in unpaid return visits to adjust levels in response to complaints. Therefore, it is important for the designer to make a serious attempt to determine how the concept of masking will be accepted prior to design. In general, the busier people are, the more they accept masking as a benefit.

6.1.4.11 Request to Mask Only Open Offices

Persons not familiar with sound masking will ask for it only in the open areas. Unfortunately, most adjacent closed offices will lack Confidential Privacy. Often they are at the knee of the Privacy Index contour (2.5), meaning that a low level of masking will provide the desired privacy. An alternative design incorporating closed offices should be made.

6.1.4.12 Corridor Masking

To provide Confidential Privacy for closed offices, sound masking may be placed in the corridor outside them. The system designer should inspect the plenum above to ensure that there is room for speakers, since often the supply air duct runs up the corridor and may almost fill it (6.3.2).

6.1.5 Choosing the Type of System

6.1.5.1 Centralized vs. Distributed

Distributed systems are best applied in very small or special projects where their uniqueness outweighs their limitations (5.3.2). Centralized systems are recommended for most projects since they are cost effective and have a number of advantages over self-contained maskers (5.3.1).

6.1.5.2 Proprietary vs. Open Systems

In a proprietary system, the prospective owner **must** purchase all components from one authorized supplier/installer. One advantage of a proprietary system is that all components are known to work together.

The advantage of an open system is that the prospective owner may choose a number of supplier/installers; each is free to buy components from a number of manufacturers. A potential disadvantage is that an inexperienced supplier/installer may choose incompatible components that will result in operating problems. There are several manufacturers that make complete lines of masking equipment known to work together, so that the supplier may purchase all equipment from that manufacturer. The prospective owner should choose the most experienced supplier to install and service the system.

6.1.6 Choosing Audio Functions

Since these systems can carry sound masking, paging, and music, it is possible to have any combination of these signals go to any location. The purpose of each function is different. Masking provides privacy, paging provides communication, and music provides a pleasant atmosphere. Note that the function of masking conflicts with that of paging.

Masking is used in rooms where privacy is needed, and not in such spaces as break rooms, mailrooms, or conference rooms. The system designer must determine with the owner where those areas are.

Paging is used in rooms where communication is needed; this function may operate in areas with masking and in areas where there is no masking. The paging may be All Call or zoned. When used in conjunction with sound masking, there is a common opinion that the paging will be *muffled*, particularly when the speakers are above a suspended ceiling or under an access floor. That is not so; both the spectrum contour and level of the paging can be set to have high intelligibility in the presence of masking (Chapter 7). As a result, **neve**r mute (duck) the masking when pages occur (except for emergencies). Zoned paging increases the complexity of the design, but is commonly done. For paging only zones with suspended ceilings, the speakers may be placed above the ceiling, as are masking speakers, to increase spatial uniformity.

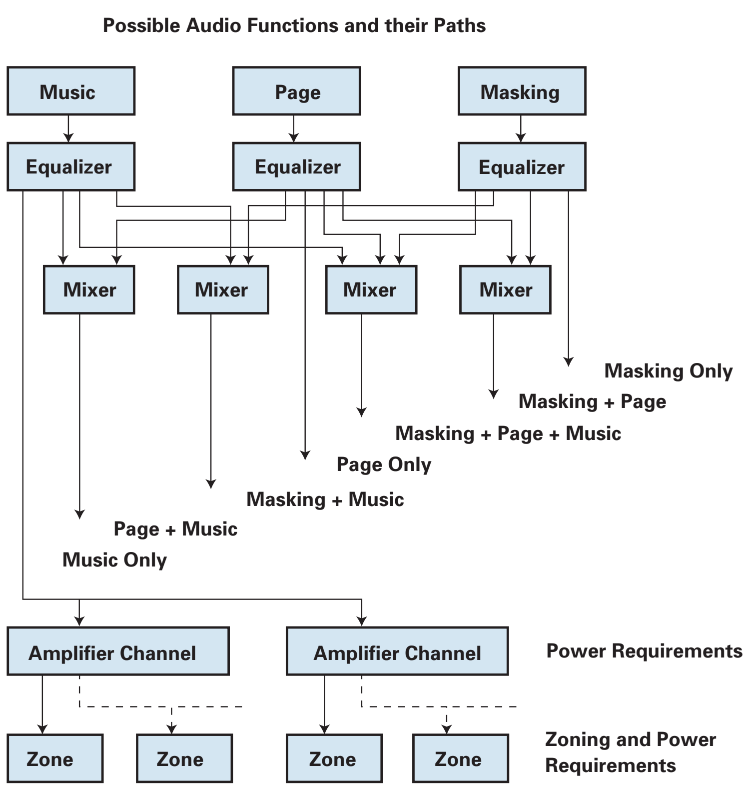


Figure 6-9

Music is often desired in areas where repetitive tasks are performed, and is not often used in areas where complex or difficult tasks are performed, or where it is socially or psychologically inappropriate. Music used as sound masking does not work; the levels fluctuate too much and the frequency range may be inadequate. Worse, music conveys information, violating Design Rule Two. Music as an adjunct to sound masking, however, does work, and there are several ways music can be combined with masking. In areas where very routine tasks are performed, the music should be in the foreground to create a pleasant working environment, and the sound masking should be used to reduce the Radius of Distraction and may be set lower than recommended. In some areas, the music may be set to be almost subliminal; the mood of the music is conveyed but is not intrusive. Experience has suggested that the level of music **never** be set between 3 and 6 dB above the masking because it sounds like a radio station with a bad noise problem. If combined with paging, it may be muted. ***Figure 6-9*** shows the seven audio functions that can be created, and the need to have one, or more, separate amplifier channels assigned, feeding one or more separate zones. The number of amplifiers assigned depends on the power required by the zones assigned to that channel. The larger the amplifier power, the smaller and lighter the system. The number of zones is determined by the power capacity of the zone controls and the zone assignments (6.1.9). It is very important to have an equalizer for the sound masking and an equalizer for the paging, if the speakers are above a suspended ceiling or under an access floor. Very often the equalizer for music is omitted, but it is recommended for speakers in the ceiling plenum, and strongly recommended for speakers under an access floor.

6.1.7 Choosing Channels

A masking channel is defined as a broadband electrical signal with a specific spectrum contour. The overall level of the signal is set elsewhere. An equalizer (5.1.2, 5.4.3) is used to create it. Some situations where more than one channel is needed are discussed below:

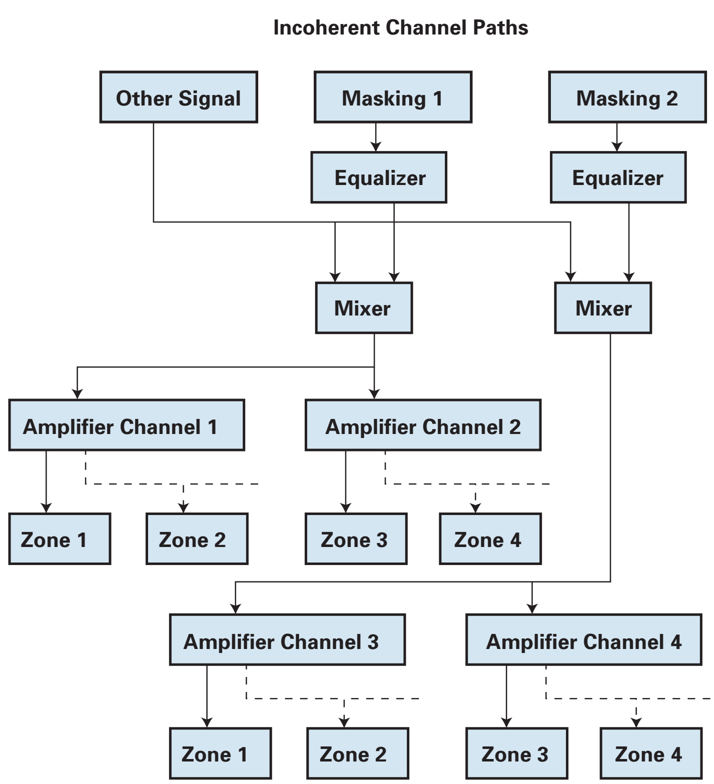


Figure 6-10

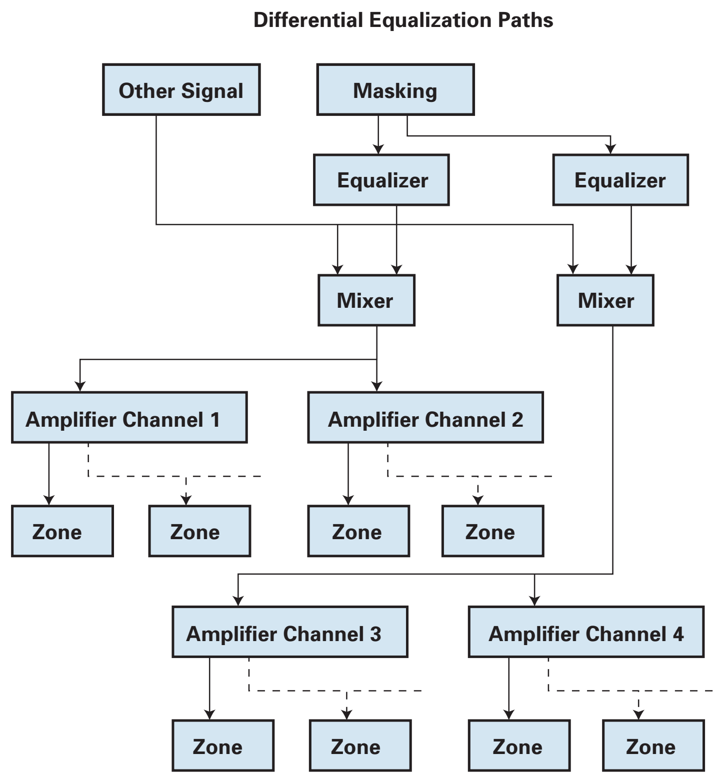


Figure 6-11

6.1.7.1 Incoherence

It has been popular among consultants to require that alternate loudspeakers be fed signals from alternate masking channels. This design is called *incoherent* or *checkerboard* (6.4.1.3). ***Figure 6-10*** shows a typical schematic. When a person moves through a point exactly between two speakers fed from the same channel, a "swishing" sound can be heard as the various frequencies reinforce or cancel. This can create a negative response. The effect does not happen when the two speakers are fed from two statistically independent (incoherent) channels. A number of experiments with masking sound passing through various types of suspended ceilings, open ceilings, and access floors have found that two masking channels feeding a checkerboard wiring design are *not* needed for most of these situations. The exceptions are face-down speakers and a fiberglass ceiling tile that has no foil backing. Suspended ceilings and access floors act as mixing boxes and create enough incoherence so that this effect is not noticeable. The same is true for properly designed speaker layouts for open ceilings. A two-channel checkerboard design is **mandatory** for direct radiating speakers (6.1.10). When such a design is made, care must be taken to make sure that the sound masking from each channel has the same spectrum contour and level. Installing checkerboard design wiring can be a problem, and as can be seen in ***Figure 6-10***, it requires twice as many amplifiers.

6.1.7.2 Differential Equalization

The masking spectrum contour is vitally important in open areas (3.1.10), but not so important in closed offices (3.2.4). The sound spectrum created by the speaker is modified by the plenum or cavity volume. When these volumes are different in the various zones, additional channels are required to create the proper masking spectrum. ***Figure 6-11*** shows a typical schematic. There are a number of situations where this applies:

1. *Plenum or Cavity Depth*. This applies to suspended ceilings and access floors. Typical depths of a ceiling plenum are near 3 feet. When the plenum is very shallow, less than 1 foot, or greater than 6 feet, the equalization must be different

than that for the 3 foot plenum. If all three depths exist in a given project, three channels are needed. If the access floor cavity in one area is 1 foot or greater, and less than 1 foot in another area, two channels are needed.

2. *Ceiling Tiles*. This applies to suspended ceilings only. Another channel is required when one area has a standard mineral tile ceiling and the other has a fiberglass tile. This does not occur very often but the difference is significant enough to require two channels. More common is the use of mineral tile in one area and gypsum board in another. Again, two channels are required.

3. *Discontinuous Ceilings*. This applies to suspended ceilings only. There are ceiling designs that have "clouds"; one part is covered with gypsum board or mineral tile, while other areas are open to the structural ceiling. Two channels are recommended. Section 6.3.5 discusses speaker array solutions to this problem.

4. *Open Ceiling*. If one area has no suspended ceiling and another does, two channels are required.

5. *Different Speaker Locations*. If one area has speakers in a suspended ceiling and another has speakers under a raised floor, two channels are required.

6.1.7.3 Audio Functions

Each audio function needs a separate channel (6.1.6).

6.1.7.4 Reliability

Installing a two-channel generator and equalizer when only one channel is used, provides a spare in case of failure. Failure rates of generators are so small that a spare is not required. Most generators have two or more channels, so a spare is often included anyway.

6.1.8 Choosing Amplifiers

Amplifiers feed their outputs directly to a zone of speakers or to a bank of zone controls.

6.1.8.1 Characteristics

The bandwidth of most common amplifiers is so broad that no changes in the masking spectrum contour occurs, so they can be used to power speakers and adjust overall levels. If two, or more, channels of generator/equalizers, or audio functions, are used in large systems, two, or more, channel amplifiers are recommended to reduce weight and cost. It is recommended that these amplifiers feed zone controls (6.1.9), but they may feed directly to speaker zones on small projects where it is not feasible to use zone controls. It is tempting on large multi-zone systems to use multi-channel amplifiers as zone controls. This is not recommended because amplifiers have analog controls that lack the precision of zone controls (6.1.9). For large systems, they must be rack mountable. It is important to have any analog volume controls on the rear of the amplifier, or if not, the amplifiers should be put in a lockable cabinet (5.1.4, 5.4.4).

6.1.8.2 Number

The number of amplifier channels is determined by the number of audio functions, the number of differential equalizations required, and the number of speakers fed. Each amplifier channel must have sufficient power to handle all the zones assigned to it, so it is strongly recommended that large amplifiers be used to limit system size.

6.1.9 Choosing Zones

A zone is a group of speakers that are fed the same audio function. A zone control is used to adjust the level of the mixed signals in large systems (5.4.5). Why is more than one zone desirable or necessary? With respect to desirability, if there is a request to alter the masking (or paging, or music) in one area of a building that has only one zone, everyone must have their privacy altered. Typically, this results in a request to create multiple zones so this unfortunate event does not happen again. With respect to necessity, there are situations where more than one zone is necessary to satisfy the design rules. Home run wires and zone controls are inexpensive, so it is difficult to *over-zone* an office. Zoning choices are discussed below:

6.1.9.1 Open and Closed Offices

The required masking level in an open office is always higher than that in a closed office. Each should be zoned separately. If there are extreme panel height differences in an open office, two zones should be created. In small systems where cost or space is limited, there is a way to design around this added zone (6.3.3).

6.1.9.2 Administrative Functions

Experience has shown that managers of areas, such as accounting or sales, desire control over their area; one control is acoustical privacy. The masking system designer should attempt to define administrative functions and zone accordingly. Masking levels are designed to handle the worst-case situation where all people are talking all the time. Sales areas, or call centers, are conversationally busy, and recommended masking levels are most likely applicable (3.1.7). In other areas, where conversations are less frequent, the design levels may be excessive. If both areas are in one zone, the installer would have to adjust each and every speaker in the relevant area to accommodate any request for a change in level and since speakers can only be adjusted in 3 dB steps, the Privacy Index change would be significant (2.5). Thus an added benefit of zoning is that zone controls are more precise than speaker taps (5.4.5), and are readily accessible.

6.1.9.3 To Accommodate Audio Functions

There are seven possible combinations of audio functions (6.1.6) and each must be separated from the others by a separate zone as well as a separate amplifier channel. The zone must be fed from an amplifier channel that has the proper audio function.

6.1.9.4 As a Substitute for a Channel

There are cases where cost prohibits the use of more than two channels and a compromise must be made. The level capability of a zone is used to replace the desired spectrum. This choice should be avoided whenever possible.

6.1.9.5 Amplifiers as Zones

When the system is small (two or fewer zones) and cost is an important consideration, amplifiers may be used as zones. There may be some loss of desired features when this is done.

6.1.10 Choosing Locations and the Speakers That Go There

Figures 6-12 through 6-17

Although historically, sound masking speakers have been located only in the plenum space above a suspended ceiling, there are a number of other locations that may be used. These locations can be subdivided into those that have indirect radiating speakers, and those that have direct radiating speakers. Indirect radiating speakers are located where there is an intervening material between the speaker and the listener, such as a ceiling, wall, floor, or the speaker is positioned to reflect sound from a surface such as a ceiling.

The purpose of this section is to provide the masking specialist with ideas of where to apply masking when standard locations are not viable. The choice of speaker is dependent on the location chosen. All the speakers shown in this section operate on either 25V or 70V lines. Actual speaker arrays are discussed in Sections 6.2 and 6.3.

6.1.10.1 Indirect Radiating – Above a Suspended Ceiling

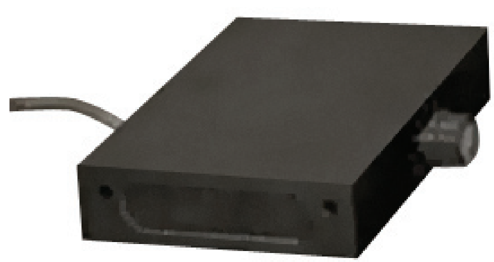


Figure 6-18

Speakers in the ceiling plenum are the most common location. Most masking speakers are designed for this location. This location is considered as the second choice, if a raised access floor is available (6.1.2). The specific speaker depends on plenum depth. Most masking speakers require a plenum depth of more than one foot to be effective, so special speakers are required for smaller depths. Samples of speakers that work well in deeper plenums are shown in ***Figures 6-12 to 6-17***. Some have been around for some time (the infamous paint can masker), while others are relatively new. ***Figure 6-18*** shows a speaker that fits into a plenum depth of less than one foot.

6.1.10.2 Indirect Radiating – Above a Discontinuous Suspended Ceiling

When the suspended ceiling covers only part of an area, the situation is often referred to as having "clouds". Masking speakers used for suspended ceilings may be used here. Care must be taken in designing for this condition (6.3.5).

6.1.10.3 Indirect Radiating – Open Ceiling, Upward Facing

Figure 6-19

When there is no suspended ceiling, masking speakers can be hung successfully facing upward in the open space. These speakers are hung from the structural ceiling and will be visible. When the structural ceiling is high, as is typically the case, the uniformity of the sound can be as good as with a suspended ceiling. It is possible to use speakers that go above a suspended ceiling. They may have to be repainted to be acceptable to the owner or architect. ***Figure 6-19*** shows a speaker that was designed specifically for hanging in open ceiling spaces. It is circular and all controls and wiring connections are on the top and are not visible from the office below.

6.1.10.4 Indirect Radiating – Open Ceiling, Horizontally Facing

Figure 6-20

Figure 6-21

When there is no suspended ceiling, masking speakers can be hung successfully facing horizontally in the open space, as shown in ***Figure 6-20***. The speakers are hung from the structural ceiling and appear like acoustical panels. When the structural ceiling is high, as is typically the case, the uniformity of the sound can be as good as with a suspended ceiling. ***Figure 6-21*** shows panels hung in a customer support area. Not only are the panels decorative, they are acoustical absorbers as well as a source of masking.

6.1.10.5 Indirect Radiating – Under a Raised Floor

Raised floors have migrated from computer rooms to both open and closed offices. If the ceiling of an older building is acoustically hard with no plenum above, wiring and ventilation to offices is often accomplished with a raised access floor. These floors have certain advantages for sound masking. The sound attenuation of such a floor is much higher than that of a suspended ceiling, so it provides superior mixing (incoherence), and better diffusion of the sound masking. Masking from a suspended ceiling can be detected as coming from above even though a specific source cannot be detected, but that is not the case with under floor masking. We consider under floor masking superior to that above a suspended ceiling. The speakers that go into the floor cavity can be those that go above a suspended ceiling. If the cavity is less than 6 inches, the small plenum speaker must be used (***Figure 6-18***).

6.1.10.6 Indirect Radiating – Furniture Panel Mounted

Figure 6-22

Figure 6-23

The speakers are mounted at the junction of workstation panels and face upward. In that sense they are similar to open ceiling speakers except that they are typically mounted on panel systems near 60 inches high and radiate sound toward an open or suspended ceiling. ***Figure 6-23*** shows a furniture panel system with these maskers and ***Figure 6-22*** shows a close up of the masker. Each is a self-contained masker so there is no coherence problem, but they suffer all the limitations of distributed systems (5.3.2). The uniformity of the masking is completely dependent on where the speakers can be located, since workstation layouts do not always form an optimum grid for speaker layouts.

6.1.10.7 Direct Radiating-Ceiling Flat Panel Lay-in

Figure 6-24

The speaker has no intervening structure between it and the listener and faces downward toward the listener from a suspended ceiling. The intent with this design was to make the speaker invisible, since it looks like the surrounding ceiling tiles. Typical suspended ceiling heights put the speaker about 5 feet above seated listeners. ***Figure 6-24*** shows the top of a lay-in speaker made by one manufacturer. That particular speaker has six taps from ¼ watt to 8 watts. The author attempted to use similar speakers for sound masking in the 1980's and comparison tests showed that plenum speakers were much preferred by listeners. Aside from violating most of Design Rule Two (6.1.1), this speaker has several other drawbacks as noted below. This is not to say that flat lay-in maskers cannot be used beneficially; they can be effective with high ceilings and they fit into a plenum that is as little as 3 inches high.

Drawbacks:

1. *Invisibility.* Although the speakers can be made invisible visually, the close proximity to occupants, in particular standing ones (about 3 ½ feet away), it is quite obvious where the speaker is by listening.

2. *Cost*. Because of the complexity of design, these speakers are more expensive. For uniformity, the speakers need to be placed closer than plenum speakers, adding additional cost.

3. *Portability.* Moving plenum speakers to a new location is a matter of cutting wires and removing the wires and speakers. The system is not considered part of the building. To remove flat panel speakers, the now empty opening must be filled with a ceiling tile that matches the surrounding ones. This can be a problem because ceiling tiles change color with age.

4. *Level and Spectral Uniformity.* Uniformity of level and constancy of the masking spectrum throughout a zone is a critical factor that is very difficult to meet with flat lay-in panels; the physics of flat panel radiation precludes it. To increase spatial uniformity, the manufacturers have made an enormous effort to overcome this difficulty. Further, speakers must be spaced closer. If not designed properly, a listener walking between speakers will experience both a level change and a spectrum change.

5. *Suspended Ceiling*. These speakers require a suspended ceiling to function so their applicability to other locations is very limited.

6. *Speaker Layout.* Suspended ceilings have a number of penetrations, including return air grilles, supply grilles, light fixtures, sprinkler heads, and security detection devices. To design a system with flat speakers, all relevant drawings must be accessed. It is very difficult to create a uniformly spaced speaker array with all these penetrations.

7. *Phasing.* Since these speakers are direct radiating, alternate speakers must be incoherent. (6.4.1.3). A two-channel system is mandatory.

8. *Shadowing*. In open offices with higher panels (66 inches or higher), the direct field of the speaker can be shadowed by the panels, resulting in noticeable non-uniformities in masking level (7.5.4).

6.1.10.8 Direct Radiating - Ceiling Face Down Speaker

Figure 6-25

This speaker has no intervening structure between it and the listener and faces downward toward the listener from a suspended ceiling as does a typical paging speaker. Originally, paging speakers were used to create sound masking. It was not a success since it violated Design Rule Two (6.1.1). Recently, a masking system with a very small face-down speaker, ***Figure 6-25***, has been introduced. The masking spectrum is more like pink noise (3.1.6) and the speakers are located quite close together. This system also violates Design Rule Two. Some of the disadvantages are similar to those for the flat lay-in panel (6.1.10.6). Because the speaker is about two inches in diameter, it lacks low frequency sound, limiting its ability to blend with the existing background sound.

6.1.10.9 Direct Radiating – Furniture Panels

This speaker is mounted directly on the surface of a workstation panel. They are small self-contained maskers, such as personal maskers, that can be hung on a workstation panel. They are under the control of the person in the workstation, so they bypass Design Rule Two. There are vibration transducers that can be built into a panel and powered by a local generator or controlled centrally, so they are not under the control of the occupant. This application is not common and normally the system is installed by the user (7.5.5). We call them *task maskers*.

6.1.10.10 Direct Radiating – Ducts

When all preferable locations fail, it is possible to use the supply air ducting system as a source of sound masking. This application is restricted to metallic ducts. The best speaker to use is a vibration masker fixed to the outer wall of the duct (8.6.5); the duct wall becomes a loudspeaker. Some sound will radiate into the plenum or cavity into which the duct is placed, but the internal sound will radiate from the air diffusers. There are duct loudspeakers that are mounted on the outer surface, but penetrate the duct wall (rectangular only) and radiate sound directly into it, with little sound outside. This speaker is preferable for ducts that are in open ceilings. It is not recommended that any speaker be placed *inside* the duct; wiring can be a problem and it interferes with airflow. The uniformity of duct sound masking in open areas depends on the air diffuser spacing and ceiling height, but generally it is acceptable with high ceilings, either suspended or open to the structural ceiling. The one positive aspect is that listeners tend to accept the masking as part of the air handling system noise, and in warm climates this translates subjectively to good air conditioning. Sound masking is not recommended for use in ducts under raised access floors in open areas, as the presence of furniture causes severe non-uniformity of the levels. Duct masking can work well in closed offices, as uniformity is a lesser consideration.

A very unusual application occurred in a warm climate. In a large warehouse store with high ceilings, duct sound masking was used to augment the sound of air conditioning. Apparently, the additional sound allowed the thermostats to be set several degrees warmer with no adverse response from customers. It was estimated that operating cost savings were significant.

6.1.10.11 Direct Radiating – Simulated Ducts

There are situations with closed rooms that have gypsum board ceilings and no supply air ducts. In several cases, a false air diffuser was placed in the ceiling and a self-contained masker was placed in the plenum above the cavity. Power was fed to the masker from the light fixture.

6.1.10.12 Indirect Radiating – Under Furniture

In very small applications, it is possible to place sound masking under furniture, on shelves, or in other locations where the speaker is not visible and the sound is better diffused through the space. Self-contained maskers generally are used here. This has been done in some medical consulting offices and waiting rooms. It is recommended that a more extensive sound masking system be designed when possible.

6.1.10.13 Direct Radiating – Workstation Surface

A vibration transducer is mounted on the undersurface of a table or under panel mounted work surface. The masking is radiated from the surface providing local masking for the occupant. This application is not common but does work (7.5.5). These are also task maskers.

6.1.10.14 Indirect Radiating-Tackboard Surface

Figure 6-26

A vibration transducer or a small self-contained masker is mounted on the back surface of a workstation tackboard. The tackboard is mounted on a workstation panel but is set off so that the masking radiates around the periphery of the board to provide local masking for the occupant. These task maskers are not in the market but they do work (7.5.5).

6.1.10.15 Direct Radiating – Walls

When all preferable locations fail, it is possible to mount masking speakers high on perimeter walls and point them up at either a suspended ceiling or an open ceiling. This works best in high open ceilings with no sound absorbing materials. However, masking uniformity is compromised in large rooms. The speaker should be one that can be pointed upward at an arbitrary angle such as that shown in ***Figure 6-26***, not facing directly outward or downward. Most of Design Rule Two is violated.

6.1.10.16 Indirect Radiating-Above Gypsum Ceiling

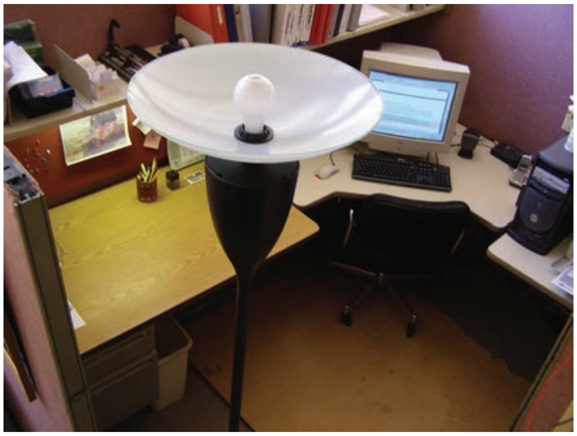


Figure 6-27

It is possible to mask through gypsum board ceilings. Like access floors, the speakers can be spaced further apart. Access to the plenum is the problem. On new projects the speakers must be installed and tested before the ceiling is installed. Paging has been done through gypsum board ceilings, but the generator must be able to make white noise and the equalizer must have a good dynamic range.

6.1.10.17 Indirect Radiating – Free Standing Maskers

Figure 6-28

There are several workstation designs that are not enclosing, but free standing. There are occasions where spatially uniform masking is not desired, but rather localized masking for a few workstations. A freestanding task masker would be applicable to this situation. ***Figure 6-27*** shows such a device. It is an indirect light fixture but below it is a loudspeaker that radiates uniformly in the horizontal plane. It can be used for paging, music, or masking. The signal is derived from a wireless transmitter, typically placed above the suspended ceiling. The wireless advantage is that no audio wiring is required, and the task masker can be moved freely.

6.1.10.18 Direct Radiating – Picture Maskers

As with worksurface maskers (6.1.10.12), a vibration transducer affixed to the back of a painting or picture will radiate sound. ***Figure 6-28*** shows an example. A painting in a workstation is an attractive decorative feature as opposed to a loudspeaker grille. It can be used for masking, paging, or music. As yet, there are no wireless features for such a masker, so hard wiring is needed. There are other possible locations for such maskers: along walls in open office areas, in corridors, or in closed offices.

6.1.11 Using a Distributed System (Self-Contained Maskers)

A number of early systems (vintage 1970) were of this type. They were easy to manufacture but lacked the requirements given in the present standards. Evolution of these systems has improved their functionality, but the basic components retain the same limitations (5.3.2, 5.4.1).

6.1.11.1 The Masker

Figure 6-29

Figure 6-30

Figure 6-31

Each masker is self-contained. It has a generator (typically pink noise), an equalizer of limited capability (typically a low pass filter), an external level control for the small power amplifier and a loudspeaker. Most are powered by low voltage, but some can work on 110VAC. The latter are used on very small projects. ***Figures 6-29 to 6-31*** show examples of these maskers. The masker in ***Figure 6-31*** is the 110VAC version, but a 16VDC version is also available.

6.1.11.2 Power Supply

Most maskers are used inside a plenum so low voltage AC power is used most often. A receptacle with 110 or 220VAC power is needed in the plenum. The power supply converts that voltage to low voltage DC power. A multiplicity of power receptacles must be distributed throughout the masked area for large offices, since the capacity of DC power supplies is limited. A wiring distribution network for the low voltage is needed.

6.1.11.3 Music or Paging

Some maskers have an input for these signals. The source equipment must be centralized and a separate audio wiring distribution network is needed.

6.1.11.4 Controls

The maskers have local controls, some on the side and some on the bottom. A discussion of the limitations of these controls is given in Sections 5.3.2 and 5.4.1.

6.2 Normal Speaker Arrays

CAUTION: Most of this section relates to rooms that have a suspended ceiling with an open plenum above, a completely open ceiling or a raised access floor. These are the most common situations so are called normal arrays.

6.2.1 Indirect Radiating Speakers – Array Concepts

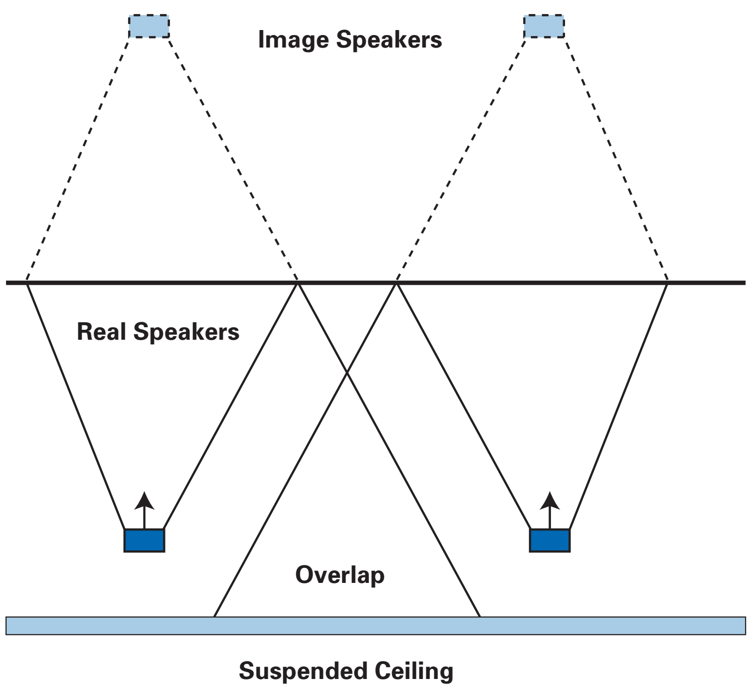
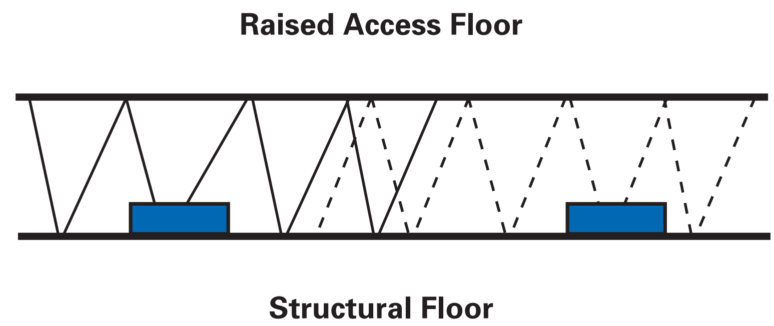


Figure 6-32

The objective in spacing speakers is to maximize spacing (to minimize cost) while retaining spatially uniform levels throughout the masked area. This is best accomplished in a ceiling plenum or open ceiling by having the speakers face upward to reflect from the structural ceiling. *Figure 6-32* shows a schematic. The best overlap of the speakers occurs when the **speakers are as low as possible**. If the structural ceiling is very high, the overlap is accomplished with the speakers spaced further apart. Materials that absorb sound, either on the structural ceiling or lying on the suspended ceiling reduce the levels, change the sound spectrum contour, so they must be accounted for, even though their effect is small. Not shown are the multiple reflections within the plenum that increase incoherence of adjacent speakers, and improve diffuseness of the sound field. All reflections feed back on the loudspeaker, reinforcing speaker output at some frequencies and inhibiting it at others. This is another reason that one-third octave band equalization is strongly recommended. Eliminating peaks and notches with the equalizer creates a smooth masking spectrum that is important to acceptability.



RAISED ACCESS FLOOR MASKING

Figure 6-33

In under floor masking, ***Figure 6-33***, the speakers are laid directly on the sub-floor facing upward. Because the sound transmission loss of the floor is much greater than that for a suspended ceiling, and is very reflective, there are a number of strong sound reflections in the cavity (like a small reverberation room). The coherence between speakers is greatly reduced when it appears at the listener. The diffuseness of the sound is generally so great that listeners are unable to locate the source of the masking.

The suspended ceiling (or access floor) acts to create these smoothing reflections so its sound transmission properties are important, sound absorption being less so. The greater the transmission loss, the more diffuse and uniform the sound field is for the listener. It should be noted that the transmission loss of gypsum board is similar to access floors; so masking speakers can be placed beneficially above gypsum boards.

The character of the room plays a role in the smoothing and diffuseness of the sound masking. The higher the height of the suspended ceiling the more uniform the sound field will be and greater speaker spacing is possible.

6.2.2 Spacing Data for the Three Most Common Indirect Radiating Locations

Masking speakers must be spaced so that the level is as uniform as possible over the area masked. The optimum spacing is determined by the choice of location (6.1.9); optimum meaning adding the fewest speakers to achieve the desired uniformity. Below are listed the factors that control the spacing for each of the three major locations. The following data are needed:

6.2.2.1 Ceiling Plenum

1. The height of the suspended ceiling.

2. The height of the structural ceiling; it determines the height of the plenum.

3. The material of the suspended ceiling.

4. Whether there are sound absorbing materials within the plenum

5. Whether the plenum is open or divided by walls to the structural ceiling.

6.2.2.2 Open Ceiling

1. The height of the structural ceiling.

6.2.2.3 Access floor

1. The height of the raised floor.

6.2.3 Defining Zones and Getting Room Dimensions

6.2.3.1 Choosing the Area for a Speaker Array
Zone the project (6.1.9) and get the dimensions for each zone.

Common Room Shapes

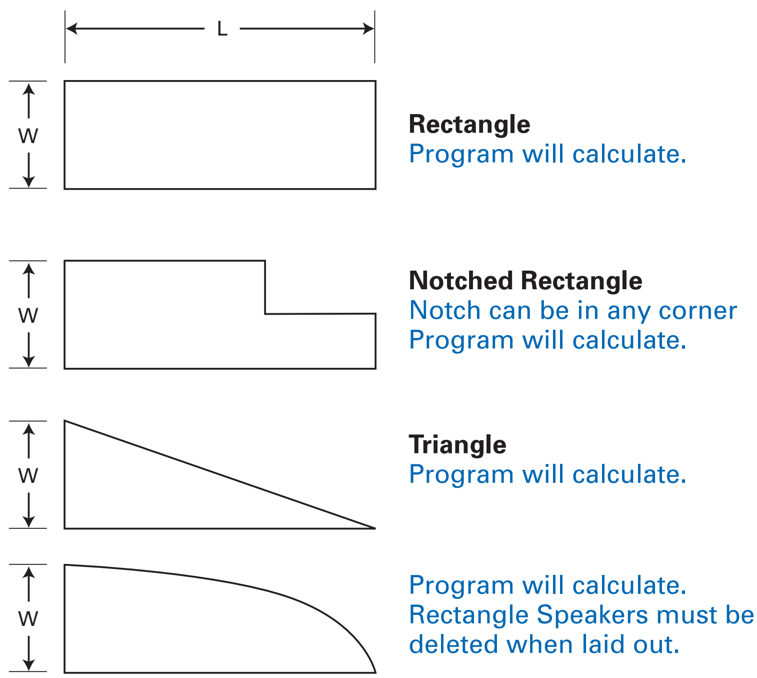


Figure 6-34

6.2.3.2 Handling Various Room Shapes
Rooms requiring sound masking come in a number of shapes. Several of the more common shapes have been put into MDesign (6.5) to simplify creating speaker arrays. These are shown in ***Figure 6-34***. Rectangular rooms result in a rectangular grid of speaker rows and columns. The triangular room results in several rows, each of which has fewer speakers. The notches in the notched rectangular room can be placed in any corner. It results in two speaker rows and columns, one for the larger area and one for the notched area. For irregular rooms, the maximum dimensions should be analyzed as a rectangle. The excess speakers must be deleted when translating the layout to a drawing.

In any of these areas, it is possible to have interior areas within the zone that will not have sound masking, such as closets and bathrooms. The excess speakers must be deleted.

When there are adjacent areas that do not need masking, such as connecting corridors, use the concept of Soundscaping (6.3.1) to add additional speakers to that zone.

6.2.3.3 Translating Room Dimensions from, or to, Drawings

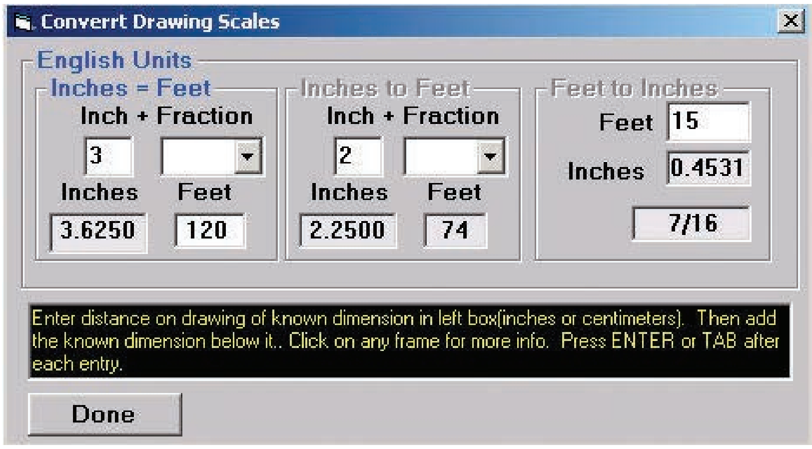


Figure 6-35

The MDesign program includes a module that can be used for determining the dimensions of objects in a printed floor plan when the plan is not to scale. Either obtain the dimension of a room or building or find an object for which the dimension is known (e.g. a doorway). Measure the distance on the plan in inches and fractions of an inch, such as shown in ***Figure 6-35***. The building length was 120 feet and the plan distance was 3 inches. The conversion factors are then calculated. The dimension of one zone was 2 inches; the program showed the length was 74 feet.

The first step is to define the boundaries of zones, based on the various design factors (6.1.9). In ***Figure 6-36***, next page, the room was divided into two zones of open office workstations. One zone is shown in the figure. Using the scaling module, the lengths of the zone boundaries were determined. The zone is notched. To use the MDesign program module, the largest dimensions of the room must be measured. In this case, it was 150 by 67 feet and the size of the notch was 102 by 22 feet. Note that this notched rectangular zone extends beyond the building boundary.

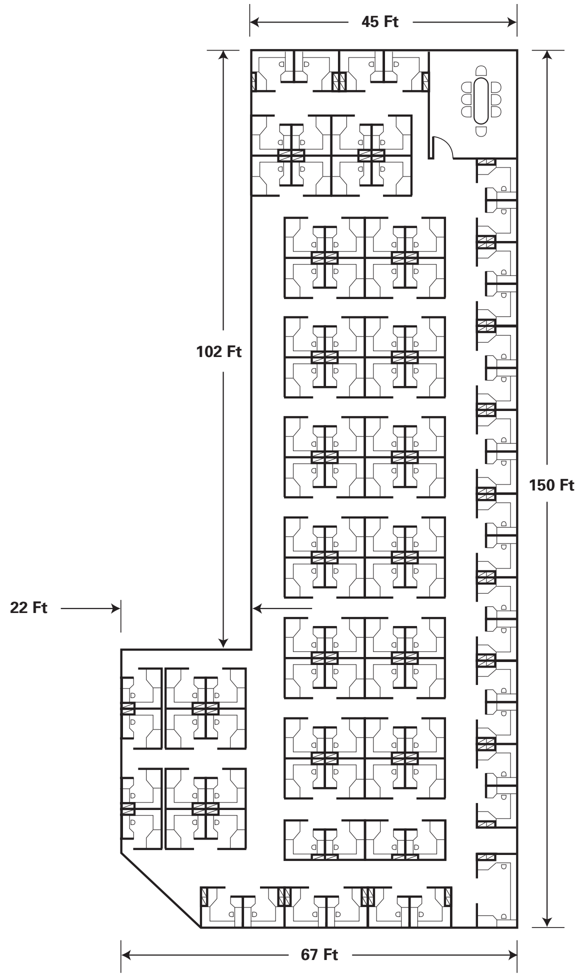


Figure 6-36

6.2.4 Using Software to Create a Speaker Array for Common Locations

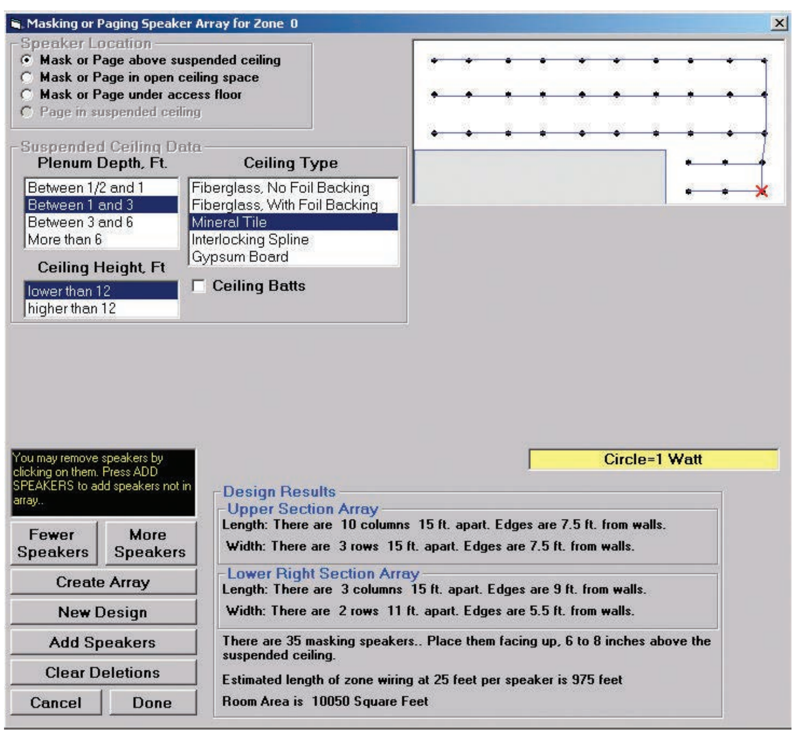


Figure 6-37

The acoustics of locations where masking speakers are located is sufficiently complex that no simple formula for hand calculation may be applied. The MDesign program includes a module that requires the data listed above (6.2.2) to function; it uses historically successful field results as the basis for conservative spacing rules rather than theory. The program creates a speaker array in rooms with the shapes noted above. (6.2.3.2). The speaker array is rectangular with the end spacing set as close to ½ the normal spacing as possible to fit into the room dimensions. ***Figure 6-37*** shows an example of an array for a notched room. Because of the notch, two arrays are required, but they are connected in a tree wiring design. The module provides estimates of amount of wiring required for the zone.

The array module can be used for speakers in a ceiling plenum, in an open ceiling, under an access floor, and for face down paging speakers.

There are occasions in which cost constraints dictate using fewer speakers, and that option is included, as well as one to increase the number to ensure additional uniformity. It is always possible to start the design over at any time. If additional speakers are needed for this zone but do not appear in the array, "Add Speakers" can be pressed. These will be added to the total number of speakers in the equipment list but will not appear in the array. A typical reason for such an addition is Soundscaping in an adjacent corridor.

Running the cursor over the speaker array will show the current location of the cursor in feet. If the cursor is positioned directly over a speaker, a box will open allowing the user to delete the speaker from the array. The speaker count will be reduced by one. In this way, for example, the unneeded speaker in the lower left corner of ***Figure 6-37*** is be deleted. If the deletions are erroneous, pressing "Clear Deletions" will restore the original array, and other deletions can be entered.

6.2.5 Connecting the Array to the Drawings

SECURE SOUND
PRINT DATE: Wednesday, August 09, 2006 FILE NAME: HARTFORDB100.RCK FILE DATE: Wednesday, Augu
MASKING SPEAKER LAYOUT
FOR THE HARTFORD
OVERALL DIMENSIONS: Length: 150 ft Width: 67 ft. Actual Area: 8994 sq ft

DIRECTION	DIMENSION	NR ROWS	SPEAKER SPACING	END SPACING
LOWER AREA				
Length	150 ft	10	15 ft	7.5 ft
Width	45 ft	3	15 ft	7.5 ft
UPPER LEFT AREA				
Length	102 ft	3	15 ft	9.0 ft
Width	45 ft	2	11 ft	5.5 ft
Number Speakers:	30			
Zone Number:	2			

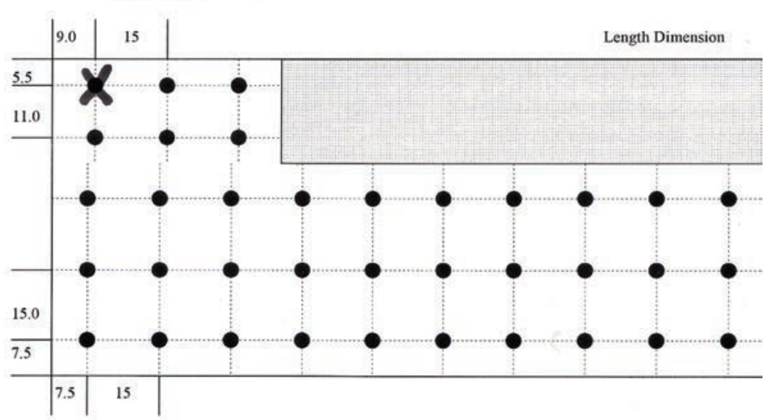


Figure 6-38

If the array module is called from other design modules, it is possible to print it. ***Figure 6–38*** shows the print for a design with a speaker deleted. It can be on paper or in electronic format if Acrobat™ is installed. It provides all the information an installer will need to properly install the speaker array. The print is tied to the drawing by Zone number. It should be necessary to transfer the array to the drawings only if called for in a specification.

6.3 Special Speaker Arrays

6.3.1 Soundscaping

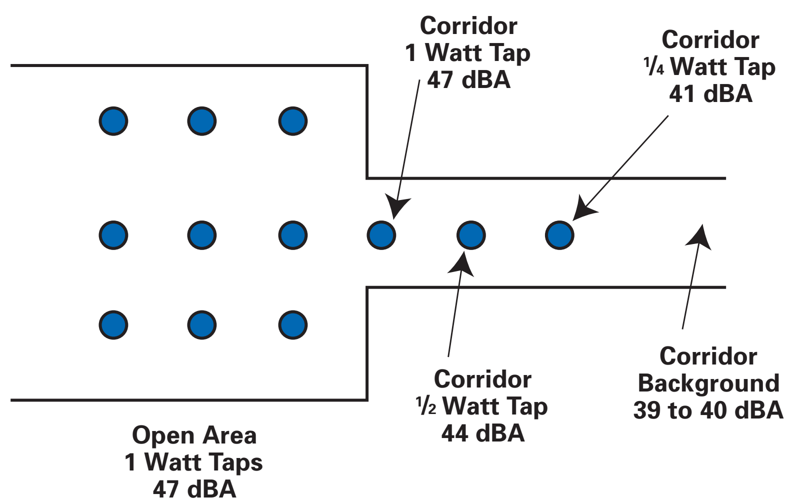


Figure 6-39

To minimize hearing masking level changes when occupants move from a masked area to an unmasked area, the concept of Soundscaping should be applied. Masking speakers are added to join the two areas. ***Figure 6-39*** shows a corridor connecting to a masked area. Speakers are added to the corridor, and the taps are set lower sequentially to smooth that change. The speakers used for this purpose are not included in the layout software so must be added separately.

6.3.2 Corridors

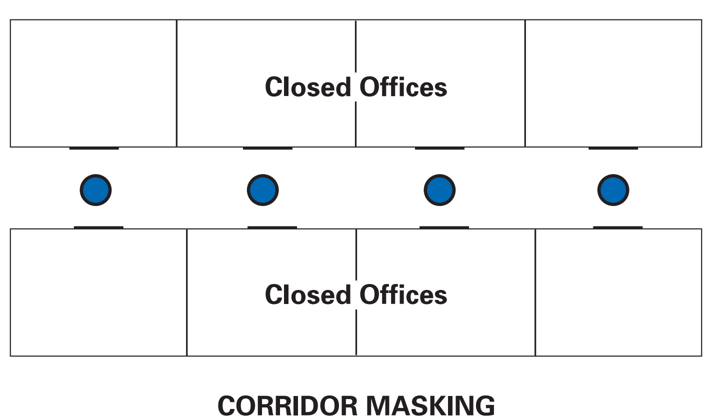


Figure 6-40

Because corridors are much narrower than occupied spaces, it is recommended that speakers above a suspended ceiling be spaced at 12 foot intervals. Since a corridor is similar to a small room, it is recommended that the overall masking levels be limited to 44 dBA.

There are cases where closed offices have high STC walls that extend to the structural ceiling; attorney's offices are examples. Masking is not needed in the offices, but Confidential Privacy from the corridor is desired, so sound masking speakers are added as shown in ***Figure 6-40***. In this case, it is best to place the speakers in front of the office doors, or midway between opposing doors if they are not symmetrical.

When cost considerations are paramount and the ceiling plenum is open, it is possible to achieve Confidential Privacy between the closed offices as well as from persons in the corridor. Masking levels in closed offices are recommended to be about 3 to 4 dB lower than in open areas. If the levels in the corridor are set at open office levels, the spillover can provide that privacy with fewer speakers. The drawback of this approach is that corridor levels need to be higher than recommended.

6.3.3 Double Use of Speakers

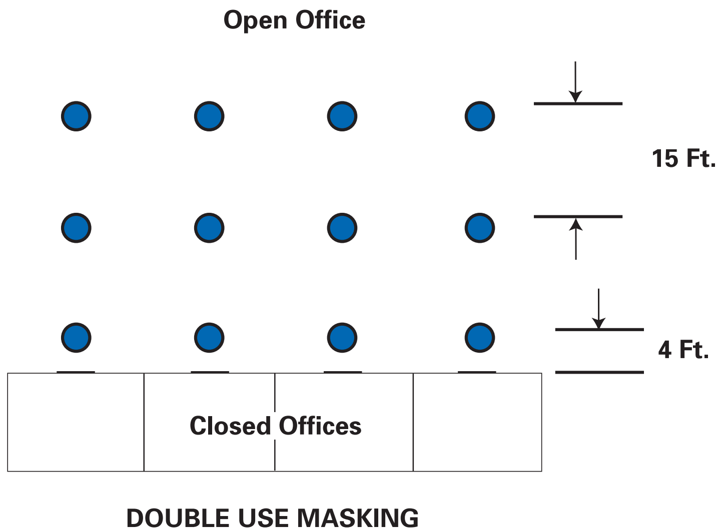


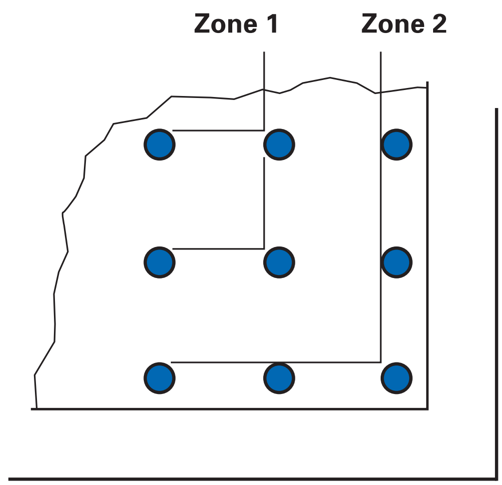
Figure 6-41

In some smaller projects, there are closed offices adjacent to an open office area, but the size of the project makes multiple zones too costly. The concept noted in Section 6.3.2 may be used here, provided the ceiling plenum is open. The row of open office speakers next to the closed offices provides Confidential Privacy between closed offices as well as from the closed offices to the open office. The speaker array is shifted so that the speakers nearest the closed offices are placed 4 feet from the closed office walls, as shown in ***Figure 6-41***.

6.3.4 Walls to Structural Ceiling

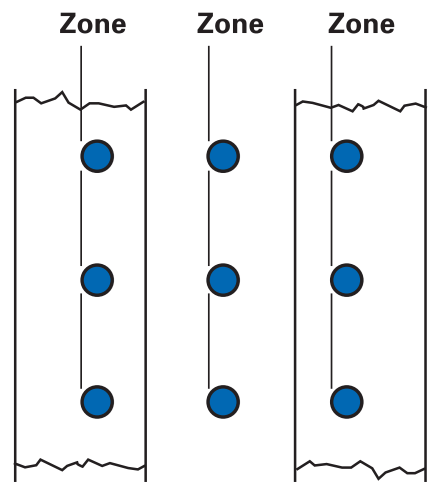
The speaker layout software does not handle a case where the walls between closed offices extend to the structural ceiling. If masking is desired in those rooms, the speakers must mask each room individually. Often Confidential Privacy is desired from corridors, so speakers are placed there. It is recommended that wire runs to each office be from the corridor so that no penetrations between closed offices occur.

6.3.5 Discontinuous Suspended Ceilings



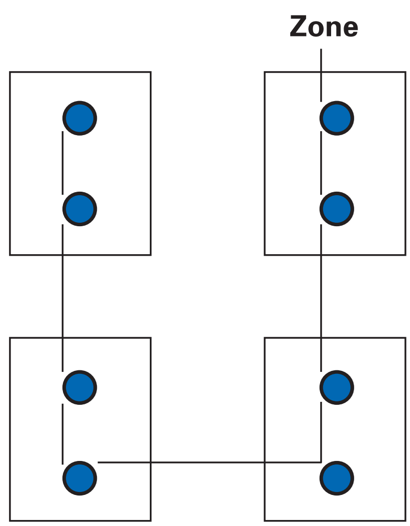
PERIMETER OPENING

Figure 6-42



LINEAR OPENING

Figure 6-43



CLOUDS

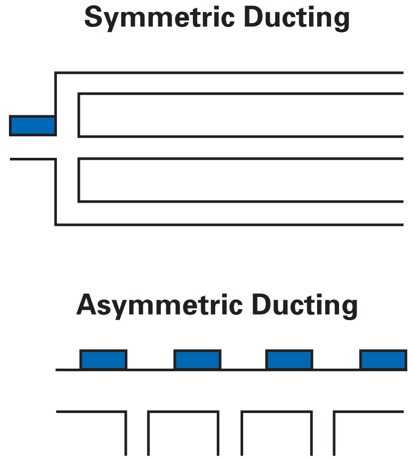
Figure 6-44

When the suspended ceiling is discontinuous, it is not possible to create spatially uniform levels over the area. ***Figure 6-43*** shows a linear array of open ceiling between two rows of suspended ceiling over closed offices. The open area should be zoned separately. It is tempting to simply make one zone and set the speaker taps in the open area one setting higher (3 dB). This reduces flexibility in setting independent levels in each area. ***Figure 6-42*** shows an open ceiling around the perimeter of the room; the speakers should be at least 4 feet back from the edge and zoned separately. In this case, since there are no differences in office function, it is possible to reduce to only one zone by tapping the outer speakers one setting lower. ***Figure 6-44*** shows "clouds" within the room; they should be at least 4 feet from the edge, but nothing is gained by separate zoning, or tapping, unless the gaps are very large.

6.3.6 Ducts

There are two basic designs for sound masking of ducts. *Figure 6-45* shows both. If the ducting is a symmetric tree structure with few diffusers, such as might occur in a small office, a masker can be placed at a central location. This works well in small metal ducts that have little sound attenuation, so levels at the further locations are not much less than those closer in. The masker tap should be 2 watts. It is not recommended for fiberglass ducts.

In larger facilities, the ducts may be long and lined with sound absorbing materials. In that case, it is recommended that the pattern for Asymmetric Ducting as shown in the figure be used. The maskers are set at the midpoint between air diffusers. The maskers should be centrally set. Vibration maskers are recommended for application to rectangular metal ducts.

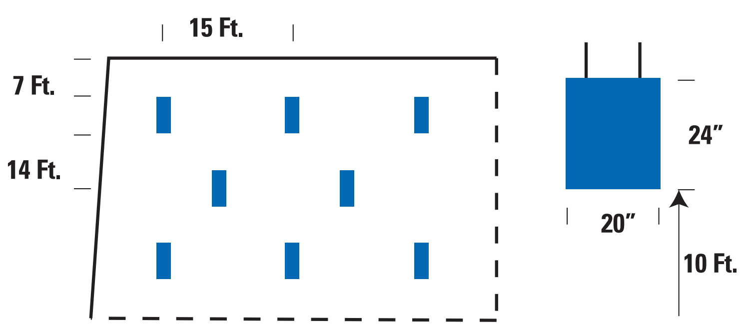


DUCT MASKING

Figure 6-45

6.3.7 Open Ceilings

It is possible to hang sound masking speakers vertically in a room with no suspended ceiling. *Figure 6-46* shows an example layout. The speakers are hung 10 feet high; they are spaced 15 feet in one direction and about 14 feet in the other (exact spacing depends on structural ceiling height). The rows are staggered to offset the directional characteristics of the speakers. One possible advantage would be to mount the speaker on a sound absorbing panel, since large rooms tend to be more reverberant (6.1.10.4).



VERTICALLY HANGING MASKING SPEAKERS IN AN OPEN CEILING

Figure 6-46

6.3.8 Few Closed Rooms in Large Open Offices

When a few closed rooms, such as managers' offices or conference rooms, are embedded in a large open area it is impractical to assign a special zone to them. The speaker array for the open area should extend to these rooms. The speaker tap for the closed offices should be set one step lower to yield a level 3 dB lower than the open office. The speaker tap for conference rooms should be set to "Off", since masking is not needed there. But masking speakers should still be installed so when the conference room is later changed to an office, the speaker can be activated.

6.4 Wiring Designs

6.4.1 Wiring for 25 or 70 Volt Systems

These systems are wired in parallel, much like the wiring systems for power distribution. There is one line and each speaker is connected to it. There are three methods for centralized systems: daisy chain, tree, or checkerboard.

6.4.1.1 Daisy Chain

There is one wire run and it passes by every speaker in the zone as shown in ***Figure 6-47***. The current required for the last speaker in the chain is carried by the wire connected to the first speaker. The voltage at the last speaker will be less than that for the Tree method. For smaller zones, the difference in these two methods is not significant.

6.4.1.2 Tree

This method is shown in ***Figure 6-48***. The advantage is that the wiring branches out so as to minimize the current in any branch and is the recommended design and installation method.

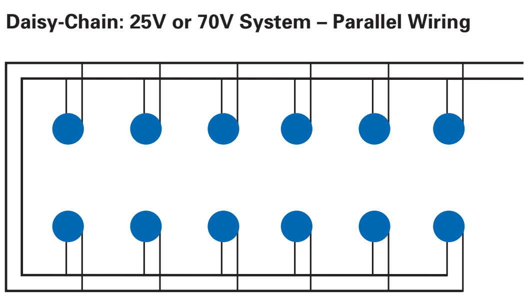


Figure 6-47

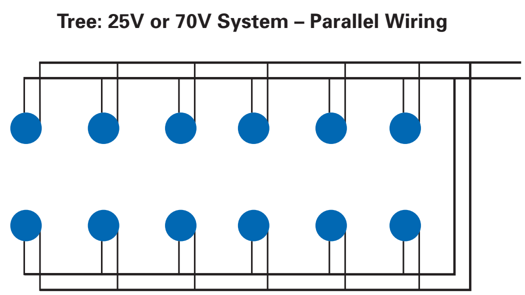


Figure 6-48

6.4.1.3 Incoherent (Checkerboard)

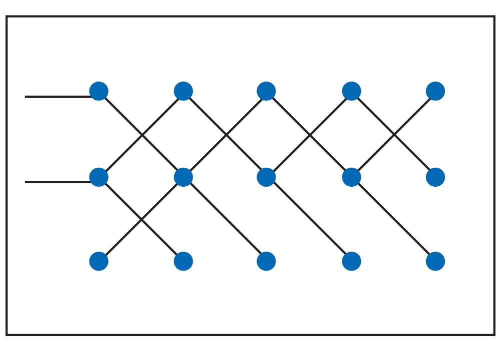


Figure 6-49

This method is required for systems that utilize the concept of incoherence between nearby speakers. It requires two independent channels of masking fed through two home runs to the zone. Every other speaker is connected to the other channel as shown in ***Figure 6-49***. It is clear that more wire is required and that care must be taken in making sure the wires are connected to the correct speakers. The advantages and limitations of this design are discussed in Section 6.1.7.1. Since the diagonally spaced speakers are still on the same channel, the incoherence benefit is only reduced, not eliminated. Some systems have multiple incoherent channels to further improve the benefit of incoherence.

6.4.2 Wiring for Eight Ohm Systems

6.4.2.1 The Problem

This system requires a combination of series parallel wiring to maintain a reasonable impedance for the amplifier. There are two methods, modified tree and checkerboard. The latter method is required for incoherent systems and is simply a duplicate of the tree method described below. The design of a multi-speaker array depends critically on the number of speakers involved, which is why this system is avoided in most cases. The equation for parallel-series design of the wiring is:

$$R_t = \frac{1}{\sum_{n=1}^{m} \frac{1}{R_n}} + \frac{1}{\sum_{n=1}^{p} \frac{1}{R_n}} + \ldots$$

R_t is the total resistance seen by the amplifier and R_n is the resistance of each speaker. For example, the first term represents the resistance of *m* speakers connected in parallel. The addition of each of these terms in series results in the total resistance. The designer's job is to arrange the *m* and *p* quantities so that the total resistance is within the limits of the amplifier (the word "resistance" is used here for illustrative purposes). Even if the designer were a mathematician, the solution would have to be by trial and error for each zone with a different number of speakers.

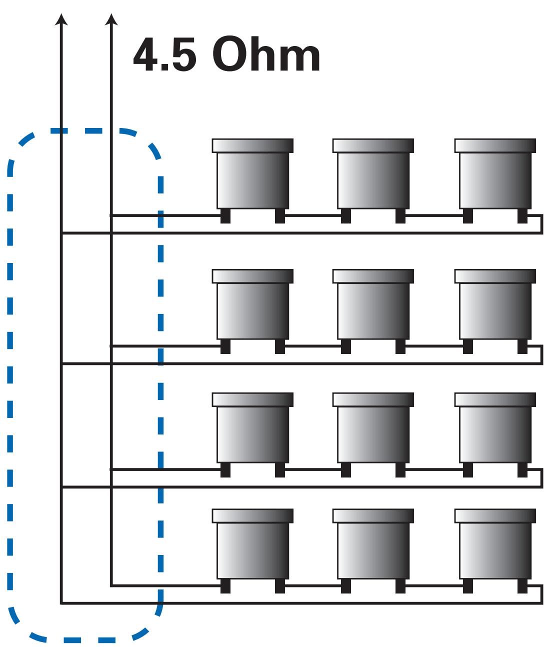


Figure 6-50

Low Impedance System – Series Wiring

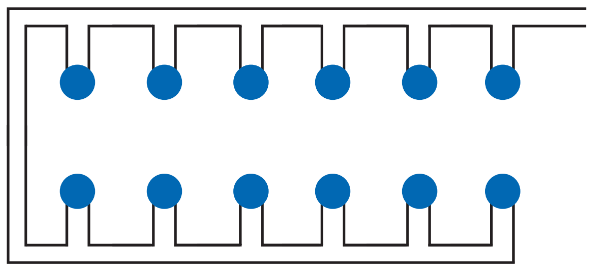


Figure 6-51

Low Impedance Systems – Parallel Wiring

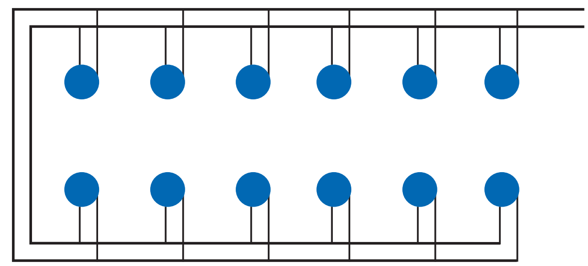


Figure 6-52

Masking speaker layouts are rectangular arrays of columns and rows. Should the columns be in parallel or series to get the proper resistance? For a zone with 12 speakers of 8 ohms each, 3 parallel paths of 4 speakers connected in series would yield a resistance of 6 ohms. Parallel-series wiring is shown in ***Figure 6-50*** where there are 4 parallel paths of 3 speakers connected in series for a resistance of 4.5 ohms. ***Figures 6-51 and 6-52*** show the two extreme designs. Although it is possible to design a wiring layout similar to those shown, it is not simple to get an installer to carry out the design, particularly if the 12 speakers are laid out in six columns of two speakers each. Wiring errors will result in different sound levels between speakers, violating Design Rule Two. As a result, 8 ohm systems should be designed only for smaller applications where the added wiring complexity will not create problems.

6.4.2.2 Using Software

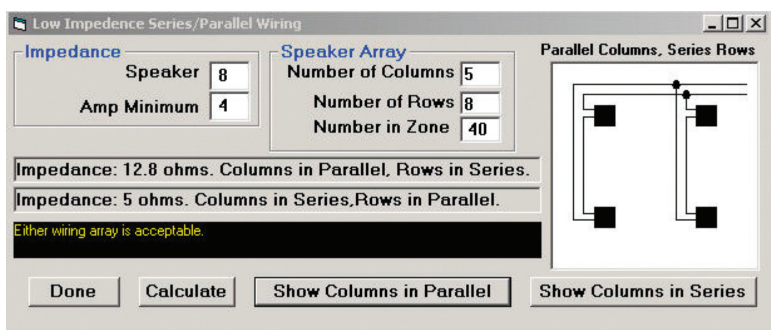


Figure 6-53

The MDesign program has a module that will calculate the resistance for a rectangular speaker array of columns and rows for two conditions: (1) columns wired in parallel and rows wired in series, or (2) columns wired in series and the rows wired in parallel. The speaker impedance, and minimum impedance load for the amplifier, is entered, as well as the number of columns and rows. The program will calculate the impedance for each wiring configuration as shown in ***Figure 6-53***. In almost all cases, a suitable result will be found. If the array is irregular, the program will not be helpful.

6.5 Computer Aided Design and Costing

Since there are many design variables and cost/performance tradeoffs, a computer program, called MDesign, has been written to assist in the design and costing of a sound masking system that covers most, but not all, situations. It is restricted to 70 Volt systems. Several of the design modules permit the screen or the data to be printed. If the user has Acrobat™, these prints will be in electronic format. If the user has Microsoft Word™ and

Excel™, he will have more options. Excel™ is used to store cost and price breakdowns to a file. Word™ is used to call a number of documents to the screen. All data can be saved to a file and later retrieved. The user must enter client data first, so the project will be clearly defined later. Almost all of the products are manufactured by Atlas Sound™.

CAUTION: MDesign uses Microsoft Windows™ and uses Access™ for the product database. If Access™ is not installed, the program will not work.

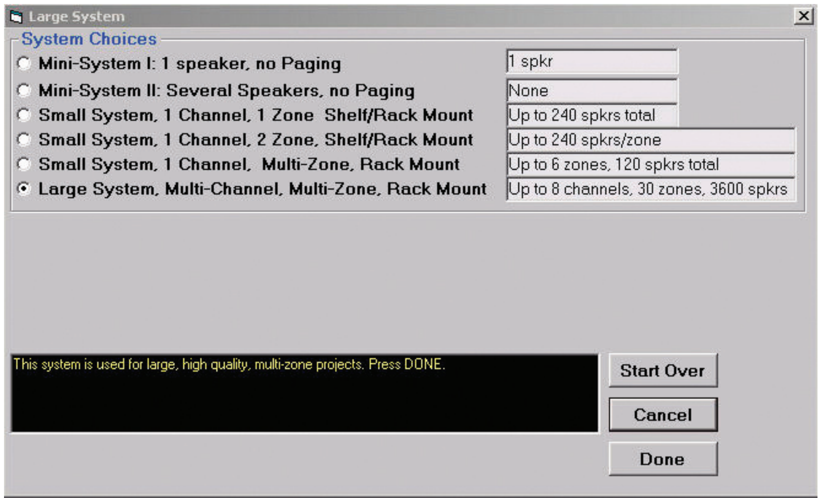


Figure 6-54

6.5.1 Choosing System Size

The choice is roughly based on the area of coverage (the number of speakers in the system). The approximate number of speakers can be estimated by dividing the area in square feet by 225 (15 foot spacing). A secondary consideration for small systems is whether there is an unusual or special use where self-contained maskers may be needed.

There are six size choices in the program. The first two are for very small distributed systems using the AM1100 series of self contained maskers. The next three are for small centralized, one to six zone systems. The size is small enough so that the control equipment can be mounted on a desktop, shelf, or in a small rack cabinet. The last choice is for large multi-channel, multi-amplifier, multi-zone applications. The descriptions below relate to choosing the system in the MDesign program. ***Figure 6-54*** shows the screen for system choice.

6.5.1.1 Mini-System I

This system contains only one self-contained masker, the AM100-LH, which is powered from a local AC outlet. It is the type of system that is used for the interior of a room, such as a small waiting area, or a home with coverage in the low hundreds of square feet. To keep costs reasonable, all controls are on the unit and the equalization is limited to low pass filters. It is essentially a one channel, one zone system. Since such a small system may not be well hidden, the user may have access to the controls. If this system is chosen, no further equipment data need be entered.

6.5.1.2 Mini-System II

This system contains several self-contained maskers, the AM1100-16VH, which are powered with low voltage AC from a power supply, the PS16-40AC. The power supply will handle up to seven maskers. It is a distributed system and is practical for areas up to 1500 square feet. It can be multiplied several times over to create a larger distributed system. Since each unit has an independent masking generator, it has as many channels of equalization as maskers and since each speaker is a zone unto itself, it is very adaptable to special situations. It does not meet ASTM standards, nor would the user have ready access to any controls. If this system is chosen, only the number of speakers desired need be entered. A speaker array can be calculated and printed for this choice.

6.5.1.3 Small System

This system is a smaller centralized system, and is restricted to a maximum of six zones. There are seven generator choices:

ASP-MG24
ASP-MG24 + Level Control Scheduler
GPN1200B
AA120M+SMG
AA120M + SMG + EQM131

These products are described in Section 5.3. The first three choices are generators chosen by the user and amplifiers up to 240 Watts chosen by the program. The latter two choices are 120 Watt amplifiers with built-in masking generators. The last choice permits an external equalizer to be linked to the generator/amplifier.

The first three choices could be used to mask up to 50,000 square feet as one zone. Zones this large are NOT recommended. Two zone systems can be created with the first three choices and meet ASTM standards.

The number of speakers for each zone must be entered. The speaker layout module is available to create speaker arrays. The M1000 Speaker (5.4.6) is chosen normally. A check box is available to use low profile speakers (5.4.6) in case the speakers are to be placed in a ceiling plenum, or under floor cavity, that is too small for standard speakers. There are four choices for housing the equipment:

1. *None*. The equipment is placed on a desktop, or an existing shelf.
2. *Open Shelf*. The equipment is placed on an open shelf mounted on a wall.
3. *Closed Shelf*. The equipment is placed in a closed shelf mounted on a wall.
4. *Rack Cabinet*. The equipment is placed in a rack cabinet.

6.5.1.4 Large System

Large systems can be of any size conceptually, but are limited by the choices within the program related to the number of channels, zones, and amplifiers. It is restricted to two choices for generators: MG24, and MG24+ Level Control Scheduler. These choices insure that ASTM standards are met. The system can have up to eight channels of equalization, up to ten channels of amplification, and up to thirty zones. The CP700 two-channel amplifier has been chosen (5.4.4.1). To keep the levels precise, the E408-100 zone control has been chosen (5.4.5). This control is limited to 100 Watts, but seldom do masking speakers run at one Watt, so a 20% overage is permitted. This yields a maximum of 3600 speakers, if the zones are distributed equally. Since few zones will be at the maximum zone control capacity, system size will be limited to fewer speakers. The speaker chosen is the M1000 (5.4.6).

The generator and the number of generator channels must be chosen, as well as the audio function of each channel, (masking only, masking + page, page only or other auxiliary signal). The building plans must be consulted to go further. The generator channel to which a zone is assigned must be entered first. It is necessary to know the number of speakers, or the room dimensions for each zone. The entry for speaker number can lead to the speaker array module where the array can be designed. The M1000 speaker (5.4.6) is chosen automatically, but several other options are possible. A check box to use low profile speakers (5.4.6) is available, in case the speakers are to be placed in a ceiling plenum, or under floor cavity, that is too small for standard speakers

6.5.2 Cost Considerations for One and Two Zone Systems

System design is a tradeoff between cost and equipment performance. The performance aspects have been discussed, but which of the four system groups is most cost effective? Centralized systems using the ASP-MG24 generator are clearly necessary for large projects, since it meets all codes and standards. But what about the smaller one or two zone systems that are more frequent? As the system gets smaller, the cost of centralized components per square foot rises. At some point does a small centralized system become more cost effective than a large system, and when does the distributed system become more cost effective than the small system? Atlas Sound manufactures all the components for masking systems, so a cost tradeoff analysis was made for small *one-zone* systems. ***Table 6-1*** shows costs *relative* to the least expensive Atlas system for a given number of speakers. The systems with only generators had an amplifier size chosen to fit. It is clear that the Mini II system is not the most cost effective for even small projects, so it should be chosen for special situations only. The GPN1200B system is the least expensive for almost all sizes, but it does not meet ASTM standards, is a rack mount frame, has no paging, and requires an added amplifier. The AA120M system with a built-in amplifier does not meet ASTM standards either, but it is a one-unit package, handles several inputs, and is cost competitive at 35 speakers and above. The AA120M system, with an external one-third octave equalizer (EQM131), does meet ASTM standards and becomes cost competitive with GPN1200B above 35 speakers. The ASP-MG24 system is more costly than the AA120M series and is in a rack mount frame and requires an amplifier to operate.

The analysis suggests that, if ASTM standards need not be met for a one zone system, no paging is needed and cost is critical, the GPN1200B generator system may be used for up to 35 speakers. For slightly more cost, the AA120M system is recommended for up to 120 speakers. If ASTM standards are to be met, or precise equalization is needed, the AA120M with the EQM131 equalizer is recommended.

Another common small system is the two-channel, two-zone system. A *relative* cost comparison is shown in ***Table 6-2*** for those products that are best used for that application. Two AA120M units are required. For this application, the extra capabilities of the ASP-MG24 makes it very competitive with the AA120M systems.

System Speakers	Mini I	Mini II	AA120M	AA120M +EQM131	GPN1200B	MG24
1	1					
2		1.26	1.31	1.80	1	2.20
7		4.79	1.20	1.53	1	1.80
35			1.07	1.19	1	1.32
60			1.02	1.09	1	1.22
120			1	1.04	1.02	1.21
240					1	1.14

Table 6-1

Speakers	GPN1200B	AA120M	AA120M+EQM131	MG24
2	1	1.58	1.85	1.44
7	1	1.45	1.66	1.35
35	1	1.21	1.31	1.16
60	1	1.14	1.21	1.11
120	1	1.05	1.09	1.06
240	1	1.00	1.02	1.03

Table 6-2

6.5.3 Choosing Large System Functions

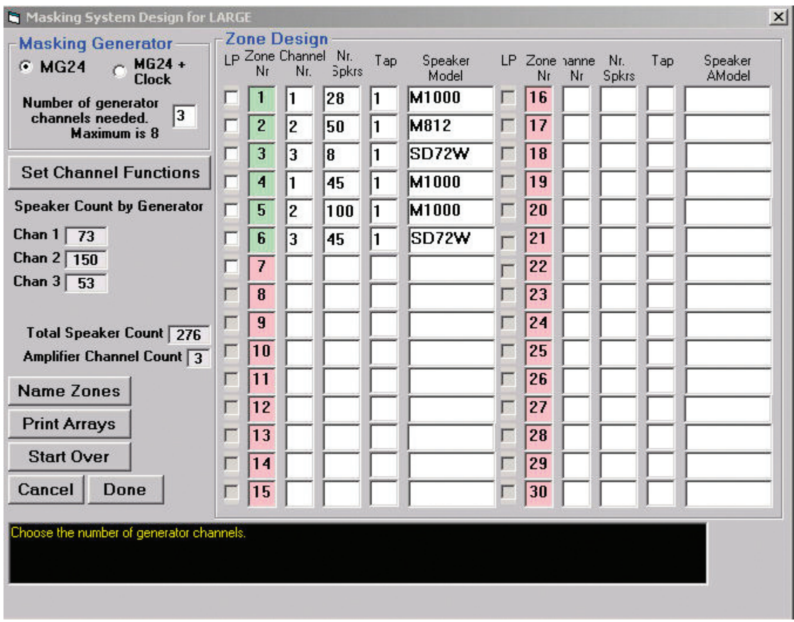


Figure 6-55

Figure 6-55 shows the input screen for a large system. The masking generator must be chosen first. The speaker tap setting defaults to 1 Watt; it should be changed only for under floor or above gypsum board situations (6.1.9). The number of channels and the audio functions for each must be chosen. The channel assignment for each zone is first chosen. Then the number of speakers in the zone is entered, either manually, or with aid of the speaker array module (6.2.4). If the module is used, additions outside the array may be made. This might be for Soundscaping (6.3.1) or for small corners. Speakers may be deleted for areas within the array that should not have masking. This might be for a conference room, or an extension beyond the building. The default tap setting and the M1000 speaker are added automatically, either one can be changed. The tap setting can be either 1 or 2 Watts. Double click on the speaker model to get a list of available speakers. If the ceiling plenum or the under floor cavity is too small for that speaker, check the LP box and a low profile speaker will be chosen. If paging only is chosen, it may be placed as the masking speakers or face-down in a suspended ceiling.

The program permits up to 30 zones, each zone is capable of handling up to 100 Watts (up to 120 speakers at 1 Watt and 60 speakers at 2 Watts). It is possible, and strongly recommended, to identify each zone by pressing the “Name Zones” button.

6.5.4 Large System Schematic

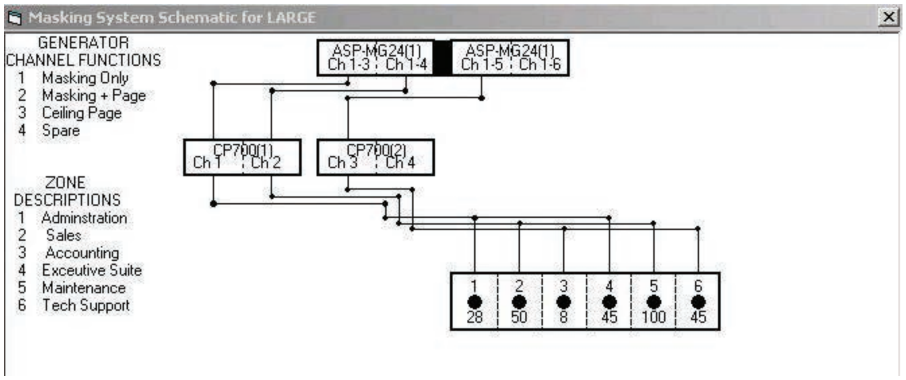


Figure 6-56

A functional schematic is displayed, showing products chosen and wiring connections. *Figure 6-56* shows an example. The system was three-channel, six zone and required three amplifier channels. The generator audio functions are displayed in the upper left and the zone descriptions are shown directly below. The number of amplifier channels assigned to a generator channel is determined by the number of speakers assigned to the generator channel. The screen can be printed, but cannot be modified. The large system function module must be altered to modify it (6.5.2).

6.5.5 Filling a Rack Cabinet

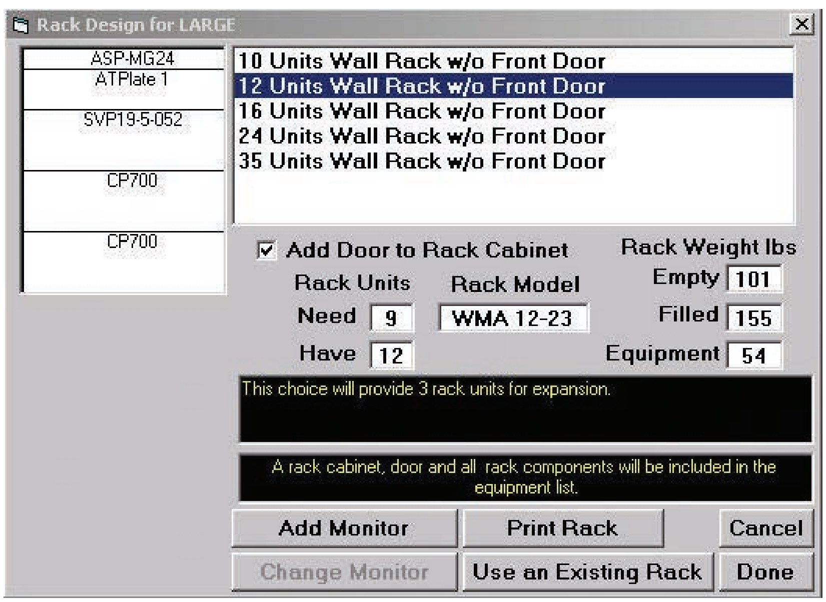


Figure 6-57

It is possible to use a rack cabinet for both small and large systems. The program will display how many rack units are needed and provide a list of cabinets. Wall mount cabinets are all that is needed for these systems. Since all products have been chosen already, a rack layout will be displayed once an adequate sized rack is chosen. *Figure 6-57* shows an example. The model number and various weights are shown. The layout can be printed. There are several options. The cabinet can have a lockable front door or no door. A monitor panel can be added. If the equipment is to be included in an existing rack, the equipment layout will be preserved but the cabinet will be omitted from the equipment list. The ATPLATE is used to hold up to six zone controls.

6.5.6 Entering Service Costs

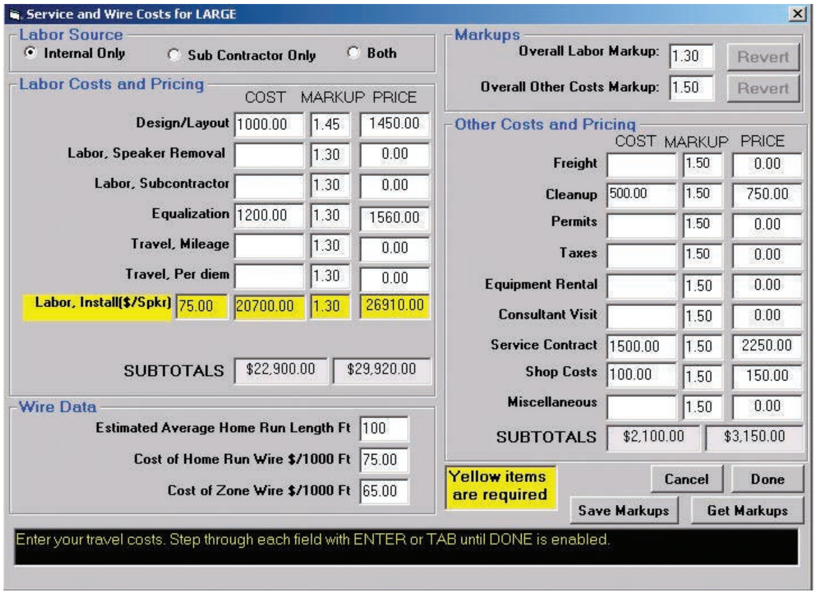


Figure 6-58

For all sizes of projects, the user may enter labor, service costs, as well as estimated wire lengths and cost. If only an equipment list is desired, this module may be bypassed. An example is shown in ***Figure 6-58***. Data from the default database is entered automatically, but can be changed. Installation labor can be internal, by subcontract or jointly. The costs for each item may be filled as required and the price will be shown based on the existing markup. Labor and service subtotals are shown. The markup for any item can be changed or all can be changed together. When all are changed, the "Revert" button is active. In this way pricing options can be explored. Using this module along with the equipment pricing module, will allow total costs and pricing to be modeled.

6.5.7 Determining Project Costs and Pricing

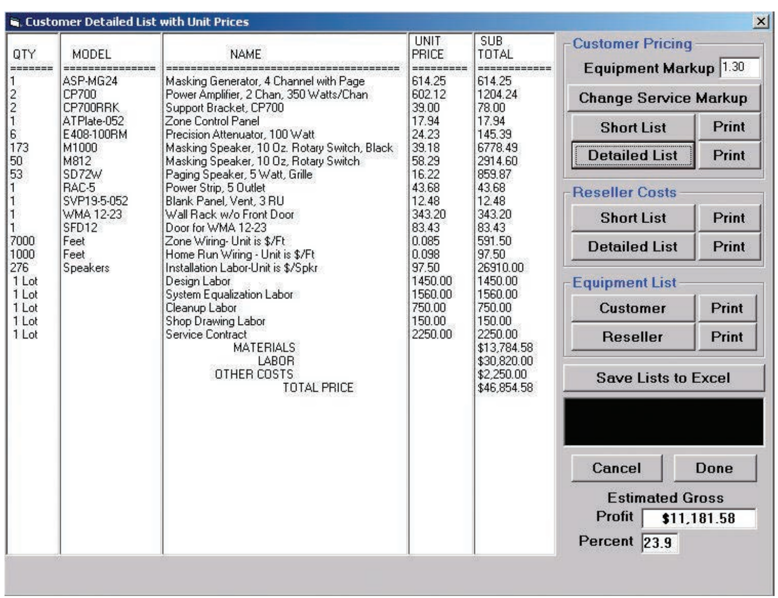


Figure 6-59

With the equipment chosen and labor/service costs entered, it is possible to make a complete cost evaluation. ***Figure 6-59*** shows one set of results. It is possible to see a short or detailed price breakdown for the customer and contractor. An equipment list can also be shown separately, and is available even if no service costs are entered. Any of these lists can be printed. They can also be downloaded to an Excel™ file, if Excel™ is installed. The equipment markup can be changed as desired; it is also possible to change labor/service costs so that total cost and pricing can be modeled.

6.6 System Installation

This section is restricted to some recommendations for improving the efficiency of installations. Most installers need little guidance on project management.

6.6.1 Pre-Installation

6.6.1.1 Contractor Qualifications

The sound masking industry has evolved into two distinct methods of installation. The traditional method is where an acoustical consultant, under an architect, designs, specifies, and may equalize the masking system. The general contractor then has the electrical contractor receive bids from sound contractors. The more recent method has followed the evolution of design/build firms; a contractor specializes in sound masking systems, is capable of designing, installing, and equalizing them, and may bid directly to an end user. The reason most often given for this development is that responsibility is fixed on one firm. Since there may not be any direct supervision, these firms should have the credentials to do the project satisfactorily. Since most customers do not fully understand what a sound masking system does, it falls on the installing firm to explain the concepts as well as do the installation. Below are listed some capabilities that may assist in choosing a sound masking specialist contractor:

- A working knowledge of Privacy Index, how people respond to sound, and the ability to explain it.

- The ability to set the appropriate masking spectra in different areas to meet the various privacy needs of the user. To do this, they must have a real time analyzer with one-third octave band capability.

- Specialization to some degree in sound masking, so they have a record of successful installations.

6.6.1.2 Equipment Cabinets

Using amplifier products with high power ratings permits the system to remain small and thus wall-mounted cabinets may be used. These cabinets do not use floor space, so the end user has more space for other equipment in the chosen room. A large system may require sturdy wall mounting for the cabinet.

6.6.2 Speaker Installation in a Ceiling Plenum

6.6.2.1 Procedure

For speakers to go into a plenum above a suspended ceiling, it is best to install them when the ceiling grid is in place, but before the suspended ceiling materials are installed. The grid can be used for determining speaker placement. A recommended procedure is as follows.

1. Lead all home runs to their zones and attach a radio, or other low level sound source, to the home run.

2. Lay the speakers on the floor under the positions called for in the plan, using the ceiling grid as a ruler. Open the ceiling, if necessary, to see if there are any objects that would prevent using that position (6.6.2.5). If there is a problem, the speaker can be moved an acceptable distance, and nearby speakers should be moved to provide a new average spacing. This should be done prior to any speaker installation.

3. Hang the speakers (6.6.2.2, 6.6.2.3, 6.6.2.4, 6.6.6) starting from the home run location and working outward, preferably in a tree pattern. Run the zone wiring and check that the tap setting is correct. Connect the home run to the zone wiring and start at the speaker nearest the home run. If wired correctly, a sound will be heard that verifies a good connection. This eliminates the frustrating process of checking line impedance and having to open the ceiling or floor to find a short or open circuit.

6.6.2.2 Fixed Height Plenum

Typical plenum heights are about 30 inches so normal plenum speakers can be installed. The speaker should be faced upward and about six inches above the suspended ceiling. Although chain has been used in the past, modern practice is to use the same wire (or slightly lighter) used to hang the suspended ceiling grid. Many modern masking speakers have built-in hanging brackets rather than chain (5.4.6). This makes hanging easy. Avoid speakers that have hanging chain; assembly time is excessive, especially if the speaker itself is to be chained.

The speaker spacing for a very high plenum (more than 10 feet) is greater, but the distance of the bottom of the speaker above the suspended ceiling should be the same. When paging is added in a high plenum, it is recommended that the speaker be hung about two feet from the structural ceiling and faced downward, so that sound spreading is adequate to provide reasonable mixing of the masking, but speech intelligibility is not severely compromised.

In a plenum that has been created by the addition of a suspended ceiling under a gypsum board or concrete ceiling, the plenum depth is around six inches, too small for normal masking speakers so low-profile speakers are needed.

6.6.2.3 Variable Height Plenum

Some buildings have a top floor with a peaked roof and therefore a variable height plenum. The resolution of the potential problem should be done in the design phase, since spacing and sound output must be higher in the area with a higher plenum depth. Speaker bottoms should remain the same.

6.6.2.4 Closed Office Plenum

When the ceiling plenum is used for return air, a return air grille will be installed in each closed office. This penetration will create excessive and localizable masking (violating Design Rule Two). Short sound attenuating ducts have been installed, but they are expensive, increase system pressure drop, and may unbalance the air handling system. An inexpensive solution is to add a simple sheet metal cover on top of the grille, which is normally a 2 by 2 foot square. An example is shown in ***Figure 6-60*** The 2 by 4 foot piece can be made by a local sheet metal shop from material used for creating air ducts. To keep the pressure drop of this piece negligible, the cross sectional opening should be equal to that of the grille itself (4 square feet). Smaller openings are not recommended. Note that the openings of the cover must be as close to right angles to the masking speakers as possible to get maximum benefit. This cover reduces the sound level through the grille and also reduces the potentially objectionable high frequency content of the masking.

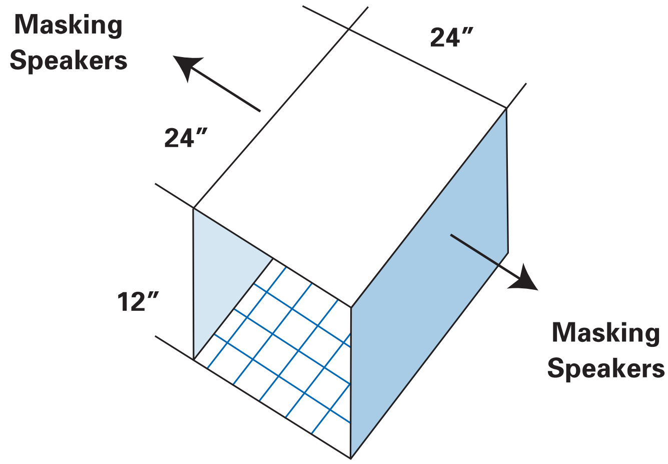


Figure 6-60

If the plenum is too small to fit the cover, the speaker grille can be covered with a thin piece of sheet metal. Both the level and spectrum contour are changed.

6.6.2.5 Mounting Near Ducts

Air ducts within a ceiling plenum can interfere with the correct positioning of masking speakers. Practice has suggested that no speaker should be within three feet of a rectangular metallic duct. Round metallic ducts or fiberglass ducts either scatter the masking or absorb it, so they are not critical. When a speaker must be moved to comply with this restriction, the adjacent speakers in that row or column should be moved proportionately. For example, if a speaker must be moved three feet, the closest speaker should be moved two feet, and the next speaker moved one foot. This will minimize the non-uniformity of the masking level under the duct. There are occasions when the duct is so large that it barely clears the suspended ceiling. In that case, there will be some non-uniformity that cannot be avoided.

6.3.2.6 Discontinuous Ceilings

Suspended ceilings exist in some areas of a room and not in others to form “clouds”. Often the clouds are over open office workstations to provide a place to hold light fixtures. Most times the designer is not aware of the impact on sound masking, so severe “hot spots” occur and they must be fixed by the installer. See Section 6.3.5 for recommendations to how to solve this potential problem.

6.6.3 Speaker Installation in a Fully Open Ceiling

There is no suspended ceiling in this case, so the speakers will be visible. Typical applications are in warehouse-like structures with high structural ceilings. It is desirable to have the speakers higher than when placed above a suspended ceiling. The speaker array module of MDesign provides recommendations on speaker height based on structural ceiling height (6.2.1). Again they should be faced upward. Before hanging speakers, it is important for the customer, or architect, to approve the color of the speaker and the method of leading the zone wiring.

6.6.4 Speaker Installation under an Access Floor

The high sound loss associated with access floor panels allows speakers to be placed at greater distances (6.2.4). Since many of these floors are later screwed in place and covered with furniture systems, it is important to install and wire the speakers immediately after the floor grid is installed. The speakers can be laid on the floor face up, so installation time is less than for plenum speakers.

CHAPTER 7

SYSTEM EQUALIZATION AND OPERATION

Installing a sound masking system without equalizing it is a sure way to ensure failure.

Once a sound masking system is installed it is necessary to make it work, which we call *equalization*. "Working" means the system not only provides the privacy desired by the user, but also is acceptable to those exposed to it. Sometimes it is not easy, but avoiding it is worse. The task includes both technical and social aspects. As can be seen in Chapter 1, "acceptability" can be a two edged sword. Experience over thirty years has shown that well designed and equalized systems are acceptable to the vast majority of listeners. Complaints of headaches, nausea, dizziness, disturbance of biological rhythms, caused by masking are generally manifestations of other problems. Persons with vision or hearing loss have a legitimate cause for complaint that must be taken into account. Most often, poorly equalized, or unequalized, systems give rise to legitimate complaints.

Both the spectrum contour and the overall level are critical factors and must be applied in the appropriate areas. There are two extremes of the spectrum contour. By emphasizing the low frequencies over the high, we get a contour that can be described as "sounds great, works lousy." The other extreme is to emphasize the key speech intelligibility frequencies around 2000 Hz to get a spectrum that can be described as "sounds lousy, works great." The latter spectrum is described as hissy or sounding like a leaky steam radiator. Good equalization avoids both of these extremes. The overall level depends on not only the physical properties of the space, but also the activity levels of the occupants.

7.1 Technical Aspects

7.1.1 Equalization Objectives

There are several general aspects of equalization that enhance the performance and acceptability of masking.

1. *The spectrum must strike a balance between performance and acceptability*. Performance is determined by the spectrum contour, the overall level, and the uniformity of those levels over the areas needing privacy. Acceptability is determined by these same factors, but also the smoothness of the spectrum contour and the diffuseness of the sound (6.1.2). If there is substantial high frequency content, the privacy is better but acceptance is less. Higher levels increase privacy, but lessen acceptability. Performance is objective (2.3), while acceptability is subjective (1.12). After the technical objectives are accomplished, the social aspects must be addressed (7.7) to take the subjective factor into account.

2. *The spectrum must be relevant to the area in which it is applied*. There is a tendency to create similar levels of masking in all projects and in all zones of a given project, regardless of the activity levels associated with those zones (one spectrum fits all). This can result in deficient masking in one area and overkill in another. The decision to set a masking spectrum and overall level often comes from a specification or other guidance. If tests have been done to determine the spectrum, they are hopefully based on worst-case situations where it is presumed that all persons are talking all the time (e.g., call centers). Such levels may be appropriate there, but are often excessive in areas where conversations

are less frequent. Proper zoning during design (6.1.9) will give the equalizing person the opportunity to accommodate different activity sounds.

3. *The overall level should take into account the changing privacy needs of the occupants.* A certain masking level may be appropriate during working hours, but overkill outside working hours when the need for privacy changes to a need for community (1.8). If the advanced function of programmed level control was not designed into the system (5.5.1), then a compromise may be required to keep the masking acceptable. The classic fix for this problem has been to turn the system off after working hours. However, if the turn on is forgotten until later in the next workday, a negative response is sure to occur.

4. People love progress but they generally hate change. This adage applies to sound masking as well. The initial opinion of masking is formed at the first introduction to it (1.11). Going from a low background level to a higher background level in a new environment generally creates immediate negative responses (1.13). This problem can be avoided in two ways. The first is to design the system with stepped zone controls (5.1.5); they can be set at low numbers initially and manually stepped up over a given time period. The second is to design with a generator that has the advanced function of slow ramp up (5.5.2). It can be programmed and forgotten.

5. *The smoothness of the spectrum is as important as the actual contour.* The more peaks and valleys in a masking spectrum, the more it appears like a sound with information (tonal). This must be avoided. It is as important to create a smooth spectrum in ⅓ octave bands as it is to have it perfectly match the desired spectrum on average (7.1.5). This should be done in the final inspection after equalization.

7.1.2 Responding to Specifications

Weaknesses in specifications can create problems for the person equalizing the system.

There are two types of specifications: a performance one and an equipment one. Since the purpose of a sound masking system is to provide acoustical privacy, it would be desirable for a performance specification to require a certain degree of privacy. However, the problem with such a specification is that it tacitly involves all the structural, or sound attenuation factors, *none* of which are under the control of the person doing the equalization. Tacitly implied in all masking specifications is that it must be acceptable to occupants. So if the specification requires a specific degree of privacy to be achieved, do *not* respond unless you are positive it can be achieved. While it is possible to satisfy any privacy requirement with sufficient levels of masking, it may result in unacceptably high levels. An equipment specification generally details the equipment to be used and the spectrum of masking to be set. The relationship between the desired degree of privacy and the level of masking is seldom provided in the latter specification. As a result, the task for the person equalizing is much simpler (provided the equipment is adequate to the task); and the burden of meeting privacy goals is on the person writing the specification. Unfortunately, owners almost always expect the masking system installer to satisfy privacy requirements. The pre-design review (6.1.4) is crucial in avoiding this problem.

RED FLAGS: There are several inclusions in specifications that should create concern in a responder. These are signs that the person writing the specification copied an old specification or may not be current, or responsive, to modern developments. In any case, the documents should be examined carefully:

- Use of the words “noise masking” instead of “sound masking”. The latter terminology is well-established.

- A spectrum given in one-octave bands instead of one-third octave bands. ASTM standards have not been addressed.

- Use of “Sound-Power Level” instead of “Sound Pressure Level” to describe the masking spectrum. The former is determined by a spatial integration of sound intensity around a source, while the latter is simply a one-point measurement of sound pressure.

- The requirement for constant masking levels over short periods of time. This potential problem disappeared many years ago.

- The requirement to achieve a specific degree of privacy with masking.

The specification of a fixed spectrum can create difficulties. Is it the best one for the given situation (3.1.7, 3.1.9)? *One spectrum does NOT fit all situations*. If masking is used in open areas with varying administrative activities, different panel heights, or in closed offices, one spectrum will not be sufficient to achieve the goal of the system and clarification is needed. If it specifies the masking spectrum in octave bands; they should be changed to one-third octave bands to conform to recent standards. Specification of spectrum levels to tenths of dB, such as 40.7 dB, makes compliance impossible.

Often a specification will include tolerance limits on the masking spectrum, such as +/- 2 dBA, to ensure a degree of spatial uniformity. Some specifications include tolerance limits by frequency band, creating much more difficulty in compliance. This aspect is addressed below (7.1.3).

A specification may include a broader range of frequency bands than that associated with speech privacy (3.1.6). Masking speakers typically begin to roll off at around 160 Hz; it permits them to cover the speech range. Most often, air handling systems fill in the spectrum levels below that (3.1.8), so a specification that cites sound masking levels below 100 Hz, may not be achievable, and may not even be relevant. There are masking speakers that can go to lower frequencies to provide privacy from sounds other than speech (3.2.5).

7.1.3 The Quest for Spatial Uniformity

The concept of spatial uniformity for sound masking is derived from Design Rule Two (6.1.1) and is a noble quest. One is reminded of the paper by Benoit Mandelbrot entitled “How long is the coastline of England?” His point was that the length was determined by the scale of the measurement. As one made the ruler smaller, the minor irregularities of the coastline were accounted for, increasing the measured length. The same concept applies to measurement of spatial uniformity. For example, if measurements are made everywhere in an open office, the results would show not only significant changes in level (more than +/-2 dBA) but also changes in the spectrum contour, demonstrating the practical limits to the uniformity goal.

One practical goal of spatial uniformity is to reduce the awareness of masking by not permitting detectable changes in level as one walks around a room. Experience has suggested that level changes within a workstation or closed office, if reasonable, are seldom noticed. This suggests that measurements of uniformity be made in the aisles of open offices or in corridors with masking. One beneficial result of such measurements is to detect installation problems. Listening while making measurements will quickly detect gross effects such as inoperative speakers, or large level changes caused by unprotected return air grilles, noisy air handling ducts, or speakers located too near obstructions.

The problem with all this is that the quest is actually for *spatial uniformity of speech privacy* within a zone. The structural similarities between closed offices are so great that both quests generally merge so zoning closed offices as a group works. In open offices, the various panel heights and possible proximity to vertical reflecting surfaces keep these two quests separate. Since measurements need to be made, it is desirable to measure the masking spectra within workstations and closed offices. Although variations in the results may be interpreted as lack of uniformity, they depend critically on the nature of the physical environment surrounding the person. The presence of walls and furniture systems, particularly those with varying height panels, create spatial variations in both overall level and the spectrum contour, very little of which can be controlled by the person doing the equalization. If extreme height differences occur in an open office, the design should have created separate zones (6.1.9). These level changes should not be interpreted as failures of uniformity.

To have uniformity of privacy merge with uniformity of masking, the structural aspects of an area must be the same. This strongly suggests that adequate zoning is the best means for keeping these two quests together (6.1.9).

7.1.4 The Mostly Ignored Time Factor

When a masking system is zoned and equalized, a spectrum is set in that zone that is considered to be optimum for it. Because there are numerous possible talker and listener positions between workstations, the masking spectrum should be set by worst-case analysis, either through measurements or by modeling. Worst-case analysis assumes a person in an adjacent office or workstation is facing the listener and talking all the time, which of course is not true. This can lead to masking overkill. In one office with such overkill, an employee stated that she had to get up occasionally to see if anyone was around. She had lost her sense of community. A well-designed sound masking system takes into account the balance between the need for privacy and the need for community (1.8); it is a function of time. To take the time factor into account, we use the results of highway noise studies [23], and use percentile levels (A.5). The symbol L_{10} = 60 dBA, for example means that 10 percent of the time during a measurement period, the level of 60 dBA was *exceeded*. As the subscript increases the level must be lower; L_{100} is the level that is exceeded 100 percent of the time, which, of course, is the lowest level. It is common and practical to use L_{90}, as a representative background level; which for this application would be either the existing pre-masking level or the masking level.

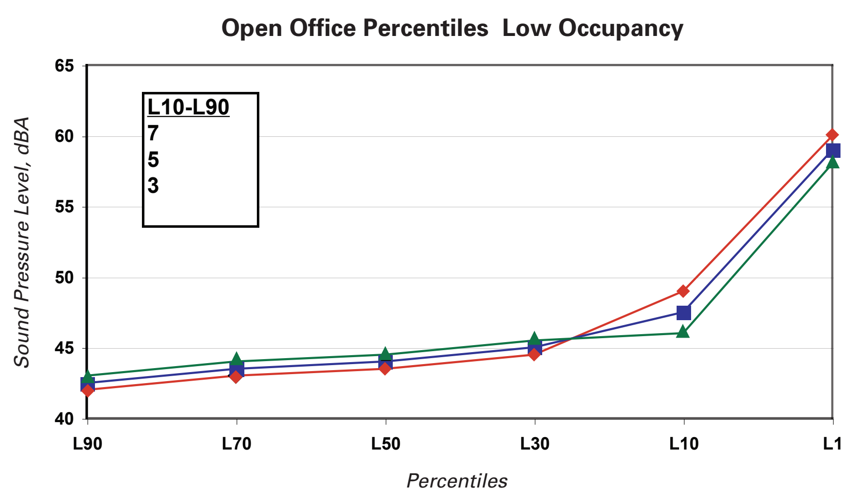


Figure 7-1

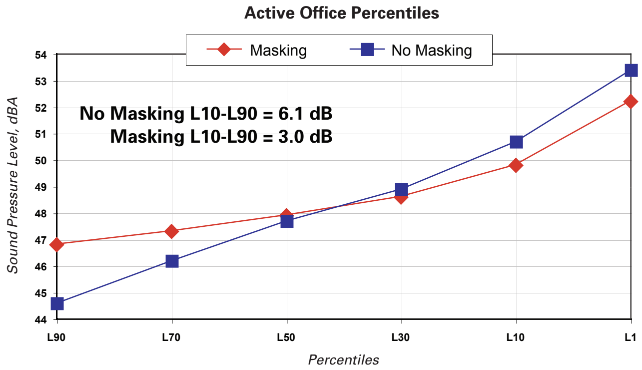


Figure 7-2

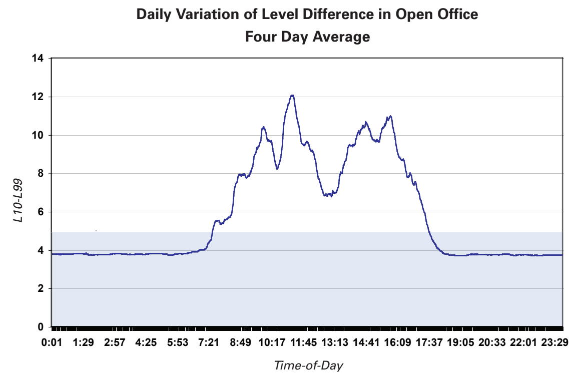


Figure 7-3

The first consideration is whether the sound masking contributes to variations in level. The Level Difference (LD = L_{10} - L_{90}) is insignificant in modern systems. ***Figure 7-1*** shows percentile levels typical of a relatively quiet office for three different days, each averaged over several hours. The Level Difference varied from 3.3 to 8.0. ***Figure 7-2*** shows the percentile levels for another office during working hours with and without sound masking. During working hours the air handling system without sound masking created the lowest level. For many offices that level is near 40 dBA, too low to provide speech privacy. In this office the level was nearer 44 dBA. Human activity sounds rose above that level. In open offices with more effective characteristics and lower workstation panels, the L_{10} can rise above 70 dBA. In the present example, the design was good enough to avoid such levels. Now view this chart with regard to distractions. A working rule among acousticians is that a rapid 10 dB rise in level will cause definite distraction. During the workday, with no masking, that rise occurs about 10 percent of the time in most offices. This percentage is enough to reduce productivity. The distractions may enhance the sense of community but do destroy privacy. The most commonly used measure is the Level Difference (L_{10} – L_{90}) percentile difference (A.5). For the example in ***Figure 7-2***, that value was 6.1 dB, suggesting some distraction. With the addition of sound masking, it was reduced to 3.0 dB, a significant reduction in potential distractions. A graph like that in ***Figure 7-2*** is really a snapshot over a limited period of time. ***Figure 7-3*** shows the percentile differences as a function of time during a work day. The masking level for this graph was 45 dBA with a spectrum like that recommended (3.1.7). If we use 5 dB as a threshold of significant distraction, we see that distraction was low during the early morning hours but distraction was high during the late morning hours. Distraction was significant during afternoon hours. A higher level of sound masking (about 2 to 3 dB) would have eliminated the afternoon distractions. Since it is impossible for the person equalizing to determine what the cumulative distraction potential will be, he or she must at least be aware that it can be a legitimate cause of complaints.

7.1.5 Spectrum Smoothness

Despite the fact that everyone involved in sound masking seems to have a preferred spectrum contour, they all agree that the spectrum must be smooth, implying that there should be no dips or peaks in adjacent frequency bands. The lack of smoothness can be detected by a listener and thus violates the Design Rule Two (6.1.1). This criterion is considered to be as important as spatial uniformity.

7.1.6 Preliminary Inspection

The first task in equalization is to make sure everything is as planned. Some checks are as follows:

1. Turn on the system when not occupied and make sure masking can be heard in all areas and that it has no operating deficiencies.

2. Check that all loudspeakers are working by a walkthrough. Part of this is to ensure that speakers have been placed in the areas where masking is desired.

3. If the system is multi-zone, turn on the zones one at a time to ensure that the masking is heard in the areas planned. If zone level controls are used, alter each setting to ensure they do in fact change levels.

4. Inspect closed offices that have masking and look for any open return air grilles that may permit excessive masking levels. There are simple ways to reduce the impact if such exist (6.6.2.4).

7.2 Equalizing a Distributed System With the AM1100 Maskers

There are two versions of these self-contained maskers: one requires 110 Volts and the other requires a 16 Volt power supply. Aside from that, they both operate the same. ***Figure 7-4*** shows the faceplate of one of these units.

Figure 7-4

7.2.1 Controls

- **On-Off** – Power on/off switch.
- **Master volume** – Course volume control with analog potentiometer. Rotation counter-clockwise increases level.
- **LP-1** – Low pass filter. Rotation counter-clockwise flattens spectrum.
- **LP-2** – Low pass filter. Rotation counter-clockwise flattens the spectrum. It works in conjunction with LP-1.
- **Stepped Attenuator** – Fine volume control with eleven steps- the first three steps are 2 dB and the remainder are about 1 dB.

7.2.2 Operation

If more than one unit is to be used, the first unit should be installed and the various controls set to produce the spectrum desired. It should then be removed and the controls on the remaining units set to the same position. If the units are to be placed above a suspended ceiling, the following settings can be used to get between 45 and 47 dBA in the room below:

- **Master Volume** – Rotate fully clockwise then rotate CCW 45 degrees
- **LP-1** – Rotate fully counter-clockwise
- **LP-2** – Rotate fully counter-clockwise then rotate clockwise 135
- **Stepped Attenuator** – Position 5

7.3 Equalizing a Centralized System with the AA120M

7.3.1 Description of Important Controls

7.3.1.1 AA-SMG Module Panel

- **Gain** – Maximum gain is 23 Volts on a 70V line and minimum gain is 0.2 Volts. This control is used to set the masking output level of the amplifier.
- **EQ** – The EQ is a Low Pass (or Hi-Cut) filter with a cutoff frequency between 1 kHz and 6.3 kHz with a slope of 6 dB per octave. When fully clockwise, the cutoff is 6.3 kHz. The control is used to set the masking frequency spectrum.
- **Line Out** – This jack sends the masking signal out to other amplifiers. It works in conjunction with the Pre-EQ/Post-EQ Shunt (See below).
- **EQ Insert** – A TRS-203 connector is used to send and receive a signal from the EQM131 external equalizer. See 7.3.1.4 for details.

7.3.1.2 AA-SMG Module Board Shunts

- **Out to Amp (Shunt J8)** – In the right position (On), the output of the module is sent to the AA120M. In the left position (Off), no signal is sent to the AA120M. Only the Line Out control has a signal. The default position is "On".
- **Post or Pre EQ (Shunt J11)** – In the up position (Pre-EQ) the signal to the Line Out jack is 250mV and is unaffected by the Gain or EQ settings of the module In the down position (Post-EQ), the Gain and EQ settings are sent to the Line Out jack as well as those from the external equalizer, if used. The default position is Post-EQ.
- **Amp Direct and Mixed Bus (Shunt J10)** – In the up position (Amp Direct), the SMG module signal bypasses the front panel controls and goes directly to the amplifier without modification. In the down position (Mixed Bus), the signal passes through the front panel controls. The default position is Amp Direct. If mixed bus is chosen, it will not be possible to equalize the paging or music signal independently from the masking.
- **Pink and White Noise selection (Shunt J5)** – The up position sends white noise while the down position sends Pink noise. The default position is Pink.

7.3.1.3 AA120M Amplifier

- **Dipswitch 5** – On the rear panel of the AA120M are ten dipswitches, Set Dipswitch 5 to the up position (Amp Direct). This directs the output of the AA-SMG module to the last stage of the amplifier and bypasses the front panel controls.

7.3.1.4 EQM131 Equalizer

The addition of this unit permits the masking system to meet ASTM standard with a one-third octave band equalizer. It is connected to the system through the EQ insert on the AA-SMG module with a TRS-203 cable. It is a stereo ¼ inch phone plug as the connector to the AA-SMG and at the other end are two ¼ inch mono phone plugs; **the Tip is connected**

to the input jack of the equalizer and the Ring is connected to the output jack. When connected, the equalization settings of this device are added to those of the Gain and EQ settings of the AA-SMG module.

7.3.2 One Channel - One Zone System

This system can have an external equalizer connected to the AA-SMG Module.

Turn AA120M power OFF

7.3.2.1 AA-SMG Module Setup

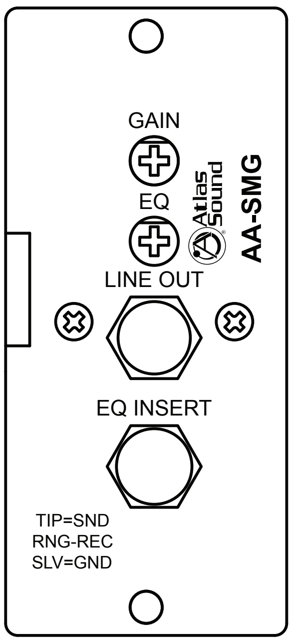


Figure 7-5

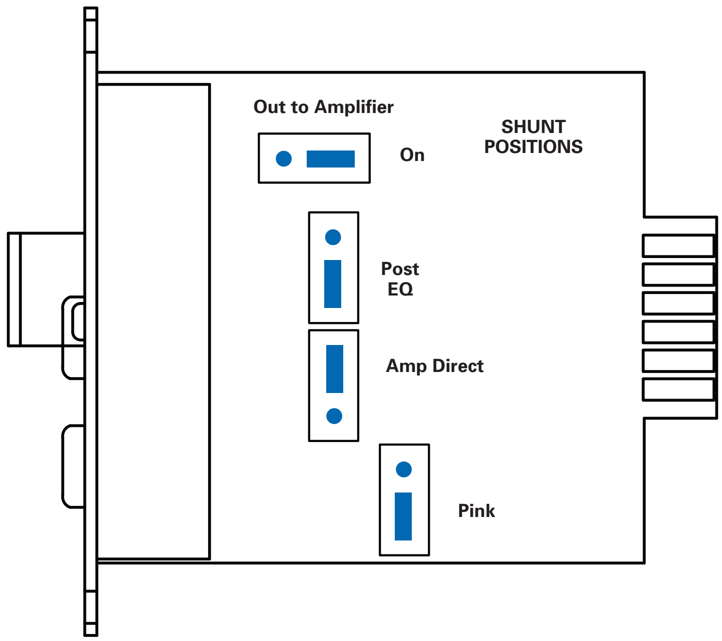


Figure 7-6

There are choices that need to be made prior to installing the module in the AA-120M amplifier. To move shunts (jumpers), use needle nose pliers. ***Figure 7-5*** shows the back panel of the AA-SMG. ***Figure 7-6*** shows the module board with recommended shunt positions (solid lines).

1. **Back Panel**: Turn GAIN fully counter-clockwise to turn signal off
2. **Back Panel**: Turn EQ fully clockwise (Hi-Cut is off).
3. **Board**: Select White or Pink Noise (Shunt J5). Pink Noise is the default selection. Change to White for under floor systems and gypsum ceiling systems.
4. **Board**: Select Amp Direct (Shunt J10) to bypass front panel controls.
5. **Board**: Select Post-EQ (Shunt J11).
6. **Board**: Select On position for Out to Amplifier (Shunt J8).

7.3.2.2 AA-120M Setup

Figure 7-7 shows the back panel of the AA120M.

Figure 7-7

1. **Back Panel**: Insert the AA-SMG module into the card guide rails. Push until card is seated and the panels are flush. Secure with screws.

2. **Back Panel**: Set dipswitch 5 to "On" (Up). This sends SMG module signal directly to the amplifier and bypasses front panel controls. See black marked switch in ***Figure 7-7***.

3. **Back Panel**: Connect 70 Volt output to the zone home run.

4. **Back Panel**: Connect any line level inputs, such as paging or music, to Inputs 1 to 4. All front panel controls will operate on these signals. The Input volume control for each will permit setting relative levels. The Master volume control will permit setting levels relative to the masking. The Bass and Treble controls will permit setting the equalization of these signals, independently of the masking.

5. **Front Panel**: Turn the Master volume control and the Input controls fully counter-clockwise.

7.3.2.3 EQM131 Setup

1. **Back Panel:** Connect the tip and ring plugs.

2. **Front Panel:** Set Range to +12 dB.

3. **Front Panel**: Set Bypass Off.

4. **Front Panel**: Set Lo-Cut to 40 Hz.

5. **Front Panel**: Set Hi-Cut to 8 kHz.

6. **Front Panel**: Set Level to 4 to maintain the same amplifier output. A level setting of 0 will result in a 6 dB reduction.

7. **Front Panel**: Set the 20 to 63 Hz ⅓ octave band filters to –12.

8. **Front Panel**: Set the 10 to 20 kHz ⅓ octave band filters to –12.

9. **Front Panel:** Set 80Hz to +6

10. **Front Panel:** Set 100Hz to +3

11. **Front Panel:** Set 125Hz to 8kHz to 0.

These will be the initial settings for speakers in a suspended ceiling plenum.

7.3.2.4 Operation

1. **Front Panel**: Turn the amp on. You should hear only masking at low level.

2. **Back Panel**: Rotate GAIN clockwise until masking is heard at noticeable levels.

3. **Back Panel**: Rotate EQ counter-clockwise to reduce the high frequencies. For ceiling plenum installations, little rotation should be necessary. For open ceiling installations, more rotation is necessary. If the EQM Equalizer is used, make fine frequency adjustments to create a smooth spectrum.

4. **Front Panel**: Adjust the line level inputs as desired AFTER setting the sound masking level.

7.3.3 One Channel - Two Zone System

The AA120M feeds a signal to another amplifier. That amplifier can be from 35 watts to 240 watts. The larger amplifier is not recommended as it would make a zone that is too large.

The setup is the same as for the one channel, one zone system except that an output from the primary unit is connected to the secondary amplifier.

7.3.3.1 System Setup Additions

1. Connect the 70 Volt output on the secondary amplifier to the Zone 2 home run.

2. Connect any line level inputs, such as paging or music, to the secondary amplifier. **NOTE**: The line level inputs on the primary amplifier are NOT connected to the secondary amplifier. All front panel controls will operate on these signals. The Input volume control for each amplifier will permit setting relative levels.

3. Connect **Line Out** on the AA-SMG Module to an input to the secondary amplifier. Only the masking signal will be connected to the secondary amplifier.

7.3.4 Two Channel - Two Zone System

Since two channels of equalization are required, two AA120M amplifiers are needed and the procedures outlined in section 7.3.2 must be done for each.

7.4 Equalizing a Centralized System Using the ASP-MG24

7.4.1 Introduction

The Atlas Sound ASP-MG24 has four independent masking channels, two inputs for paging or music, and four output channels. Each channel has separate equalizers.

The input channels are numbered as shown in ***Table 7-1***.

Function	Input Channel
Paging	IN1
Paging	IN2
Masking	IN3 (M1)
Masking	IN4 (M2)
Masking	IN5 (M3)
Masking	IN6 (M4)

Table 7-1

The output channels can be set up in any combination of the input channels. It is possible to have two masking input channels go to the same output channel, but that combination is not needed.

Output Channel 1	Output Channel 2	Output Channel 3	Output Channel 4
Channel 3,4,5, or 6 Masking	Channel 3,4,5, or 6 Masking	Channel 3,4,5, or 6 Masking	Channel 3,4,5, or 6 Masking
Channel 3,4,5, or 6 Masking + Channel 1 Paging	Channel 3,4,5, or 6 Masking + Channel 1 Paging	Channel 3,4,5, or 6 Masking + Channel 1 Paging	Channel 3,4,5, or 6 Masking + Channel 1 Paging
Channel 3,4,5, or 6 Masking + Channel 2 Paging	Channel 3,4,5, or 6 Masking + Channel 2 Paging	Channel 3,4,5, or 6 Masking + Channel 2 Paging	Channel 3,4,5, or 6 Masking + Channel 2 Paging
Channel 3,4,5, or 6 Masking + Channel 1 and 2 Paging	Channel 3,4,5, or 6 Masking + Channel 1 and 2 Paging	Channel 3,4,5, or 6 Masking + Channel 1 and 2 Paging	Channel 3,4,5, or 6 Masking + Channel 1 and 2 Paging
Channel 1 Paging	Channel 1 Paging	Channel 1 Paging	Channel 1 Paging
Channel 2 Paging	Channel 2 Paging	Channel 2 Paging	Channel 2 Paging
Channel 1 and 2 Paging	Channel 1 and 2 Paging	Channel 1 and 2 Paging	Channel 1 and 2 Paging

Table 7-2

The purpose of this section is to demonstrate how to navigate through the equalization process for each of the combinations. The MG24 is controlled by software on your laptop computer. The software (ASP-MG24.exe) is provided with each unit and may have been installed in the folder "C:\Program Files\Atlas Sound\ASP-MG24 v2". Later you may wish to put other files in that folder, so the location needs to be known. A companion program MEQ30.exe is used to simplify equalization; it creates a file that is used to equalize the system in few steps

7.4.2 Equipment Required

A laptop computer with ASP-MG24 installed. The MG24 can be connected to a serial or USB port. Instructions for installing and setting up the MG24 are supplied with the unit (Quick Start Manual).

Installation of MEQ will speed up the equalization process.

A sound level meter (Real Time Analyzer) to measure one-third octave band levels, such as the Larson-Davis Model 824, the Goldline DSP30, or the B&K 2250.

7.4.3 Two Equalization Methods

There is a new method to speed and improve the equalization process.

7.4.3.1 *Manual Method*

In this method, the various settings to equalize the system are done manually on the screen. It is an iterative and time consuming method, in that one has to set the masking spectrum, measure it, enter the software and make adjustments, then verify by further measurements, etc. The same has to be done for other channels.

7.4.3.2 *Fast Method*

In this method, the MEQ software is used. The masking spectrum in each channel is set, measured and stored in one of the three Real Time Analyzers (RTA) noted above. The program has a number of masking spectra stored in a database. The user picks the one desired. Meter data are then downloaded into the program and the corrections needed to match the measured spectrum with the desired spectrum are calculated. The program will generate a correction file for each channel that is stored in the folder with the MG24 software. The MG24 will open the file and make the necessary corrections. If the measurements are made correctly, the equalization will be done in one step. The advantage of this method is accuracy and speed and equalization can be done by technicians that have less training.

This document will emphasize the Fast Method.

7.4.4 Special Functions

The ASP-MG24 has some advanced functions (5.5) to improve masking system performance. The Initial Ramp and Level Scheduler require a generator with the MGTDB option.

7.4.4.1 Power Up Ramp

If the building power is lost and then restarted, it is important that the sound masking does not go to full level abruptly. This function will bring the masking up to full level over several minutes, The time can be set by the user. This function applies to all channels and all devices.

7.4.4.2 Initial Ramp

Employees accept changes slowly in most cases, particularly if they are unfamiliar with that change (sound masking). This function permits the user to have the sound masking level increase slowly to full level over many days. The user can set the start level and the number of days to full level.

7.4.4.3 Level Scheduler

It is well established that the need for sound masking varies with the time-of-day and the day-of-week. The scheduler permits the user to set the masking level for each hour of the day, for every day, each channel and each device.

7.4.5 The Main Menu

The reader is referred to the Owner's Manual and the Quick Start Manual supplied with the MG24 for detailed information about each function.

When the program is opened, the user will have to log in. Initially there is no password, but one can be set. The user then must choose one of four devices. Most systems have only one. This will open the main menu as shown in ***Figure 7-9***.

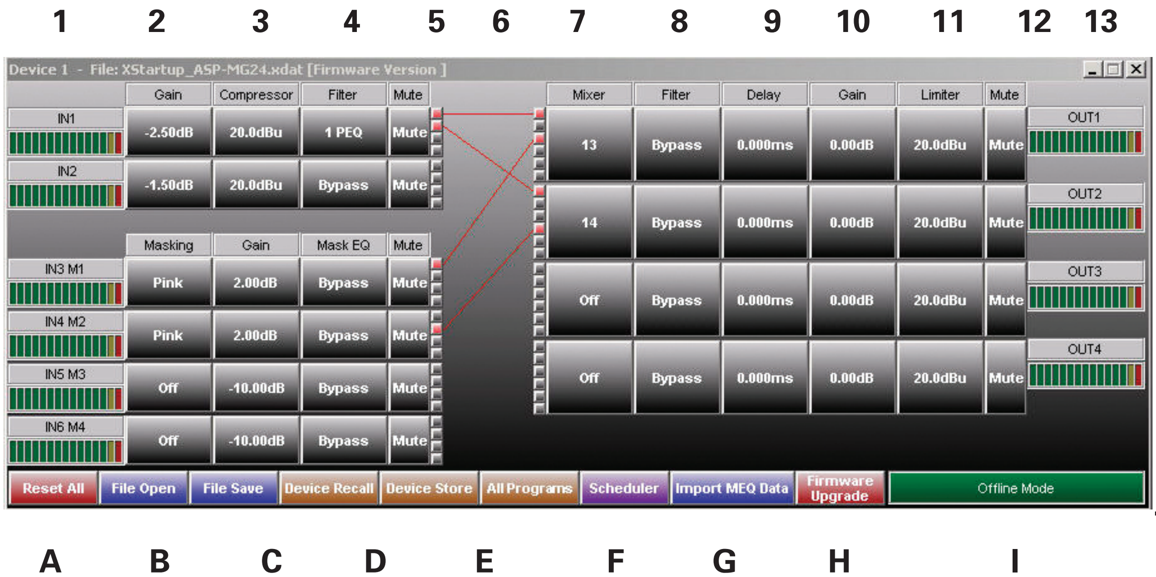


Figure 7-9

To help relate to the various functions, we have divided the action parts of the menu into columns for ready reference and the buttons into an alphabetical array.

7.4.6 Column Identification

7.4.6.1 Column 1 Input levels

If an adequate paging signal (IN1, IN2) is available, the bar graph will show it. This permits the user to know he is working with a signal.

If the masking noise source (IN3, IN4, IN5, IN6) is working, the relevant bar graphs will show activity.

7.4.6.2 Column 2 Paging Gain / Masking Active

If a signal is present, this column permits setting the paging signal (IN1, IN2) gain that goes to the output channels. If the paging is mixed with masking, this gain will set the relative levels with the masking. The mixed output levels are set in another column.

The basic characteristics of the masking (IN3, IN4, IN5, IN6) are set here. When clicked, the user can set the noise source to Off, Pink, or White.

7.4.6.3 Column 3 Paging Compressor / Masking Gain

The compressor may be used on the paging signal. The level of signal going to the mixer section is set here.

7.4.6.4 Column 4 Paging Filter / Masking EQ

There are six parametric filters that shape the paging signal and twenty one-third octave band filters that shape the masking spectrum as well as high cut and low cut filters.

7.4.6.5 Column 5 Paging Mute / Masking Mute

The six input signals can be muted without changing any characteristics set in the previous columns.

7.4.6.6 Column 6 Input/Output Connections

There are four small buttons on the right side of each of the six input channels. Pressing the top button on any input channel will connect that channel to output channel 1. There are six small buttons on the left side of each output channel. Pressing any one will connect that output channel to the input channel corresponding to the button number.

7.4.6.7 Column 7 Output Mixer

The relative levels of the various signals in any output channel are set here.

7.4.6.8 Column 8 Output Filter

The frequency spectrum of the mixed signal in each output channel can be further shaped here.

7.4.6.9 Column 9 Output Delay

The mixed signal can be delayed so that various time delays can be set in each output channel.

7.4.6.10 Column 10 Output Gain

The final level of each output channel is set here.

7.4.6.11 Column 11 Output Limiter

The compressor/limiter may be used on the output channel

7.4.6.12 Column 12 Output Mute

Any of the output channels can be muted.

7.4.6.13 Column 13 Output Meter

The bar graph provides a visual indication of how much output exists.

7.4.7 Button Identification

7.4.7.1 Button A Reset All

Returns the configuration to factory settings.

7.4.7.2 Button B File Open

A configuration file stored on the computer can be opened and set in the unit.

7.4.7.3 Button C File Save

The current configuration can be saved to a computer file either for future reference or other applications.

7.4.7.4 Button D Device Recall

The MG24 can store up to 30 configurations without reference to an outside file. Note: Only one can be recalled at a time.

7.4.7.5 Button E Device Store

The present configuration can be stored in the unit for future recall.

7.4.7.6 Button F Scheduler

If the scheduler module is incorporated, this button will be active. The initial ramp function and the scheduler for programmed level control will be available.

7.4.7.7 Button G Import MEQ Data

Any files created by the MEQ program can be opened and read. The MG24 applies the correction data to the various settings for rapid equalization.

7.4.7.8 Firmware Upgrade

This button will activate any upgrade files that have been downloaded.

7.4.7.9 Button H Online/Offline Indicator

The button label indicates whether the software is connected to the equipment.

7.4.8 Choosing the Speaker Location

The three most common masking locations are: (1) in a plenum above a suspended ceiling; (2) in an open ceiling plenum; and (3) below a raised access floor. Files have been created to pre-equalize the system.

Open the software as directed in the Owner's Manual and go to the Main Menu.

Figure 7-10

Press **"File Open"** and a screen such as shown in ***Figure 7-10*** will appear. When the MG24 opens, Xstartup_ASP-MG24.xdat is loaded. Whenever a file is saved, it is given the extension xdat. Choose the file relevant to the location of the masking speakers. These files have approximately correct equalization settings for the application. Since most masking is placed above the suspended ceiling, this file will be used as an example in the succeeding steps.

NOTE: The settings loaded into the unit are for the input channels only (Columns 1 to 4 above) since the mix of the output channels will vary with the project.

7.4.9 Setting the Masking Spectrum for Plenum Masking

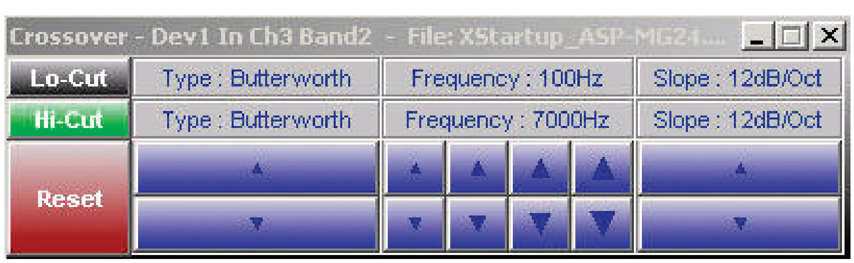


Figure 7-11

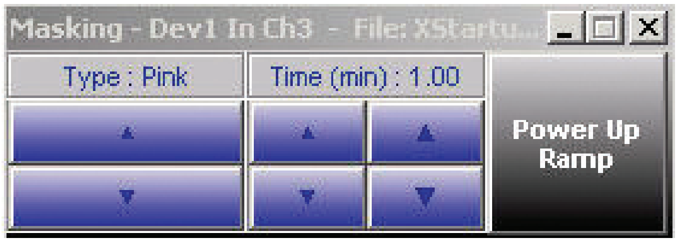


Figure 7-12

When the file SuspendedCeiling.xdat is opened, the following values will be set. ***Figure 7-12*** shows the source spectrum is Pink and the Power Up ramp time is 6 seconds. The high and low cut filters are set as shown in Figure 7-11. The choice of filter type is not important for masking, so the Butterworth filter was selected. Since sound masking speakers begin to reduce output below 160 Hz, the low cut filter was set to 100 Hz to insure some masking is permitted below this frequency so it will match with existing background sound. The high cut filter was set to 7000 Hz since the upper limit of speech is 8000 Hz. The slope for both filters was set to 12 dB/octave.

The one-third octave band filters were set as shown in ***Figure 7-13***. Each band was set to 0 dB so that the spectrum passing to the output channels is pink except for the influence of the high and low cut filters. When the sound is generated, modified by the ceiling plenum, and passed through the ceiling tiles, the spectrum near the listener is close to that most often recommended. It is approximate in that it is based on an open office with mineral tile ceiling materials, which may not be the case.

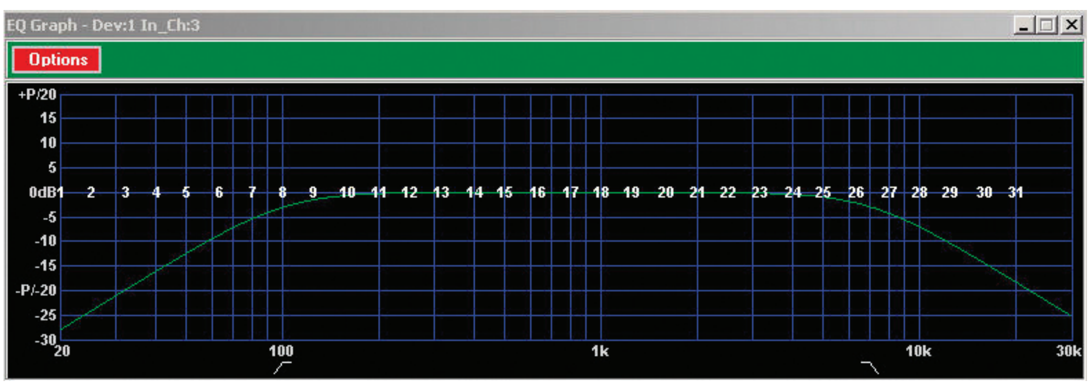


Figure 7-13

7.4.10 Setting the Paging Spectrum for Plenum Masking

Figure 7-14

Although paging may not be used, the recommended spectrum is installed for paging from the masking speakers in case it is. There are eight parametric filters available. ***Figure 7-14*** shows that only one is necessary to overcome the loss of intelligibility as the speech passes through the ceiling tiles. The filter type is parametric (PEQ). The level is boosted at 2000 Hz by 6 dB to enhance speech intelligibility at the important frequency. The bandwidth is set to 2 Octaves to enhance intelligibility at adjacent frequencies. ***Figure 7-15*** shows the spectrum shaping that results from these settings. It shows the entire spectrum contour including the parametric filter. In addition, the width of the chosen filter is shown as a dotted line. It is possible to use this screen to modify the filter characteristics by dragging the bandwidth or level settings.

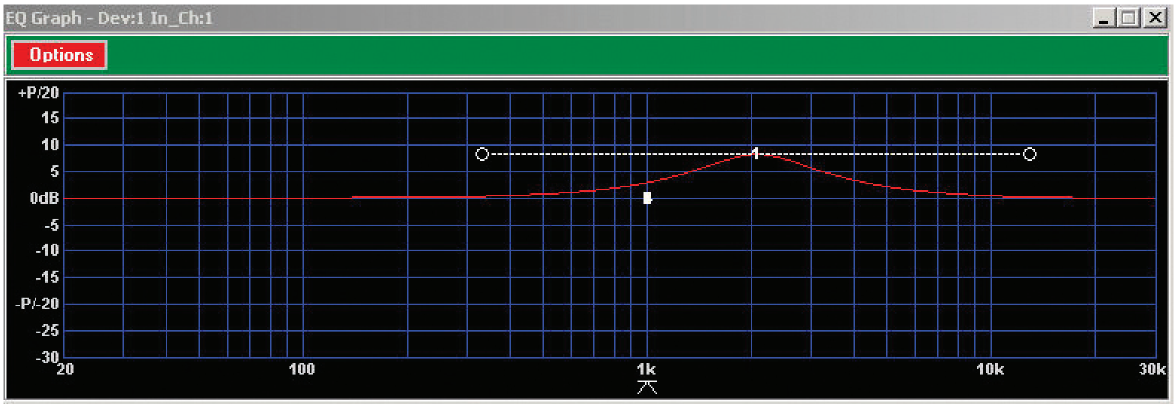


Figure 7-15

Figure 7-16

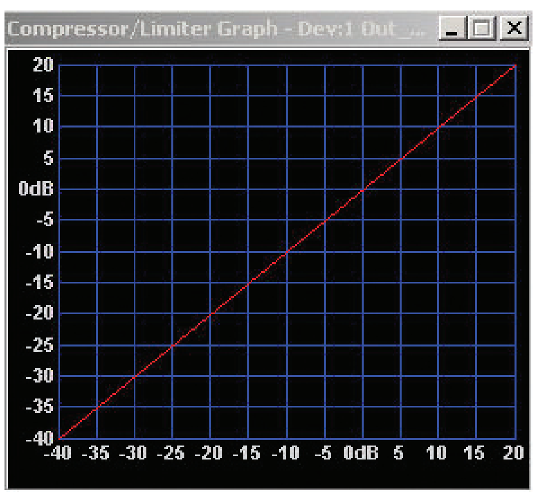


Figure 7-17

The Compressor is set as shown in ***Figures 7-16 and 7-17***. There is no compression.

7.4.11 Mixing the Paging and Masking

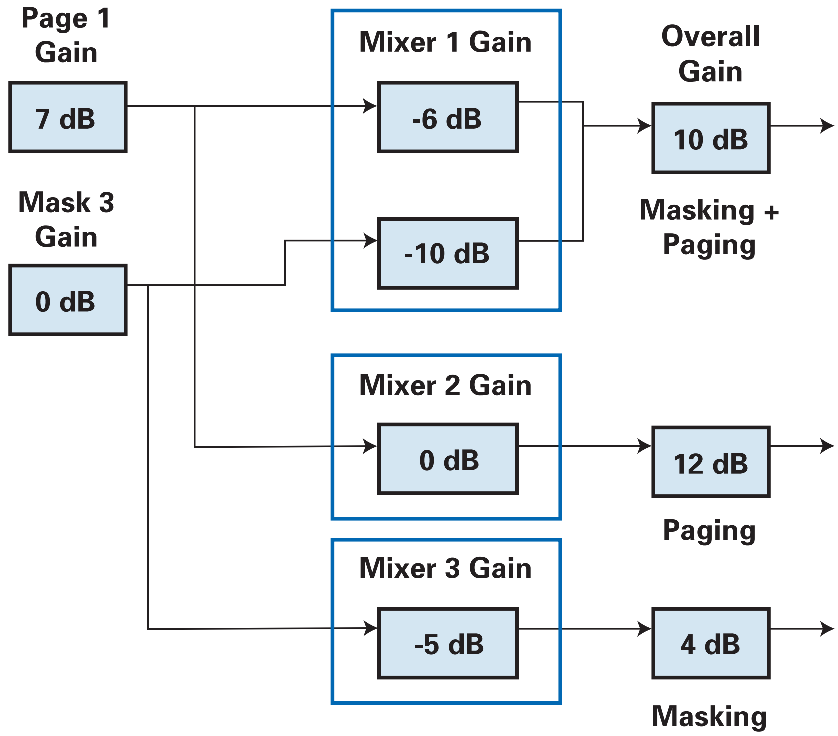


Figure 7-18

The purpose of paging is communication (the opposite of masking) so the page signal must override the masking. The ASP-MG24 has two ways to set relative levels. ***Figure 7-18*** shows an example for a system for which there is an input channel for paging and masking. The first output channel has the signals mixed, the second has paging only and the third has masking only. The gain on the input channels supply adequate signal level. Mixer 1 gain sets the required relative levels so that the paging overrides the masking, and the overall gain is set to supply the amplifier with an adequate signal. Mixer 2 gain is set to satisfy the requirements for the paging only area. Since there is only one signal, either the mixer gain or the overall gain can be used to supply the amplifier with an adequate signal. Mixer 3 gain is similar to Mixer 2, but for masking. The availability of the various gain settings provides extreme flexibility for masking systems.

The actual screen for the input gain settings is shown in ***Figure 7-19***. With about a 0.5 VAC paging signal entering Channel 1, the input settings (Column 2) shown in ***Figure 7-20*** apply. If the input signal is weaker then reduce the sound masking gain. Note the other input channels are muted.

Figure 7-26 shows the connections required to comply with the schematic shown in ***Figure 7-18***. There are two ways to make a connection. Note that there are only four buttons on the right of each input channel, one for each output channel. There are six buttons on the left of each output channel, one for each input channel. To connect page channel 1 (IN1) to the first output channel, press the top button on input channel 1, or the top button on output channel 1. To connect the masking, press the top button on channel 3 (IN3), or the third button on output channel 1. Pressing the other buttons as shown will connect to the other output channels.

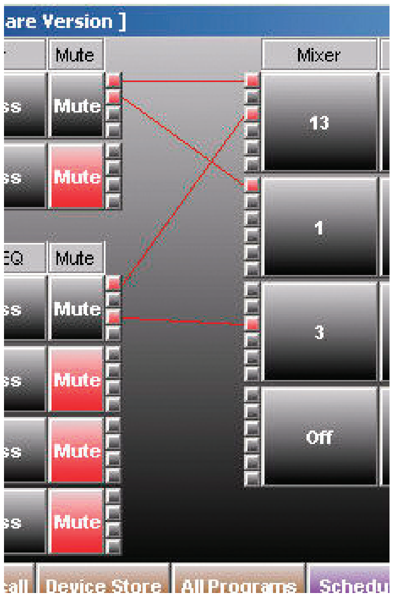


Figure 7-19

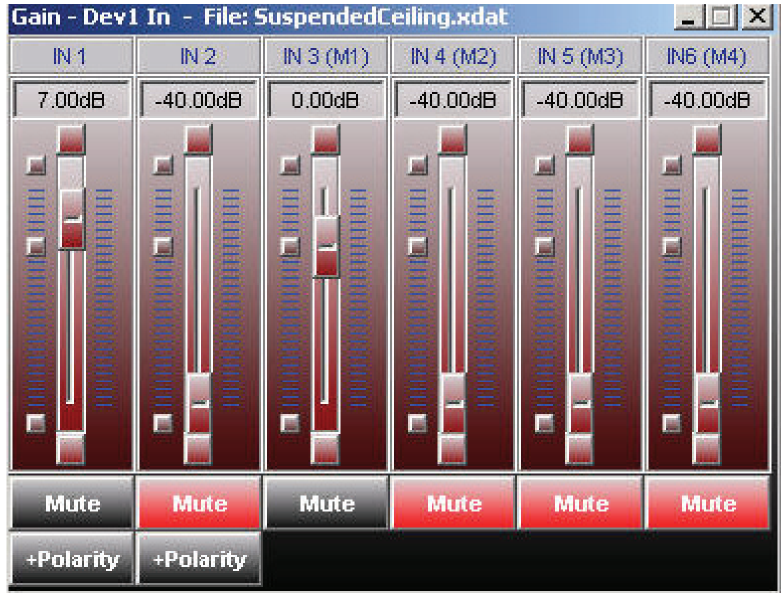


Figure 7-20

7.4.12 Setting the Level Scheduler

This section applies only to units with that additional module. *Figure 7-21* shows the input screen for these functions. The level scheduler permits the user to set the masking level time history for any day of the week in one-hour increments. The top section of the screen shows the time history set by the sliders immediately below. There is a slider for each hourly period. The level shown is the level achieved at the hour indicated. It represents an attenuation, i.e., 0 dB implies no attenuation of the signal. For example, at 7 AM, the level is set at –3 dB. The graph has been added so the level / time history can be easily seen. The maximum attenuation is 10 dB. It is generally adequate to significantly reduce levels during night hours without turning the system off. The graph shown is one commonly used for offices with regular working hours. On weekends, when office population is very low, it is recommended that the maximum setting be –5 dB during daylight hours, instead of 0 dB during the week.

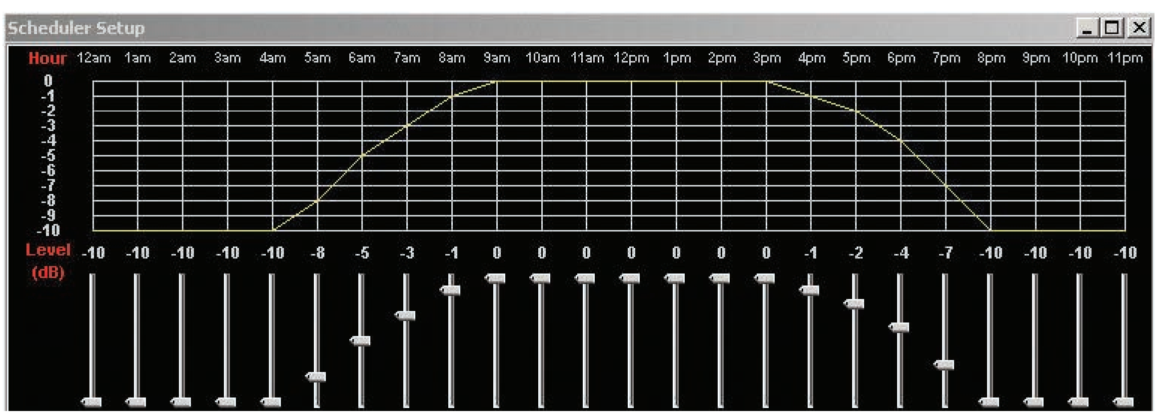


Figure 7-21

7.4.12.1 Copying Schedules

Since it would be tedious for the user to set the slider for each hour of the seven days for each of the four channels for each of the four devices, a copy routine has been incorporated.

In opening the program a particular device was chosen. The current settings show the default channel, and day, but not the device number. It is best to choose a day of the week for the initial schedule, e.g., choose Channel 3 (IN3) and Monday in the upper box under **Current Parameters.** Once the level / time history has been entered for this day, it can be copied in several ways.

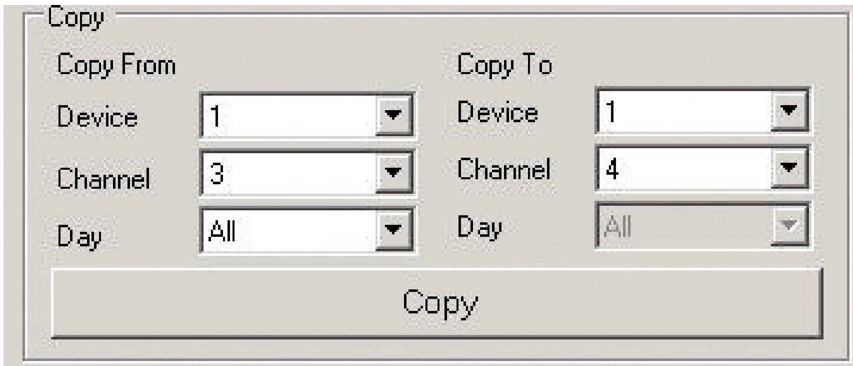


Figure 7-22

The **Copy** section permits several combinations of settings to be copied, not just the current setting. When starting, it is best to enter the parameters for the completed current setting in the **Copy From** section, such as shown in ***Figure 7-22***. Data can be copied to only one device at a time, but choosing *all channels and all days* in the **Copy To** section will transfer the settings to every day of the week for every channel in the chosen device (in this case Device 1). It is recommended that weekends have a different level schedule. After copying, choose a weekend day, Sunday for example, in channel 3 and modify the copied schedule to a weekend schedule. It is much quicker than starting from the beginning. Copy that schedule to Saturday in the same channel and then copy that schedule to all channels and weekend days.

7.4.12.2 Bypassing the Scheduler

If the masking system has to be reset to a new level, the Scheduler *must* be bypassed. If is not, the level may be attenuated resulting in an erroneous level at other times. This can be done by pressing **Bypass Scheduler.** When finished, pressing the button again activates the scheduler. While the scheduler is bypassed, the function is still active and displayed but not connected.

7.4.12.3 Terminating the Scheduler

To terminate the scheduler attenuation, set all the sliders for one day one day to 0 dB, and then copy that schedule to all other days.

7.4.13 Setting the Initial Ramp

Since both the scheduler and the initial ramp are tied to a clock, the program shows the current time and permits the user to set the clock. By pressing **Update Clock,** the computer time is set into the ASP-MG24 as shown in ***Figure 7-23***.

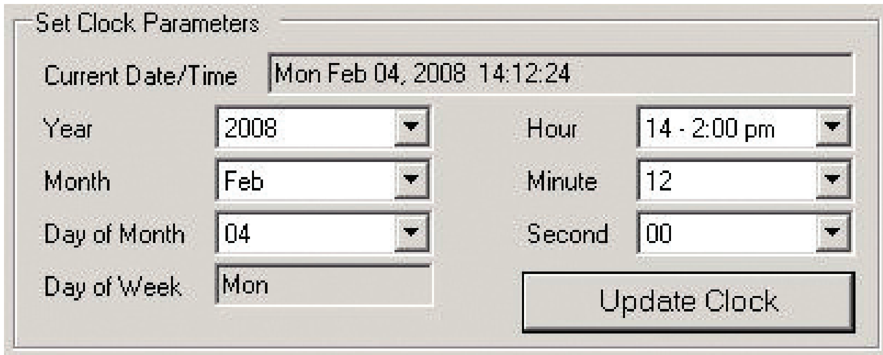


Figure 7-23

The initial ramp requires three inputs, the **Start Level,** the **Days to End,** and **Start Date.** For design masking levels near 47 dBA, the initial masking levels would be near 37 dBA, just barely detectable with the attenuation set at –10 dB. Having the masking increase gradually over 30 days reduces the ability to detect changes. It has been found that the initial ramp has positive impact. Employees may know that masking has been installed, but initially find that they have little improvement in privacy because of it. As the level increases, the resulting increase in privacy becomes evident and response is positive. The start date can be any day after the current date and the ramp will commence after midnight on that date. It is recommended that the date be the day that the office is first occupied. Once the data are entered, press **Start Ramp**.

While the ramp is operating, the current attenuation and the **Days to End** will decrease and be displayed, so that the module can be opened to determine how many days are is left. If the ramp is to be changed, press End Ramp and a new ramp can be set.

7.4.13.1 Bypassing the Initial Ramp

If the masking system has to be reset to a new level, the Initial Ramp *must* be bypassed. If its not, the level may be attenuated resulting in an erroneous level at other times. This can be done by pressing **Bypass Ramp.** When finished, pressing the button again activates the ramp. While the ramp is bypassed, the function is still active and displayed but not connected.

7.4.13.2 Terminating the Initial Ramp

To terminate the Initial Ramp, press **End Ramp**.

7.4.14 Measuring the Masking Spectrum

This section works in conjunction with the MEQ program (7.8).

1. Bypass the Initial Ramp and the Level Scheduler so they will have no influence on the measurements.

2. If zone controls are used, set each to the mid-point (5) for all zones.

3. Bring up the amplifier output in the zone to be measured until the masking level is approximately correct, typically around 47 dBA. If the meter used has a noise floor of 30 dB (as many of the lower cost ones do) raise the level another 10 dB, so that the high frequency data are more correct.

4. Collect up to ten spectrum samples that are randomly sampled throughout the area and either store the data in the meter for direct download or create a data file that can be read.

5. Open the MEQ program and choose the ASP-MG24 option. Download the spectra into the program. Choose the desired spectrum. Then let the program calculate the required corrections for each masking channel and for each channel with paging over the masking.

6. When saving the MEQ data, an EQ file will be created.

7. Activate the ASP-MG24 software, and press **Import MEQ Data** (Column G). The corrections will be set into the instrument. If the measurements have been done well, the spectrum is now set the to the desired spectrum.

8. The other zones on the channel now have the same spectrum, but it is necessary to verify that the levels in each of the other zones is that which is desired.

9. Repeat the above process for the other channels

10. Press **Bypass Ramp** and **Bypass Scheduler** to reactivate the functions.

7.5 Masking Spectrum Results

7.5.1 Indirect Radiating Speakers –Ceiling Plenum Masking

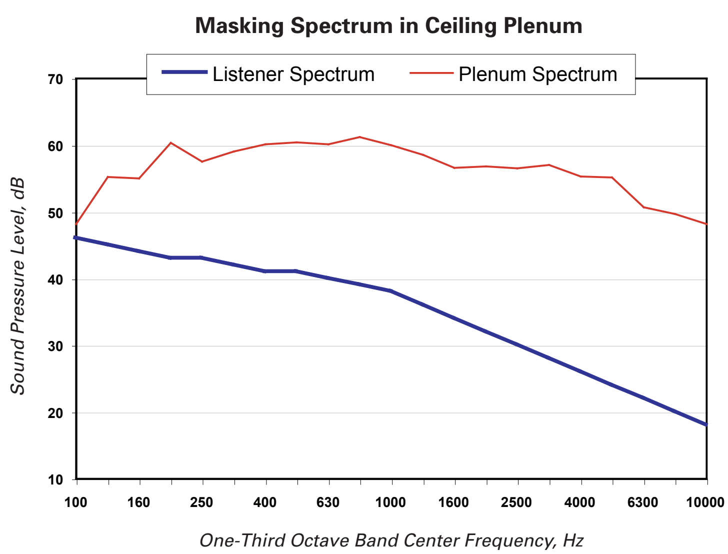


Figure 7-24

With the masking speakers in the traditional location, it is possible to achieve a very smooth and acceptable masking spectrum within the capability of most equalizers. ***Figure 7-24*** shows the sound spectrum that is necessary within the ceiling plenum in order to achieve the desired spectrum at 48 inches above the floor. The speaker face was about 12 inches above the suspended ceiling in a 36 inch high plenum and the spectrum was measured 12 inches above the speaker. It is clear that the speaker view of the plenum depends on frequency. The important point is that neither a high pass nor low pass filter alone (as we find in distributed systems) is adequate to create a smooth spectrum (7.1.1, 7.1.5). Further, the data strongly suggests that a one-octave band filter is not sufficiently narrow to create the desired spectrum. The uniformity of levels is generally good if the speaker spacing is as recommended (6.2.2). Incoherence is high for mineral tile ceilings, and is slightly detectable for foil-backed fiberglass ceilings if the checkerboard speaker array is not used (6.4.1). If the suspended ceiling is 12 feet or more in height, diffusion of the masking is sufficient to make it difficult for a listener to determine that the speakers are in the ceiling plenum. For lower ceiling heights, it is possible to tell the speakers are above.

7.5.2 Indirect Radiating Speakers -Raised Floor Masking

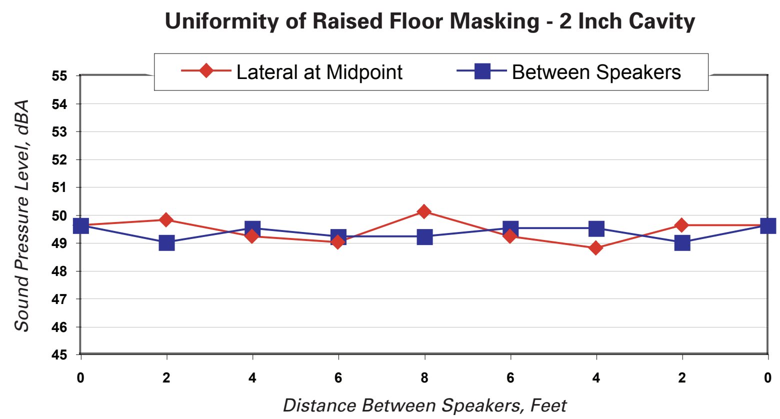


Figure 7-25

Although the first successful under floor masking system was installed in 1982, it still is not a common design even though we recommend it over ceiling plenum masking. Because of its novelty, there might have been some reluctance to install such systems, particularly since there are a variety of raised floor heights. The most challenging is a raised floor cavity 1⅞ inches deep. This requires a very low profile masker with dipole radiation characteristics. ***Figure 7-25*** shows the uniformity of masking levels in two directions as measured 48 inches above the floor. No furniture panels were present. The speakers were spaced on a 14 by 16 foot grid (data courtesy of Dynasound, Inc). It is clear that even with such a small cavity, the uniformity of masking is excellent. The incoherence and diffuseness of the sound is also good.

7.5.3 Indirect Radiating Speakers – Open Ceiling Masking

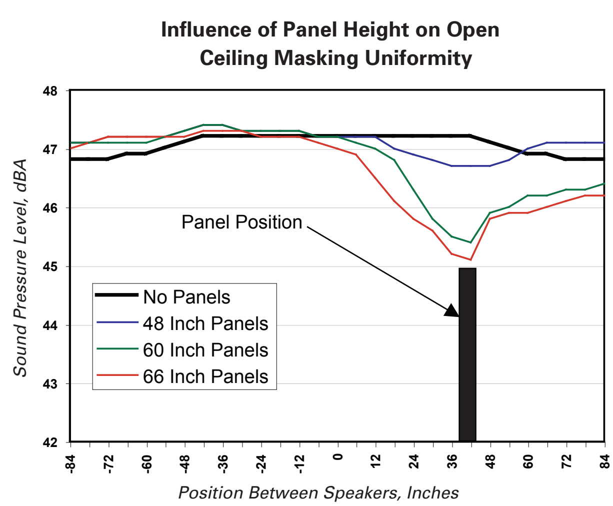


Figure 7-26

When masking speakers are hung in a ceiling space with no suspended ceiling material under them, the acoustical characteristics of the space are different, but masking can still be applied successfully. A computer model was created using multiple image sources, each with the specific directivity characteristics of eight inch masking speakers. ***Figure 7-26*** shows the distribution of A-Weighted levels where the structural ceiling is 12 feet high (worst case) and the speakers are placed 10 feet high and facing upward and spaced 14 feet apart. A furniture panel of varying height was placed 3 feet from the midpoint between the speakers. It should be noted that the level at the midpoint between the speakers with no panel is slightly higher. The maximum variation with no panels is 0.5 dBA; with 66 inch panels, it is 2 dBA. When the structural ceiling is near 12 feet high and the furniture system has panels 66 inches high or higher, some shadowing (non-uniformity of masking level) occurs. Field experience has shown that with higher ceilings, the speakers can have larger spacing and be hung higher, while maintaining sufficient uniformity of level, incoherence, and diffusion.

Since the speakers are likely to be visible, architects and owners prefer that the speaker color match the structural ceiling and the wiring connections and controls be on the top face.

7.5.4 Direct Radiating Speakers

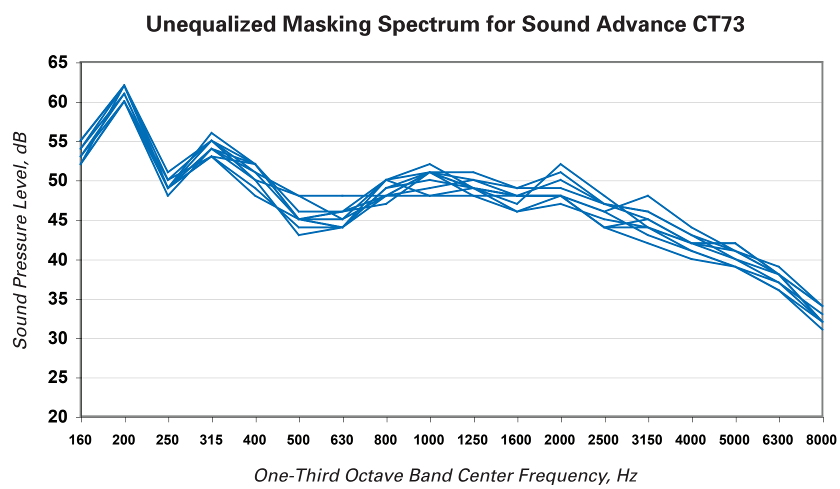


Figure 7-27

Direct radiating speakers, particularly flat panel ones, cannot take advantage of incoherence or good sound field diffusion. Further, the radiating characteristics cannot be arbitrarily adjusted to offset the inverse square law of propagation leading to estimates of spectrum and level non-uniformity. Incoherence is overcome with a checkerboard wiring design (6.4.1). It is not possible to increase the sound diffusion except possibly with very high suspended ceilings. Measurements of two products have suggested that the variations from spectral uniformity can be minimized with speakers spaced on a 12 foot grid in a ceiling 12 feet high. ***Figure 7-27*** shows the spectra as measured 48 inches high and at one foot increments between the speakers. At that spacing, it is expected that the slight non-uniformity would be acceptable to most listeners. Note that the level was arbitrary for this test.

Figure 7-28 shows the uniformity of the A-Weighted level between the speakers for two flat-panel masking speakers when spaced 12 feet apart. The speakers were in a 9 foot high ceiling and measurements were made at seated height (48 inches). The level variation at that separation distance is well within acceptable limits.

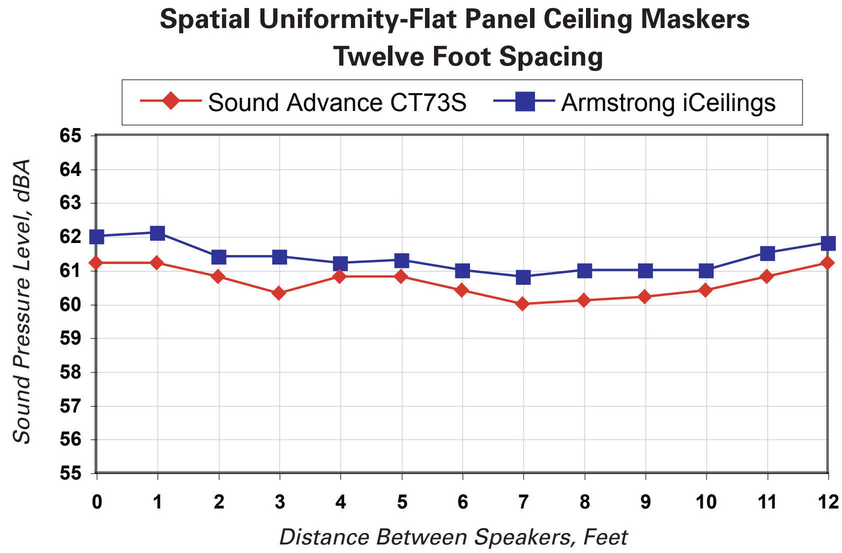


Figure 7-28

One manufacturer suggests speaker spacing distances as far as 16 to 18 feet, based on ceiling height and workstation panel height. Modeling suggests that both spectrum and level variations will be excessive at those distances.

Direct radiating speakers have some limitations. It is standard practice to use a checkerboard wiring design to create an incoherent sound field (6.4.1), otherwise persons in open offices will detect a "phase effect" (7.1.1). The sound field cannot be diffuse, requiring more care in setting levels. It is always possible to point directly at the speakers even though they may be invisible, violating Design Rule Two (6.1).

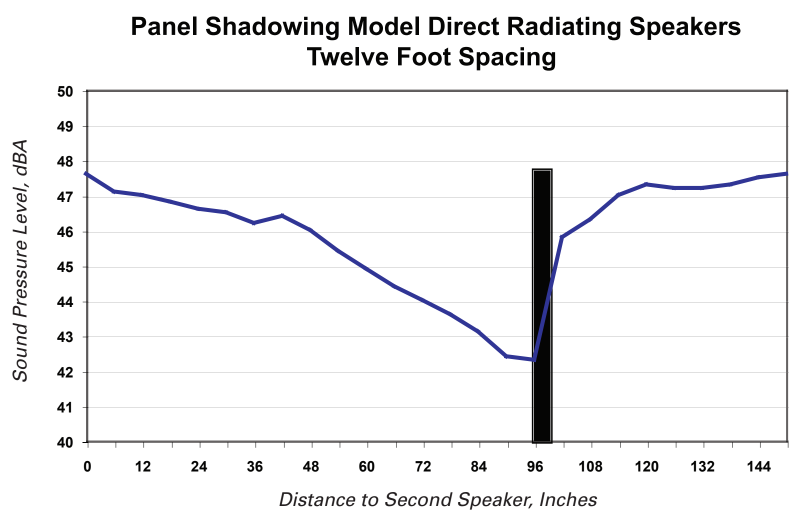


Figure 7-29

Because they are direct radiating, sound shadows will occur in the open office for certain panel heights and locations. Using the directivity characteristics of one flat panel speaker, a computer model was created. ***Figure 7-29*** shows a representative example. The distribution of A-Weighted levels at seated height is shown for a panel height of 66 inches offset by 3 feet from the midpoint between the speakers. The speakers were in a 9 foot high suspended ceiling and spaced 12 feet apart. The shadowing of the nearest speaker caused about a 4 dBA variation from directly beneath. This model was limited in that only one panel was used instead of entire workstation. It can be expected that shadowing will be reduced for higher ceilings (less severe diffraction losses), and increased for wider speaker spacing and higher panels.

Although it is possible to install plenum mounted speakers above gypsum board ceilings and properly equalize them, it is not practical if the ceiling is already installed. Direct radiating speakers can be more easily retrofitted in this situation. For example, the central core of buildings and similar areas, may have gypsum ceilings where Soundscaping applications may be needed (6.3.1).

7.5.5 Task Maskers

There are a number of ways masking can be introduced into an office workstation. We like to call it *task masking* since it is economical to apply it only locally. The work surface itself can be vibrated; a masker can be placed under the work surface, typically on the floor. A masker can also be embedded into the panel system or behind a tackboard. Maskers mounted on top of panels are more correctly identified as indirect radiating speakers since they are intended to cover wide areas.

7.5.5.1 Workstation Panel Masking

In this arrangement, a speaker or vibrator is embedded into the panel itself. The virtue of this arrangement is that the speaker is not visible. Manufacturers have considered the method impractical at this time. A special support structure and wiring is required. Exchange of panels results in the loss of distinction between those with a masker and those without. The author had a panel masking system in his office for over four years using an embedded vibration masker on a small plate. Three panels had maskers. Equalization was much like that for a centralized system and Normal Privacy (2.2.3) was achieved.

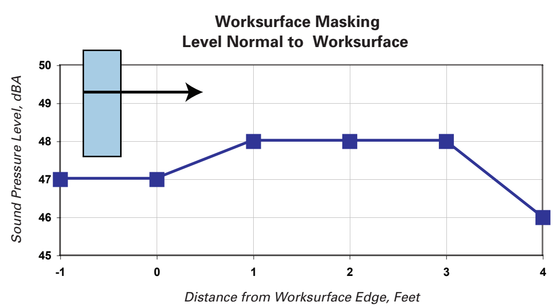


Figure 7-30

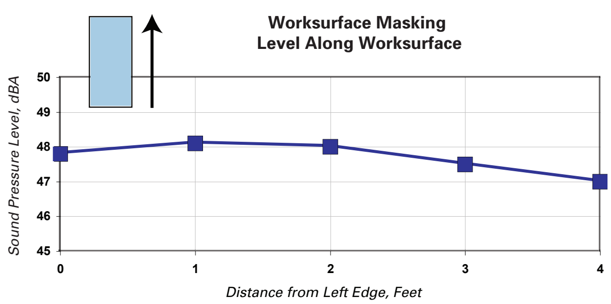


Figure 7-31

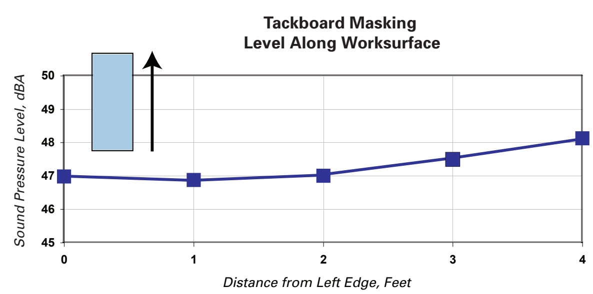


Figure 7-32

7.5.5.2 Workstation Worksurface Masking

A vibrator was attached to the underside of the work surface so it became a speaker, creating localized masking for the person working at that surface. To provide more coverage, a speaker was affixed to the underside of the work surface that radiated out into the workstation. Both devices were connected to the same source. The occupant was able to adjust both level and spectrum locally. The maskers were not visible. The high degree of level uniformity, shown in ***Figures 7-30 and 7-31*** suggests that localized masking can be effective. This design was first implemented in 1987.

7.5.5.3 Workstation Tackboard Masking

A speaker masker was attached to the back surface of a workstation tackboard. The board was offset from the supporting panel by 1½ inches. This permitted the masking to radiate around the sides of the tackboard. Again the masker is not visible. ***Figure 7-32*** shows that the level uniformity along the worksurface was good. This design was first implemented in 1984.

7.6 Computer Aided Equalization

The MEQ program has a database of commonly used spectra, which allows you to add new ones. Measurements are made in a zone, and they are downloaded to the program (if the analyzer has that capability) or entered manually. The spectrum desired is compared with the spectrum measured and the corrections needed are determined. A one-third octave band real time analyzer is needed to do it properly. A user manual is available that details the program use.

7.6.1 Available Support Information

While the program is running, multiple documents can be opened.

1. The **Comm Port** must be entered in order to download.
2. A data sheet to record measurements can be opened in Word and printed.
3. An electronic data sheet can be opened in Excel to record measurements.
4. A tutorial on equalization procedures can be opened in Word and printed.
5. A tutorial on the meters that can be used for downloading is provided.

7.6.2 Editing the Masking Spectrum Database

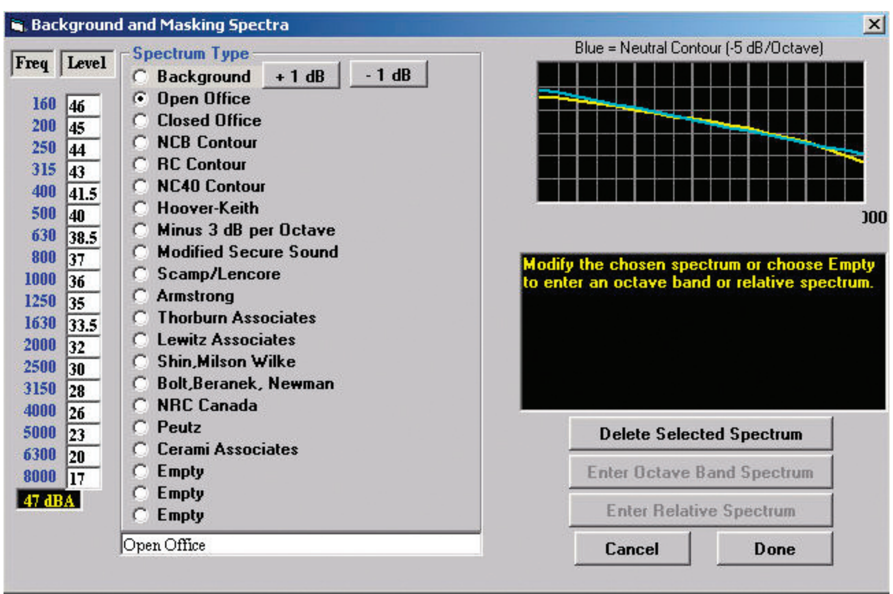


Figure 7-33

One of the spectra in this module must be used to equalize the sound masking system (the goal or desired spectrum), so whatever spectrum is required for the system must be in this database. It is not necessary for the overall level (dBA) to be correct as it can be changed later in the program.

If a specification is given in octave bands, the program will convert octave band levels into ⅓ octave band levels. ***Figure 7-33*** shows the screen. It contains a background spectrum for reference: spectra that are recommended for open and closed offices, spectra from standards, and those preferred by various acoustical consultants. Some empty records are available so other spectra can be added. Any of the masking spectra can be modified or deleted. All the spectra in the database can be printed. The neutral contour of - 5 dB/octave is shown in the graph.

7.6.3 Equalization of the Masking Spectrum

The first step in setting the proper masking spectrum is to collect a set of representative measurements for the channel/zone of interest. The detailed procedures are in the tutorial and are printable.

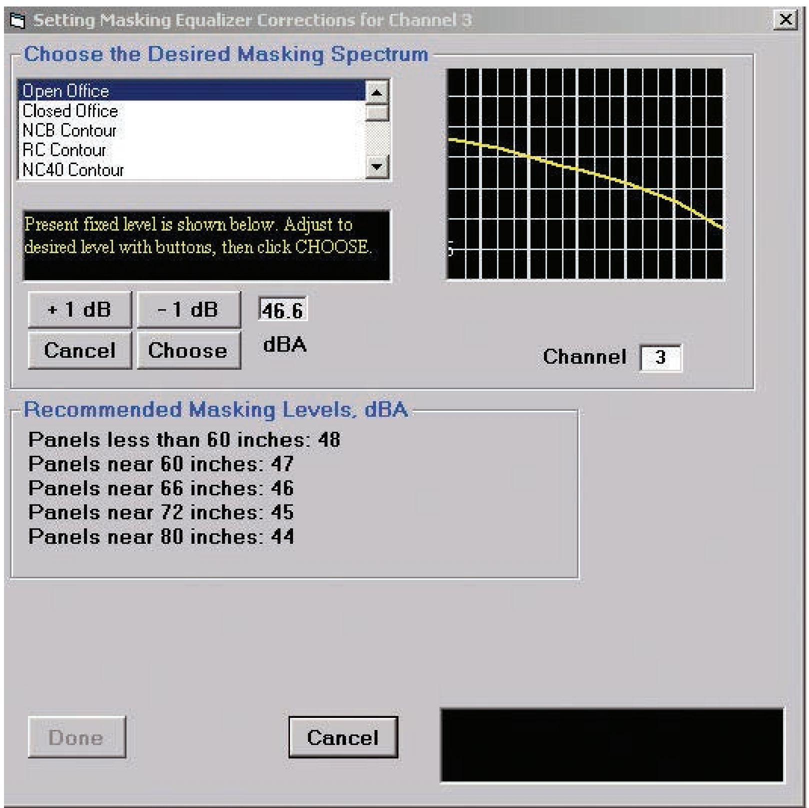
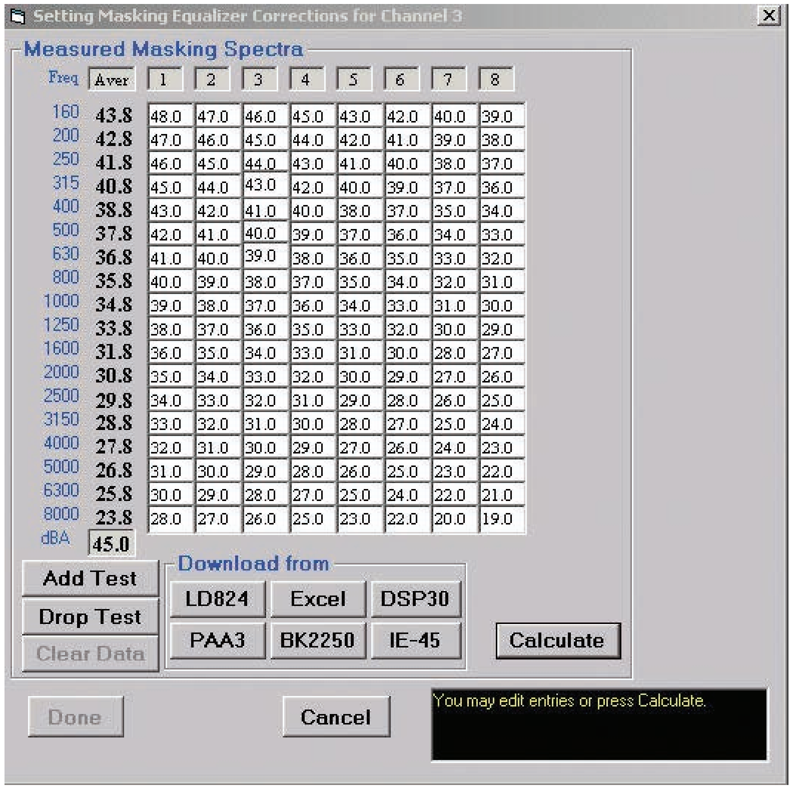


Figure 7-34

The second step is to choose the *desired* masking spectrum for that zone. ***Figure 7-34*** shows the screen. The first two choices are the spectra recommended for open and closed offices. In each case, there is a table of recommended overall levels that can be used to set the overall level of that spectrum. This becomes the spectrum we wish to match. Any of the spectra in the database can also be used.



Freq	Aver	1	2	3	4	5	6	7	8
160	43.8	48.0	47.0	46.0	45.0	43.0	42.0	40.0	39.0
200	42.8	47.0	46.0	45.0	44.0	42.0	41.0	39.0	38.0
250	41.8	46.0	45.0	44.0	43.0	41.0	40.0	38.0	37.0
315	40.8	45.0	44.0	43.0	42.0	40.0	39.0	37.0	36.0
400	38.8	43.0	42.0	41.0	40.0	38.0	37.0	35.0	34.0
500	37.8	42.0	41.0	40.0	39.0	37.0	36.0	34.0	33.0
630	36.8	41.0	40.0	39.0	38.0	36.0	35.0	33.0	32.0
800	35.8	40.0	39.0	38.0	37.0	35.0	34.0	32.0	31.0
1000	34.8	39.0	38.0	37.0	36.0	34.0	33.0	31.0	30.0
1250	33.8	38.0	37.0	36.0	35.0	33.0	32.0	30.0	29.0
1600	31.8	36.0	35.0	34.0	33.0	31.0	30.0	28.0	27.0
2000	30.8	35.0	34.0	33.0	32.0	30.0	29.0	27.0	26.0
2500	29.8	34.0	33.0	32.0	31.0	29.0	28.0	26.0	25.0
3150	28.8	33.0	32.0	31.0	30.0	28.0	27.0	25.0	24.0
4000	27.8	32.0	31.0	30.0	29.0	27.0	26.0	24.0	23.0
5000	26.8	31.0	30.0	29.0	28.0	26.0	25.0	23.0	22.0
6300	25.8	30.0	29.0	28.0	27.0	25.0	24.0	22.0	21.0
8000	23.8	28.0	27.0	26.0	25.0	23.0	22.0	20.0	19.0
dBA	45.0								

Figure 7-35

The next step is to put the measured spectra into the program. ***Figure 7-35*** shows an example of some measurements. This data can be entered manually either from the meter or from a paper data sheet, but it can be very tedious. The program has information on downloads from the Larson-Davis Model 824, the Ivie Technologies Model IE-45, the Goldline Model DSP30, and the B&K 2250. For two of the meters, the sample averaging is done in the meter, so only one spectrum is downloaded. The program does an *arithmetic* average in distinction to an energy average in order to avoid overweighting the higher levels that would provide more privacy.

At this point, the program has the desired spectrum and the actual spectrum. The low pass filter setting is entered (7000 Hz is recommended) and the button to match the spectra on a mean–square basis can be pressed. ***Figure 7-36*** shows the results. The recommended low pass and high pass filter settings are shown, the required one-third octave band corrections are indicated as well as the required overall gain adjustment.

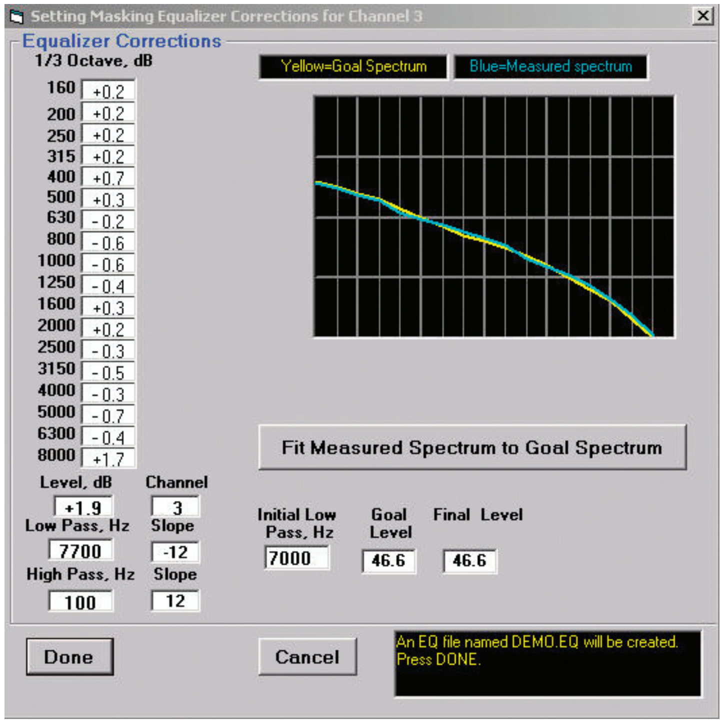


Figure 7-36

When the **Done** button is pressed, the left hand side of the data screen is saved to a file with the extension EQ.

7.6.4 Setting Paging Levels

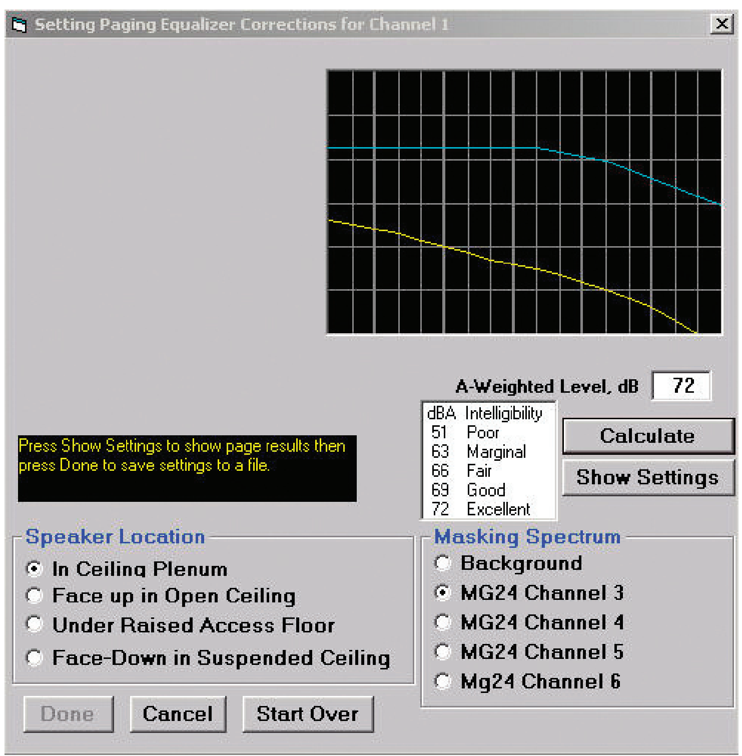


Figure 7-37

If paging is applied in zones that have masking, the paging level must be set high enough to ensure good intelligibility. The paging module permits this to be done. The basic concept is to use the masking spectrum in that zone as the background and apply the principles of speech intelligibility (A-5) to raise the paging level until intelligibility is acceptable.

Initially a masking spectrum must be chosen. The example shown in ***Figure 7-37*** is for an ASP-MG24 generator. The zone of interest was fed by Channel 3 (IN3) masking. To set the paging spectrum in the generator, one must know the location of the speakers. In the example, the ceiling plenum was chosen.

Once these data are chosen, press **Calculate** and the results will be shown on the screen and will be saved into a file that can be used by the ASP-MG24.

7.7 Final Checks and Social Aspects

Every occupant of the masked space is, in essence, an acoustical inspector (1.11). Facility managers do not like surprises, especially relating to a technology with which they are not comfortable. There are several reasons to make non-technical assessments of the performance of a sound masking system after completing equalization.

The first is to check for technical errors by making a circuit through all zones with a sound level meter set on A-Weighting. The system should be set at final levels. Before doing the circuit, the initial ramp up function (5.5.2, 7.5.6) and the automatic level control function (5.5.1, 7.5.5) of the ASP-MG24 must be bypassed, otherwise the space may wind up as an acoustical disaster area. The installer becomes the acoustical inspector. It is especially important to identify and immediately report any areas where the sound masking may be ineffective for reasons beyond the control of the installer. Particularly important are corner workstations in the open office where higher level managers expect good privacy. Another is the presence of speakerphones or other sound equipment in the open office.

If the system is multi-zone, check that wiring for each zone is correct by adjusting the settings on the zone controls. When asked to adjust levels, the owner's representative should do so only in the correct zone.

The owner's representative should experience the privacy afforded at the final levels. This is especially important for closed offices where expectations of Confidential Privacy are high. It is recommended that an employee read material in one room while the owner and the installer listen in the other. It is best accomplished when the space in unoccupied. Also, it is very reinforcing for the owner's representative to experience the effect of masking. If possible, during a circuit, read text at conversational levels in various locations (particularly the open office) with the sound masking both on and off. This can be done with a walkway test. (Appendix B).

The owner's representative should be asked about the presence of hearing or visually handicapped persons and the conditions they have to operate should be explained (6.1.4).

Finally, the levels should be set back to the initial levels. For small systems, the initial level should be about 6 to 8 dB lower than final levels. For the large system with the ASP-MG24 and zone controls, the automatic level control function should be activated, and the initial ramp up function set to about –10 dB. The ramp up time should be at least 30 days. The zone controls can be set at mid-step.

CHAPTER 8
SOUND MASKING SECURE FACILITIES

Most of the prior discussion centered on listeners that were accidental, those who had no interest in the conversations overheard. There are many cases where the listener is a deliberate eavesdropper who may make use of sophisticated listening devices to improve speech intelligibility. Examples occur in both government, military, and commercial situations. For deliberate listening, the normal methods of masking are not adequate and new techniques and equipment must be utilized.

The reason for concern is that most major strategic and tactical decisions are first made orally at meetings and if an eavesdropper can obtain access, it gives him a distinct time advantage over written or computer documents. Therefore speech is the primary focus for this application.

To protect conversations, it is normal practice to use the structural "solution" such as rooms that have high sound attenuation (3.1.3). For example, the government uses the technique of a room-within-a-room which is very expensive. Unfortunately, many facilities do not have the budget for such measures, particularly when one considers all the ways audio access might be achieved. Worse yet, rooms with high sound attenuation do *not* guarantee protection. There are three factors that play a role in protecting conversations: how loud the conversations are, how much those conversations are attenuated en route to a potential eavesdropping location, and how loud the background sound is at the eavesdropper (3.1.4). The technical weaknesses of rooms with only high sound attenuation are apparent. If a sound system is used to amplify speech such as a PA system or speaker phones, the room cannot be changed to accommodate the raised levels. When a room is constructed, there is no knowledge of the background sound level at locations where listening devices might be placed. A less obvious weakness is that modern listening devices can be placed in locations that building structure cannot protect against (inside wall cavities, remote sensors of window vibration).

Sound masking fills that gap. Not only does it permit the user to adjust and verify the degree of protection from most eavesdropping methods but it also affords very large cost reductions in both room construction and security maintenance. As shown below, this method of protection is accepted and used by the federal government. In addition, masking systems can be installed permanently or used in temporary locations such as hotel meeting rooms.

The goal for secure facilities is Secret Privacy (2.2.1).

8.1 Background

The American Society of Industrial Security and the U.S. Department of Commerce estimate the Fortune 500 companies have lost more than $45 Billion in 1999 due to the theft of proprietary information. It has been estimated this amount has risen every year. The Federal Bureau of Investigation brought back an experienced agent to head counterintelligence operations. An article in USA Today on May 5, 2004, stated that many of our "friendly nations" such as China, South Korea, India, France and Israel, do economic espionage on our defense, research, and high-tech firms. For obvious reasons, details about all the methods used to gain access to the information are not given.

Although audio surveillance is not mentioned in any of the current articles, the federal government has been well aware of this problem for many years. In the new embassy in Moscow the American eagle display was found to be a listening device. Even agencies associated with economics such as the Board of Governors of the Federal Reserve have taken steps to protect against eavesdropping during discussions at their meetings. The extension of this to commercial markets is obvious.

A standard protection method is to “sweep” a room, but this is not effective against all listening devices.

8.2 Applications

There are a growing number of applications for secure masking. Any organization that has a need for protecting sensitive conversations from actual or potential eavesdroppers should consider using sound masking as an effective deterrent. Organizations that can benefit from such protection are:

- Department of State facilities, such as embassies
- Department of Defense facilities
- All military departments
- Department of Homeland Security agencies
- Narcotics agencies
- Intelligence and counter-espionage agencies
- Corporate research facilities
- Corporate planning facilities
- Corporate human resource departments
- Corporate mergers and acquisitions departments
- Corporate boardrooms
- Legal offices
- Accounting firms

8.3 Standards

The federal government has regulations for protecting sensitive conversations. Standards organizations have not developed any for commercial use as of yet.

8.3.1 DIAM 50-3

Although this document [49] is no longer the primary one related to physical security standards, the chapter on Audio Security addresses speech privacy in general. It notes the value of sound masking as a tool.

8.3.2 DCID 6/9

This document [50] is now the primary unclassified document on physical security in Secure Compartmented Information Facilities (SCIF). Annex E of that document pertains to “Sound Masking Techniques.” It states “..systems are designed to protect SCI against being *inadvertently* overheard by the *casual* passerby, not to protect against deliberate interception of audio.” Experience with secure masking systems over twenty years has shown that military contractors and government agencies have been more concerned about the *deliberate listener*. It is likely that a publicly unavailable document exists that provides guidance for protecting against eavesdroppers. The document does note that sound masking devices may be used on doors, windows, walls, and vents or ducts, where applicable. Unfortunately, the document *erroneously* permits music as the sole source of masking. Music is variable in level and frequency so provides poor coverage, but worse, most music is commercially available for an eavesdropper to use as a canceling signal. However, music can be used effectively in conjunction with other sounds.

8.3.3 AFP 88-26

The United States Air Force has this document [51] on the construction of secure conference rooms. It goes into great detail on the methods for creating sound attenuation around the room as well as control of communication devices. It states, "The employment of sound masking in wall voids, doors, windows and overhead ducts may be a more economical technique to achieve acceptable transmission losses.". There is no "may" about it.

8.3.4 Gramm, Leach, Blily Act

In compliance with this law [52], all financial institutions must protect the confidentiality of customer information and guard against any threats to the security of it.

8.4 General Aspects of Security Masking

8.4.1 Categories of Surveillance

Two must be addressed. Uncontrolled areas are those where the persons attempting to protect themselves have little or no control over the environment. Generally, this includes all areas outside the building in which the secure room resides. Examples include parking lots or other public spaces where it is possible to gain access without detection. Controlled areas are those within a building where there is a measure of control. The method of protection depends on this difference.

8.4.2 Types of Masking Signals

Taking into account the capability of sophisticated listeners to recover speech buried in noise, it is necessary to provide *layered* protection. Instead of just one type of masking signal such as was discussed in earlier chapters, the generator creates and mixes several signals. For uncontrolled areas, *non-stationary* random noise (4.2.3) must be the first layer. It covers the entire speech spectrum as in commercial sound masking, but its non-stationary characteristic inhibits signal recovery. For controlled areas, the less expensive stationary random noise generator is adequate. Music may be used as the second layer; it is buried below the random noise so it is not actually audible to room occupants. Voice babble or speech samples may be used as a third layer; it may be set at the same or lower level as the music signal. If equalized properly, the fourth layer (the actual voices to protect) will be sufficiently buried below the other layers.

8.4.3 Types of Masking Systems

There are two types of masking systems, the fixed and the portable. Most of this discussion will concern the fixed system that is permanently installed in the room to be secured. However, there are situations where sensitive conversations must be conducted while traveling, such as in hotel/motel rooms. The portable system can be used for this situation. It provides coverage of windows, doors, walls and air vents. Installation is quick; the maskers are attached temporarily and are removed when done. Evidence of attachment can be removed easily. This system does not have the refined capability of fixed system equipment, so levels are set higher than for fixed facilities in order to guarantee protection. As a practical control, all equipment and wiring should be contained within the secure room whenever possible.

8.4.4 Handling Amplified Speech

In some secure facilities, such as conference rooms, audio amplification of speech is used. It may be with a microphone or as part of a playback system. There are several aspects of such use that make eavesdropping simpler. These systems are almost always set too loud, and the level can be too easily adjusted with the turn of a knob. Protection of speech requires precise measurement which can be completely undone with the turn of a knob. Worse yet, the adjustment of treble controls can enhance speech intelligibility just as is done with hearing aids and paging systems. To ensure that protection schemes are effective in protecting speech, audio systems should *not* be used. Unfortunately, some rooms, e.g., boardrooms, will have them. When this is the situation, physical controls need to be put on the equipment to limit the maximum level and the frequency spectrum. This requires modification of the equipment.

8.5 Locations for Protection

Consider the perimeter envelope of a room as a location for listening devices. Windows, walls, doors, ducting, piping, ceiling plenums, raised floor cavities, and loudspeakers are all penetration points. Each location is discussed below. First, the threat is addressed, then the standard solution, and finally the sound masking solution.

8.5.1 Windows

Windows face uncontrolled areas so special measures need to be taken.

8.5.1.1 The Threat

A prerogative of high office has always been windows, both in offices and conference rooms. The word "eavesdropping" originated with listening at window eaves. It should go without saying that an open window is an open invitation to listening, so that aspect is not discussed. However, speech near a closed window causes a minute vibration of the pane that appropriate sensors can detect. Since windows respond well at speech frequencies, the window easily carries intelligible speech in the form of vibration. ***Figure 8-1*** shows spectra of vibration on a window caused by a sound spectrum that is characteristic of a male talking at normal voice level at three feet and facing the window. The spectra were measured at a number of positions on a window whose dimensions were 32 inches wide by 56 inches high. The levels shown were arbitrary since the spectral contours were of more interest. The spectra shown were speech weighted (A.1.6), just as an eavesdropper would do to enhance intelligibility. It is clear from this figure that windows are ideal locations to detect conversations within a room.

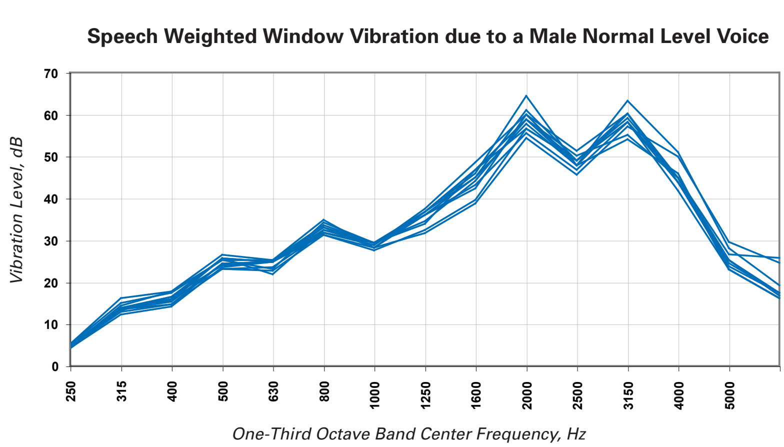


Figure 8-1

Figure 8-2

There are three ways to eavesdrop. First is the direct attachment of a *vibration detector* on the pane or the frame. Accelerometers or strain gauges are difficult to see but can be discovered by inspection so are unlikely to be successful. These devices are commonly available. Second is the *laser microphone*. The transmitter of this device sends an infrared beam that reflects from the window to a receiver. The minute vibrations of the window modulate the carrier frequency that is later demodulated into speech. Theoretically, such a device can operate from any distance and, since the beam is invisible, is a potent detection device. It can be disguised easily because it is small. ***Figure 8-2*** shows it as a camera. Since the beam undergoes nearly specular reflection, very careful positioning is essential. This is time consuming and reduces the number of microphone locations and the number of windows that can be covered. Although manufactured in Europe and the United States, ordinary citizens are not permitted such devices. The present widespread protection of windows in secure facilities suggests that these devices are in common use. Further, many websites suggest designs for such devices and remote detection of machinery vibration has been done for many years. These latter devices use a red laser so the beam is visible. Window vibration caused by high wind or high levels of traffic noise will act as masking and so will inhibit detection, but these factors are not under the control of the person attempting to protect the room.

Third is the *highly directional microphone* that detects the velocity fluctuations of the window (the radiated sound). The advantage of this device is that it can be at relatively arbitrary angles to the window. Not all such microphones have a large parabolic reflector that would make it easier to detect. These devices are commonly available, at places such as sports events. Again, window vibration caused by exterior noise sources will inhibit detection.

8.5.1.2 Standard Solutions

The most secure solution is to eliminate the windows entirely. Although it is the best solution, it is not always acceptable to occupants. Some have considered double pane windows with a higher STC rating as adequate protection. This is not the case.

Since more than acoustic emissions occur through windows, films have been applied to block any electromagnetic emissions. There have been claims that such films also will protect speech. Unfortunately, a film *cannot* be used to sufficiently reduce the mechanical vibration of a window that carries the speech.

Early masking methods placed a loudspeaker facing down from the suspended ceiling. They were called *window washers* since the sound "washed" over the window causing random window vibrations. Unfortunately, the level required at the window was loud enough to interfere with the speech to be protected, as well as to annoy the occupants. To converse, voices had to be raised, a self-defeating proposition.

Figure 8-3

Speech information is in the form of vibration modes of a plate constrained at the edges. The brighter areas in ***Figure 8-3*** show the locations where the most speech band anti-nodes are located. The frame also carries speech information.

8.5.1.3 Masking Solution

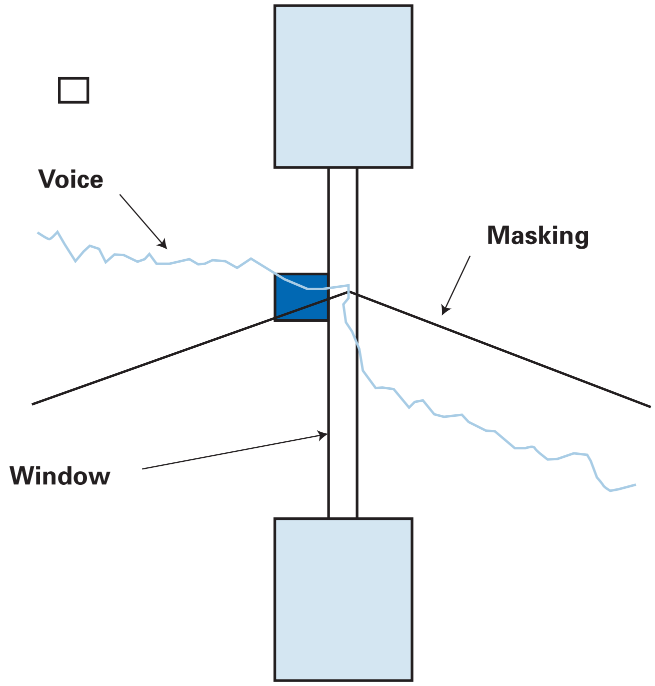


Figure 8-4

Because windows will almost always face uncontrolled areas, care must be taken in protection. The non-stationary masking generator mentioned above is needed for this case. A vibration masker is attached to the window. It converts the generator signal to a broadband random vibration covering all speech frequencies. Because windows have many vibration modes, positioning of the masker is important. A laser beam, can be aimed at any point on the window or frame. Measurements have shown that placement of one masker on normal sized windows will excite enough of the vibration modes to provide complete coverage at all points when the location and masking spectrum are set properly. The masker is located where it can drive the frequency modes that are most significant for intelligibility. The window masker is the same as that used for walls. Maskers on adjacent windows facing the same direction must *not* be placed in exactly the same locations. If one window contains only the masking and no conversation, the eavesdropper can subtract that signal from the one in which both masking and conversation vibration exist.

Practical application suggests that one masker be used if possible, but what is the best location for it? The position is determined by two considerations: (1) excitation of an effective level of masking vibration over the entire window, and (2) minimizing the visibility of the masker. With these constraints, it appears that an acceptable position for the masker is close to the frame in one direction and at the midpoint in the other direction as suggested by ***Figure 8-3***. ***Figure 8-4*** shows schematically the comparative levels of speech and masking. The masking in the room is below the speech, but is above the speech on the window and outside the room.

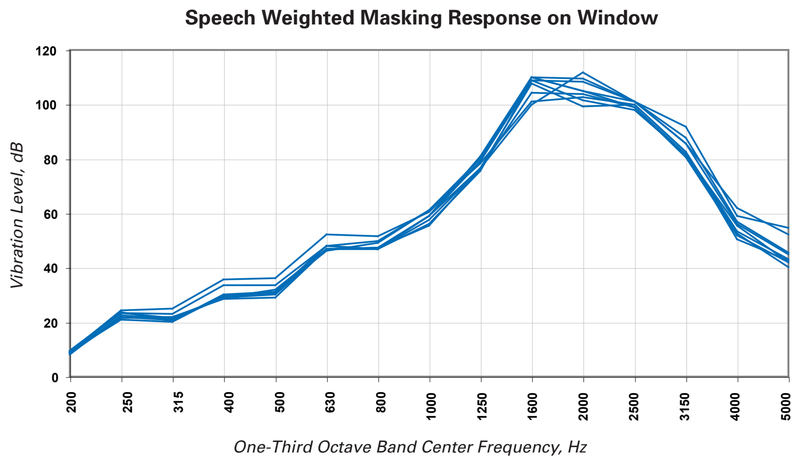


Figure 8-5

Figure 8-5 shows the speech-weighted vibration spectra caused by a masker at the position recommended for a window 32 inches wide and 56 inches high. The spectra were measured at widely diverse positions from window center to window corners. It is clear that the window responds as well to a vibration masker as it does to speech impinging on it. Despite the modal characteristic of the vibration, the level variations are small enough to be taken care of by equalization. It should be noted that the two figures have arbitrary levels. Calibration of levels is not required to calculate Privacy Index (C.3).

For design purposes there are several categories of windows:

- **Normal Windows.** These windows have a largest dimension of less than five feet so only one masker is required.

- **Large Windows.** These windows have a largest dimension of five feet or greater, so two maskers are required.

- **Multi-Pane Windows.** Each pane will vibrate in response to speech. If the pane is thick and small the vibration response is small and mostly above the speech frequencies so no masker may be necessary, unless amplified speech is used. If expense is of concern, the *window washer*, discussed in the section on walls, may be used to cover multiple panes otherwise one masker is required for each pane.

- **Double Pane Windows**. Each pane is a partially independent vibrator; the interior pane response is higher than the outer pane. Double panes result in an STC rating that is higher than that for a single pane, so the transmitted sound is attenuated, reducing the ability for a directional microphone to detect speech, but does not preclude the effective use of laser microphones. As a result, double pane windows should be treated as if they were single pane.

8.5.2 Walls

8.5.2.1 The Threat

Again, there are two categories of walls, exterior walls facing uncontrolled areas and interior walls facing controlled areas.

Exterior walls can be constructed of many materials, not all of which require protection. Because interior walls are most often constructed with studs and gypsum board to reduce weight, listening opportunities are better if access to the wall cavity can be achieved. For example, standard construction may consist of one or two sheets of gypsum board on either side of a wooden or metal stud with an air cavity that may or may not be filled with fiberglass.

There are several ways speech can be detected through walls.

Remote from the wall. On all types of walls, listening can be done remotely from the far side, with microphone or ear. On exterior walls this method is greatly inhibited by the heavy wall structure and the fact that the outdoor background sound level is generally high enough to further inhibit eavesdropping. However, on interior walls, with much lighter construction, such is not the case as persons in many closed offices can attest. This method of listening must be taken into account for both interior and exterior walls.

On the far side of the wall. Detection of wall vibration on the far surface can be accomplished with a remote laser microphone or by attachment of a vibration detector. On most, but not all, exterior walls, detection of this type is very difficult. On interior walls, with their lighter construction, vibration probes can be used quite effectively. This method of listening must be taken into account for both interior and exterior walls.

Figure 8-6

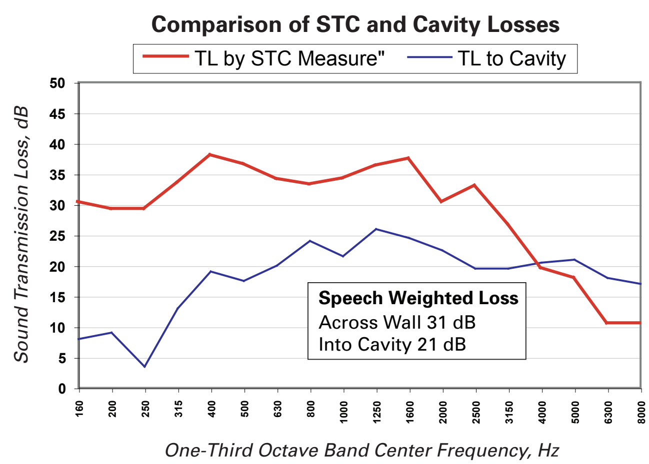


Figure 8-7

Within the wall cavity and on interior surfaces. Wall cavities can be hollow or filled with fiberglass for thermal insulation or for additional sound attenuation. Penetration of either exterior or interior walls that have cavities can be used to place acoustical devices in the cavity as well as to attach vibration devices on either of the inner surfaces of the cavity. There are two acoustical devices that can be used within the cavity. The first is the normal microphone that converts sound to an electrical voltage. Many are quite small. They may require a wire to carry the signal out, or have a transmitter to send it remotely. The second is the less known *fiber optic microphone,* ***Figure 8-6***. It is an analog to the laser microphone used on windows, except that the beam is confined to a fiber optic cable. It has no metallic parts except for a thin aluminum diaphragm. It is very difficult to detect; is quite small and may be mistaken for a normal fiber optic cable if merged with others. This method of listening must be taken into account for both interior and exterior walls.

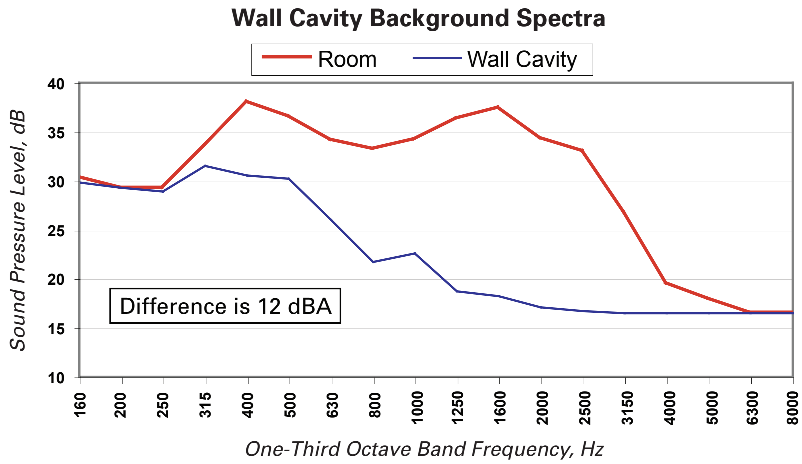


Figure 8-8

How good is the acoustical environment in a wall cavity? A sound source was placed in the source room. An STC procedure across the wall was used where each measurement point was 36 inches from the wall. A spectrum was obtained within the wall cavity at the same height. The results are shown in ***Figure 8-7***. The SL across the wall was 41 while the SL to the cavity was only 21, a considerable advantage for an eavesdropper. What about the background spectrum inside the wall? The measurement is shown in ***Figure 8-8*** and compared with the background spectrum level in the room. Lower loss into the wall and lower background level makes for excellent listening conditions.

8.5.2.2 Standard Solutions

The solution has been to require high Sound Transmission Class walls. Established methods die hard; federal standards require walls with STC ratings of at least 45. As with all structural solutions, one may ask the question: Is the sound attenuation adequate to create speech privacy? As discussed in Chapter 3, an answer (which works only for remote listening) is in knowing the background sound level on the far side of the wall. Unfortunately, the STC rating itself does not address performance degradation caused by installation (A1.1). It permits deficiencies, does not address the speech intelligibility spectrum nor does it address any of the other potential listening methods noted above. The only good thing about an STC rating in this context is that the higher the number the better the sound attenuation remote from the wall.

Adding fiberglass to the wall cavity is used to enhance the STC rating. Unfortunately, this inhibits visual inspection, is only partially effective against listening devices beyond the wall, and is not effective for devices within or on the wall. Further, fiberglass inhibits the distribution of sound masking within the wall. Whenever possible, **fill the wall with sound, not fiberglass.**

8.5.2.3 Masking Solution

One solution is to place a loudspeaker masker inside the wall cavity; it is mounted on the inside wall with an inspection plate. To keep secure room levels reasonable, no fiberglass should be in the cavity. The sound inside the cavity will fill it with masking. Also the sound field inside will vibrate both layers of gypsum board, the outer layer of which will radiate masking beyond the wall. Thus it covers *all* possible listening devices and locations when equalized properly. The best position on the wall is at standing height; although other locations can be used. The sound level within the secure room caused by the masking can be heard but does not create speech interference or annoyance.

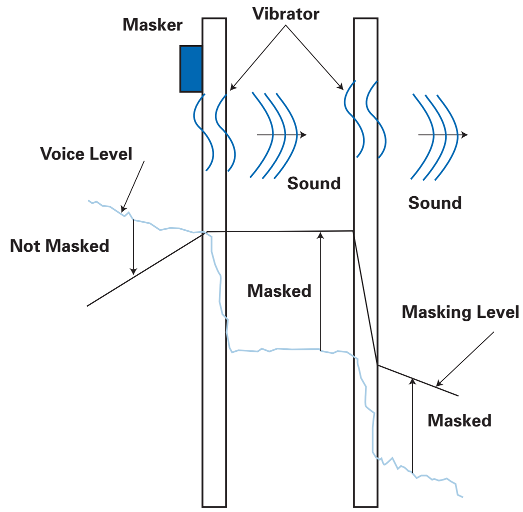


Figure 8-9

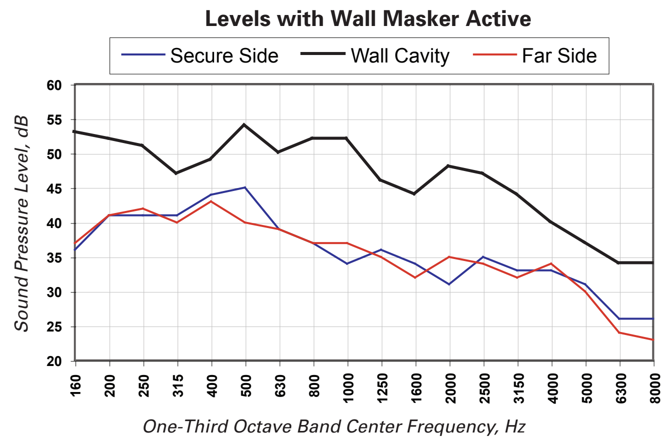


Figure 8-10

As a replacement for the loudspeaker masker, a vibrator can be affixed to the inside surface of the wall as shown in ***Figure 8-9***. This newer method has certain advantages. It is simpler to install and inspect, does not require penetration of the gypsum board, wiring can be seen and inspected, and is just as effective as a loudspeaker. If the vibrator meets building codes, it can be placed above the suspended ceiling. Some older vibrators screwed into the gypsum board. This method of attachment is known to cause the internal gypsum material to settle, reducing the vibration transferred to the wall and thus the masking protection. In newer techniques, the masker contacts the wall over a much larger area and so reduces this effect. The vibration levels are set to exceed the transmitted speech both in the wall cavity at the outer surface and beyond the wall. ***Figure 8-10*** shows that the sound generated within the secure room will always be less than that of the speech within the room.

There are two different categories of walls and they must be addressed differently.

8.5.2.4 Exterior Walls

Although infrequent, some secure rooms have walls facing the exterior of the building. Exterior exposure dictates that non-stationary noise (4.2.3) be used as a masking source. There are several wall types:

Brick or Cinder Block Walls. These walls are relatively massive so transmitted speech is low. It is difficult to use remote sensing since the material has high vibratory damping. It is more difficult to penetrate the material or affix devices because of the rough texture. Generally, these structures do not need sound masking.

Wood or Metal Stud Walls with Exterior Siding. These walls are less massive so speech is transmitted better. Although some walls of this type can be heavy, prudence dictates that they be protected. Vibration listening tests on the outer wall surface have shown that speech can be understood, so masking is required.

Concrete Slab Walls. These walls are massive but have high stiffness, transmitting speech relatively well in vibration form. Vibration listening tests on the outer wall surface have confirmed this. If furred out on the interior, protection may not be required, but otherwise protection is recommended. The junction between slabs must have a cover plate to prevent penetration of probe microphones.

Glass Block Walls. Although not common, such exterior walls occur. The masking solution noted above is not feasible, since most blocks are six inches on a side and would require an excessive number of vibration maskers. In this case, *window washers* affixed to the suspended ceiling above the wall are the recommended solution. Choosing directional maskers reduces the interference with speech within the room.

8.5.2.5 Interior Walls

These walls are generally within controlled areas, so stationary masking generators can be used. There are a variety of materials used for the construction of interior walls:

Brick or Cinder Block Walls. These walls are relatively massive so transmitted speech is low. It is difficult to use remote sensing since the material has high vibratory damping. It is more difficult to penetrate the material or affix devices because of the rough texture. Generally these structures do not need sound masking.

Walls with Studs. These walls are less massive than cinder block, so speech is transmitted better. If loudspeaker maskers are used in this construction, one speaker can be placed every other cavity if there is no fiberglass fill, otherwise one must be placed on each cavity. Vibration maskers can be spaced at greater distances but spacing will depend on the specific wall construction (8.5.2.6). When a vibration masker is used, the levels in the wall cavity provide good protection as well as beyond the wall (***Figure 8-10***).

Demountable Partitions. These partitions are intended to be moved periodically, so are lighter than any of the other walls. Most are thinner than fixed wall construction and have lower STC ratings. Since they are demountable, these ratings are further degraded by the fit at the suspended ceiling, the floor, and between the panels. Most are composed of gypsum board, so masking is required.

Concrete Slab Walls. These walls are massive but have high stiffness, transmitting speech relatively well in vibration form. If furred out on the interior, protection may not be required, but otherwise protection is recommended. Most often the room length is greater than the slab width, requiring two slabs to butt together. A probe microphone can be inserted in the filler between the two slabs. It is recommended that a cover plate be used to cover the joint. Vibration listening tests on the outer wall surface have shown that speech can be understood well, so masking is required for them.

Glass Panel Walls. Many conference rooms have glass-paneled walls that face an interior corridor. Glass panels have considerably lower STC ratings than other wall construction. Each panel must be protected in the same way as windows.

8.5.2.6 Horizontal Masker Spacing

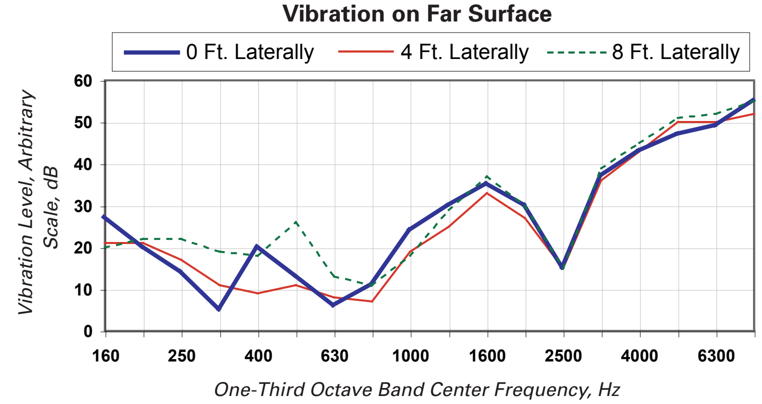


Figure 8-11

To determine how far apart the maskers may be placed horizontally, a pink sound source was placed in a room 3 feet distant from a wall and facing it. It was five feet six inches high. A masker was attached to the wall at the same height and along the speaker axis. The vibration spectrum caused by the source was measured at three points laterally on the *far* side of the wall. The results are shown in ***Figure 8.11***. The various vibration modes of the wall are evident, but the important point is that a measurement position *eight* feet laterally from the axis of the sound source shows essentially the same loss as that on the source axis. This result would imply that speakers could be placed at 15 foot intervals. That might apply to the specific wall tested, but it is prudent to place them between 6 and 8 feet. It is clear from the figure that equalization is a critical aspect of setting up wall maskers.

8.5.2.7 Vertical Masker Location

Since the vibration must make sound in the secure room, it would be desirable to place the masker above the suspended ceiling. Although slightly more power is required, the sound attenuation of the ceiling greatly reduces the levels in the secure room while there is no reduction in the system effectiveness. In a test, the sound spectrum in the (empty) cavity at the floor was found to be identical to that at a 6 foot height.

8.5.3 Doors

8.5.3.1 The Threat

Doors are weak links in walls. Typical doors may be hollow core, solid core, metal, or special. They can open to exterior uncontrolled areas, or to internal controlled areas. Every door has a gap around its periphery. These gaps may, or may not, have gaskets. Because carpeting is often used, the gap at the bottom is generally larger. Doors with built-in return air grilles are *never* acceptable. Because listening at a hollow core door results in clearly intelligible speech, such doors are *not* acceptable. Listening at a door gap, without a gasket, can result in intelligible speech at reasonable distances from the door. For interior doors, eavesdropping with the ear is the most likely surveillance method, although it is unlikely that a person will stand close for an extended period of time. It is also unlikely that detection devices will be attached to interior doors. This is not the case for doors opening to uncontrolled areas (e.g. emergency exits, or seldom used adjoining doors). Remote sensing of exterior door vibration or sound radiation are potential threats. Listening with a vibration device, or directly, at an exterior door is possible.

8.5.3.2 Standard Solution

The normal solution is an architectural (structural) one where a hollow core door is replaced with a solid core door internally or with a metal door externally. To provide more protection gaskets are added at the gaps and a *floor wiper* is placed at the bottom. Although these solutions improve matters and are recommended, they have the same limitations as all sound attenuating mechanisms and might not be enough. Avoidance of exterior doors is the best solution, of course.

A more effective structural solution is to install doors with very high STC ratings. These doors are specially built to greatly improve sound attenuation. Unfortunately, they still are sound attenuating devices. They have several drawbacks. They are very heavy, much more difficult to install and are very expensive compared to normal doors. Further, the wall framing has to be altered to accept the thicker frame and that means adding more gypsum board to match.

8.5.3.3 Masking Solutions

Figure 8-12

A vibration masker can be added to the secure side of a normal solid core door that has gaskets and a floor wiper. The masker is best placed at the upper, hinge side of the door to minimize visible wiring as shown in ***Figure 8-12*** (photo courtesy of Dynasound, Inc.) The door masker is the same as that used for walls. The door vibration radiates into the door gap as well from the outer door surface. If regulations permit, a masker should be added to the area immediately outside the door. For interior doors, this addition is only needed to make the sound spectrum outside the door more acceptable. For exterior doors, it can be placed high on the exterior wall to further inhibit eavesdropping.

There are several types of doors:

Metal Doors. These doors typically are single exterior doors. Metal panels accept sound masking very well. Gaskets around all gaps are mandatory.

Hollow Core Doors. These doors should *never* be used for secure facilities. Although speech can be secured with sound masking, the required level is much too high.

Solid Core Doors. These doors may be used for secure facilities. With a gaskets, speech privacy can be obtained with reasonable levels of masking. For double doors, one masker must be applied to each, as well as a flange plate over the gap between the doors.

Very High STC Doors. In certain circumstances (high existing background levels), sound masking is not required.

Roll Up Doors. On occasion, doors to maintenance areas need protection. If the door is composed of flat panels, vibration maskers may be applied. If the door is segmented, it is necessary to use *door washers*, akin to *window washers*, that radiate masking from properly located loudspeakers.

8.5.4 Ducts

8.5.4.1 The Threat

Listening through air ducts is a time honored source of eavesdropping since almost all rooms have supply ducts, either round or rectangular, metallic or fiberglass, that connect to a multiplicity of rooms. Local ducts are typically metallic with no sound absorbing materials and therefore are decent speaking tubes. Speech within a room is attenuated as it passes through the grille and duct bend, but after that the decay rate is quite small. Fiberglass ducts transmit much less speech so if there is more than 10 feet between openings they usually are not a concern. In unsecured commercial facilities, listening can be done by ear, but a sophisticated listener could insert a microphone into the duct for more difficult situations. It is possible to place a vibration device on the duct wall near a room diffuser to detect speech. Since the devices are on or within the duct, detection must be by visual inspection or by a search for wires. There are cases where the duct connects to uncontrolled areas and a non-stationary masking generator is needed.

8.5.4.2 Standard Solutions

Duct mufflers have been the traditional method of solution. They were added at each point where the ducts penetrate the room perimeter. For many secure rooms, this implies a number of mufflers. They are expensive, bulky, and require an adequate plenum height to fit and because of their weight are difficult to install. There are two other significant disadvantages in their use. Again, they are just a sound attenuating device. Worse, they add significant pressure drop to the air handling system that creates additional operating costs.

8.5.4.3 Masking Solutions

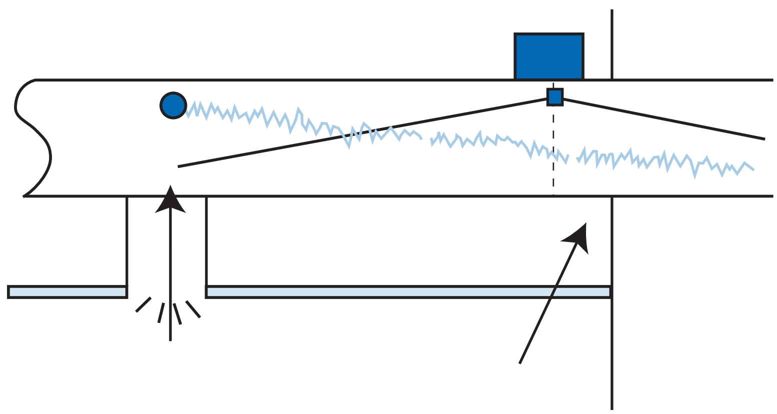


Figure 8-13

Speech that enters an air duct decays as it passes down the duct. Sound masking created within the duct can easily be set higher than the speech. ***Figure 8-13*** shows a schematic of the two sound levels. Because it also decays as it passes down the duct, masking it generally is barely heard in the secure room. Maskers should be placed at each penetration of the duct to another room.

Earlier masking techniques used a loudspeaker that radiated sound into the duct. If the speaker was located within the duct, additional pressure drop was incurred. Later designs placed the speaker outside the duct with the speaker (suitably sealed to prevent leaks and excess pressure on the speaker) radiating sound into the duct through a penetration. This latter solution could only be applied to rectangular metallic ducts.

Current techniques use a vibrator on the exterior surface of the duct wall. The device is easy to install, requires no penetrations, can be inspected, and has no impact on airflow. It can be applied to both round and rectangular ducts.

There are several types of ducts:

Rectangular Metal Ducts. Vibration maskers can be applied. They should be located near the wall penetration.

Circular Metal Ducts. Vibration maskers can be applied. They should be located near the wall penetration.

Circular Fiberglass Ducts. Normally the sound attenuation in these ducts is sufficient enough so masking is not necessary. If required, external maskers can radiate sound through the duct wall.

Stub Ducts. These ducts often are inserted into structure high walls around secure facilities to permit return airflow. Since they are penetrations they must be protected. A wire mesh grid should also be used to prevent physical entry.

8.5.5 Piping

8.5.5.1 The Threat

Normal liquid filled pipes do not carry significant speech energy nor does conduit piping filled with wires. Whenever there is a power panel in the secure room and not all conduit pipes leaving that panel are filled, there can be a loss of protection. As any sailor knows, unfilled pipes are excellent speaking tubes.

8.5.5.2 Standard Solution

Generally the threat has not been recognized, so a standard solution has not been available. When it has been, liquid filled pipes have had vibration breaks installed but empty conduits were ignored. Fitting the empty conduit opening with a rubber plug on the secure side will provide adequate protection, so masking is not needed.

8.5.5.3 Masking Solution

Masking is only required if an empty conduit is not plugged or specifications require protection on a liquid filled pipe. A vibration masker may be attached to any pipe or conduit at any convenient location within the room. It is similar to those used on ducts.

8.5.6 Raised Floors

8.5.6.1 The Threat

In some facilities a raised access floor is used. Cabling or ventilation air may be supplied to the room under it. Both imply penetrations of the perimeter that must be protected but are seldom considered. It is possible for *probe microphones* or *fiber-optic microphones* to be placed in the floor cavity, but because of the high sound attenuation of the floor they would have difficulty detecting speech unless an open grille is located on the floor nearby. *Vibration detectors* may be attached to the underside of a floor plate. Since these plates are stiff to carry the floor load, they act more like a window in that they prefer to respond at speech frequencies, making such detectors effective.

8.5.6.2 Standard Solution

If the threat is recognized, a wire mesh grid is placed over each perimeter opening. The only weakness of this solution is that alterations in the cabling often compromise the integrity of the mesh.

8.5.6.3 Masking Solution

Maskers can be placed under the floor and can serve two functions. They can be placed only at penetrations to provide protection there. They can be placed uniformly under the floor, as is done in commercial facilities, to provide speech privacy within the room itself. If plenum masking is used, this latter solution is redundant.

8.5.7 Plenum Ceilings

8.5.7.1 The Threat

Secure rooms often have a suspended ceiling with a plenum above to accommodate air ducts and cable runs. The walls defining the room may extend to the structural ceiling to create a closed plenum, or they may not to create a continuous open plenum. The plenum space is normally used for non-ducted return air. If the room has walls to the structural ceiling, there must be an opening in the wall above the ceiling to permit the air to return to the fan and it is normally not in view for inspection (8.5.4). Cable trays often penetrate the walls creating the same weakness. If the walls extend only to the suspended ceiling, the plenum is accessible to all other rooms. In each of these situations, listening devices, such as microphones, can be placed in the plenum.

8.5.7.2 Standard Solution

For return air penetrations in structure high walls, duct mufflers have been added (8.5.4). For return air in open plenums an exceedingly ineffective solution has been to lay fiberglass on the suspended ceiling. Cable trays have been either ignored or each cable has been individually sealed at the wall penetration, adding expense.

8.5.7.3 Masking Solution

For walls with a return air opening, a stub duct must be added with sufficient length to add a duct masker (8.5.2). For walls with cable tray penetrations, a loudspeaker masker should be placed in the plenum just inside the opening.

For open plenum spaces, it is prudent to distribute plenum maskers throughout the secure room. One additional benefit, not normally contemplated, is that such masking provides speech privacy between individuals *within* the room. The levels within the room can be set as with commercial facilities without compromising the protection afforded in the plenum.

8.5.8 Internal Loudspeakers

8.5.8.1 The Threat

Many building codes require the presence of speakers in a secure room for emergency announcements. Although speakers are intended for creating sound, the speaker cone also responds to external sound and the coil generates a minute voltage characteristic of that sound. With proper sensing, that voltage can be converted to speech.

8.5.8.2 Standard Solution

An optical isolator on the wire to the speaker permits a signal to go to the speaker, but prevents any signal to pass back. This is the recommended solution; and such devices are commercially available.

8.5.8.3 Masking Solution

If an optical isolator is not available, a masker should be placed next to the speaker. The required levels are sufficiently low as not to cause distraction within the secure room or interfere with the sound from the speaker.

8.5.9 Computer Keyboards

8.5.9.1 The Threat

A method has been developed to analyze the sound spectrum of computer keyboard strokes, and thereby determine the characters that have been struck. Most modern keyboards are reasonably quiet, so sensing cannot be distant. Microphones embedded in local equipment, keyboard, or desk, vibration sensors could be potential sensing devices.

8.5.9.2 Standard Solution

None known.

8.5.9.3 Masking Solution

A vibration masker applied to the underside of the keyboard, with the proper spectrum, will mask all spectral components of the keystrokes. Measurements have shown that the user is not disturbed by the low level required.

8.6 Equipment

Most of the equipment described here is rack mounted in permanent systems. Portable, or very small systems, are usually not rack mounted.

8.6.1 Generators

In some applications two types of masking generators may be needed. To keep costs down, the more restrictive generator may be used as the complete source.

8.6.1.1 Non-Stationary Noise

These generators are the most protective; their use and description were discussed earlier for uncontrolled areas. They should have more than two channels of one-third octave band equalization to accommodate the different masking spectra required; otherwise more generators of this type are required. DSP based generators are best since they are equalized through software and the computer is removed after equalization. Auxiliary inputs are needed to create signal layering. Any advanced functions (5.5) should be bypassed. To create non-stationary noise layering is necessary. Adding a music signal at the proper relative level can provide sufficient spectral and level changes to create the needed non-stationary noise. The ASP-MG24 generator is ideally suited for this application. As a minimum they should be used for (see following page):

1. All light weight exterior walls; not those made of brick or cinder block.
2. All exterior windows.
3. All exterior doors.

8.6.1.2 Stationary Random Noise

These are the most common commercially available generators. They may be either analog or digital. Again, they should have more than two channels of one-third octave band equalization to accommodate the different masking spectra required. DSP based generators are best since they are equalized through software and the computer is removed after equalization. Auxiliary inputs are needed to create signal layering. They are recommended for secure areas where there is no exposure to uncontrolled spaces. Any advanced functions (5.5) should be bypassed.

8.6.2 Amplifiers

Two channel, or greater, amplifiers are recommended to accommodate masking signals with different equalizations. Single channel amplifiers can be used when there is only one channel needed. Single channel amplifiers on larger systems add considerable weight and cost to a project. As discussed earlier, amplifiers are the most likely part of the system to fail; even if only one channel is used, having a two-channel amplifier supplies a ready back up. Analog level controls (rotating knobs) should be on the rear panel to discourage occupants from adjusting the system even when the cabinet is locked.

Adjustment of an analog control will destroy the work done in equalizing the system. 70.7V outputs are recommended and most commercial power amplifiers have this type of output.

8.6.3 Mixers

A mixer/pre-amplifier should be added if the generator does not have at least two auxiliary inputs. Almost all commercial mixers have analog controls (rotating knobs) on the front panel. Although these added signals may not be critical, they should always be placed in a locked cabinet.

8.6.4 Zone Controls

Zone controls permit fine level adjustments for each particular type of masker and each particular application. For example, vibration duct maskers may be used on air supply ducts and also on stub ducts. The mixer can have the same masking spectrum but will need different levels. The recommended controls have a number of features that are important for secure facilities.

They must be stepped so any change in knob position can be undone without destroying the equalization. They must have small steps in level, such as 1 or 1.5 dB, not 3 dB as found in many controls. A 3 dB change in level represents about nine points in PI index (2.5). Such a large change is unacceptable for secure rooms. The control should have a sufficient number of steps to permit gross changes in level without resorting to rotation of the analog control on the power amplifier.

8.6.5 Speakers

There are several types of maskers used in secure facilities:

8.6.5.1 Loudspeaker Maskers

These maskers are used in commercial applications (6.1.10). Their application to secure facilities is for ceiling plenum masking, under floor masking, or as window/wall washers. No modifications to them are required for these applications.

8.6.5.2 Vibration Maskers

These maskers can be affixed in several ways either with adhesive or clamping in permanent facilities. All adhesives should be sufficiently flexible so large changes in temperature, such as at windows, do not cause separation. If necessary, they should be taped until the adhesive is set. Since a number of these devices are applied in the same zone, they should be part of a 70.7V system with a step down transformer. Eight ohm maskers being powered by amplifiers with eight ohm outputs should *not* be used. They have to be wired in series/parallel and the failure of one would be the failure of several.

Figure 8-14

An example of the vibration masker that is attached to windows, doors, walls, or rectangular ducts, is shown in ***Figure 8-14***. It is relatively small, 2⅜ inches square and neutrally colored. To keep the device small, the transformer that powers it is separate. ***Figure 8-15*** shows that unit. It should be placed out of sight, either under a raised floor, or above a suspended ceiling. It wired in parallel to a 70.7V system. The wiring is visible for inspection purposes.

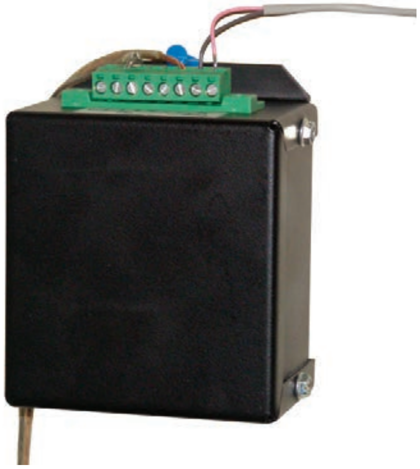


Figure 8-15

Figure 8-16

There are occasions when masking of pipes and conduits are required. An example of a pipe masker is shown in ***Figure 8-16*** (photo courtesy of Dynasound, Inc.)

Figure 8-17

Window/Wall Washer Maskers

It is not sufficient to place plenum maskers facing down from a suspended ceiling above the window or wall to be protected when circumstances require their use, so special maskers are required. These are affixed to the suspended ceiling grid and hang below the ceiling. The have support brackets that can point the speaker axis in the desired direction as shown in ***Figure 8-17***. This type of speaker is commercially available.

8.7 Design of Security Masking Systems

8.7.1 Layering of Masking Signals

Non-stationary noise may be created by adding a layer of music to a stationary masking signal at a level relative to the masking so it can be heard slightly. It may be set at a lower relative level so it is not heard by room occupants. A third layer can be added with the use of voice babble or speech samples. They should be set at a level lower than the music. If equalized properly, the fourth layer (the actual voices to protect) will be sufficiently buried below the other layers to provide good protection.

For a 1 Volt music input to the ASP-MG24 unit, the music should be:

- 15 dB below the masking to be inaudible. The masking signal will be stationary noise but will be protected by the lower level of music.
- 10 dB below the masking to be slightly audible. This will add non-stationary aspects to the masking signal.

8.7.2 Portable System Generator (GPN1200B)

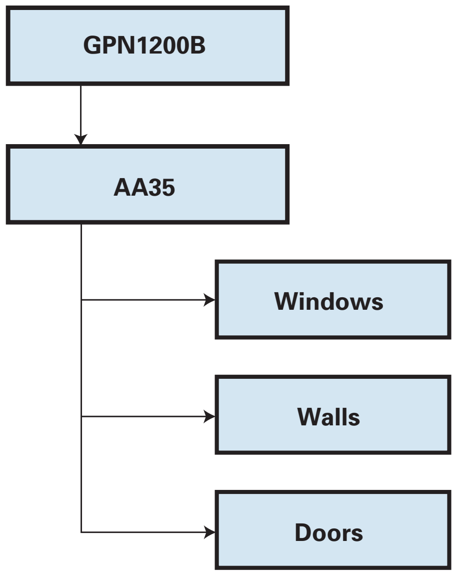


Figure 8-18

This generator less expensive, and is simpler to operate in the field. It does not have the versatility of the ASP-MG24 however. It does not have one-third octave band capability, nor does it have multi-channel capability. It creates either pink or white noise that can be modified with a low pass filter and an analog volume control. Controls are on the rear panel. It has no user controls on the front panel. ***Figure 8-18*** shows an example of a portable system used on one location.

8.7.3 Fixed System Generator (ASP-MG24)

This generator has two auxiliary inputs and four independent masking channels. Each auxiliary input channel has six parametric filters and level controls as well as compressor/limiters. Each masking channel has low and high pass filters, one-third octave band filters, level controls and pink or white noise generators. The generator has four output channels. Each can be mixed with any of the six input channels. The output channels can be frequency shaped, with independent level controls. By proper mixing of the auxiliary and masking either stationary masking or non-stationary masking can be created.

The generator is DSP controlled. Configuration files can be stored in the computer for use on other projects. Equalization data can be uploaded to reduce equalization time.

The generator has a clock option (MGTDB) that can be added. **IT IS NOT TO BE USED**.

Pre-sets are provided with the unit for the most likely applications so equalization is minimized.

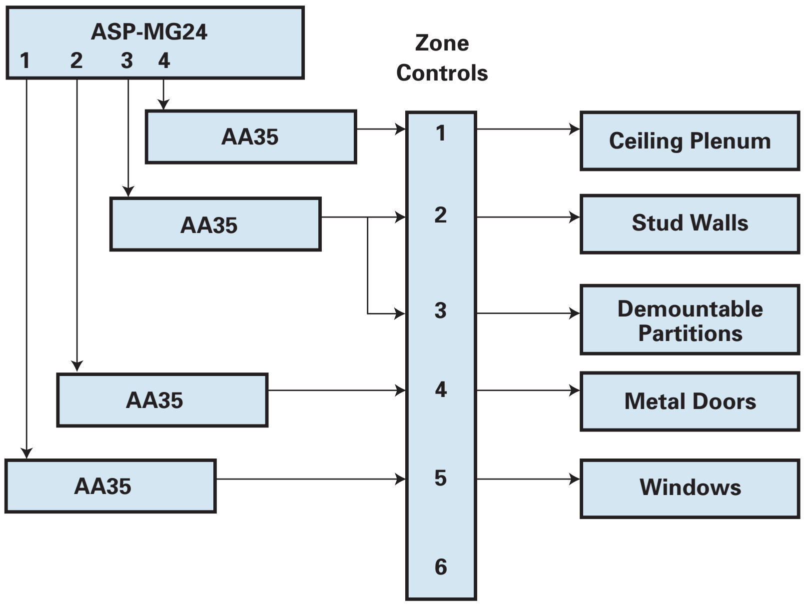


Figure 8-19

Masking channel 1: Pre-set for windows
Masking channel 2: Pre-set for doors
Masking channel 3: Pre-set for walls
Masking channel 4: Pre-set for loudspeakers

Figure 8-19 shows a schematic for a typical application. Each of the four masking channels are used. The zones are small enough to permit small one channel amplifiers to be used. An ATPLATE with 5 E-408 zone controls are added to provide the user with detailed system control. The system is housed in a lockable rack cabinet in the secure room.

8.7.4 Channel Assignments

Maskers are located in number of places. Each location may require a different type of masker, a different frequency spectrum, and a different overall masking level. For example, a vibration transducer applied to a window requires a different electrical spectrum from the generator than one applied to a door. We have identified sixteen locations that may have to be addressed in a project.

A channel is a signal path that has a specific frequency spectrum to be applied to a specific masker location. Since there are more locations to protect than channels available, additional locations will have their spectrum set the same as the more common locations. For some locations, the exact frequency spectrum is not critical, typically a location where the sound is not radiated directly to the talkers or listeners, such as in an air duct. In other cases, a slight change in level is adequate to compensate for a frequency spectrum that is not optimum for the location.

The list given in *Table 8-1* shows the assignments for each generator channel and in order of preference when more than one location is assigned to the same channel. The first channel is assigned to vibration maskers used for glass, typically windows. The second channel is assigned to vibration maskers used for hard objects such as solid core doors, concrete walls, or raised floors. The third channel is assigned to vibration maskers used for hard objects with some damping, such as stud walls or demountable partitions. The fourth channel is assigned to loudspeaker maskers used in a ceiling plenum or for masking emergency loudspeakers.

The pre-set configuration file **SecureSound.xdat** contains the default spectra, levels, and channel assignments associated with this table. Included are also those for the two paging input channels.

Masker Location	Generator Output Channel	Maskers
Windows	1	M2000-SM
Interior Glass Panels	1	M2000-SM
Solid Core Doors	2	M2000-SM
Metal Doors	2	M2000-SM
Roll up Doors	2	M2000-SM
Concrete Walls	2	M2000-SM
Brick/Cinder Block Walls	2	M2000-SM
Raised Floors	2	M1000/M2000-LP
Metal Ducts	2	M2000-SM
Piping	2	M2000-SM
Stud Walls	3	M2000-SM
Demountable Partitions	3	M2000-SM
Ceiling Plenum	4	M1000/M2000-LP
Glass Block Walls	4	SM24T-W
Internal Loudspeakers	4	SM24T-W
Fiberglass Ducts	4	M1000/M2000-LP
Computer Keyboards	Special	Special

Table 8-1

8.7.5 Zone Assignments

A zone is a group of speakers that are fed the same signal (frequency spectrum) and are set to the same input voltage. Each of the locations listed in *Table 8-1* require a separate zone.

8.7.6 Example Project

Not all problem areas are shown on drawings, so questions need to be asked.

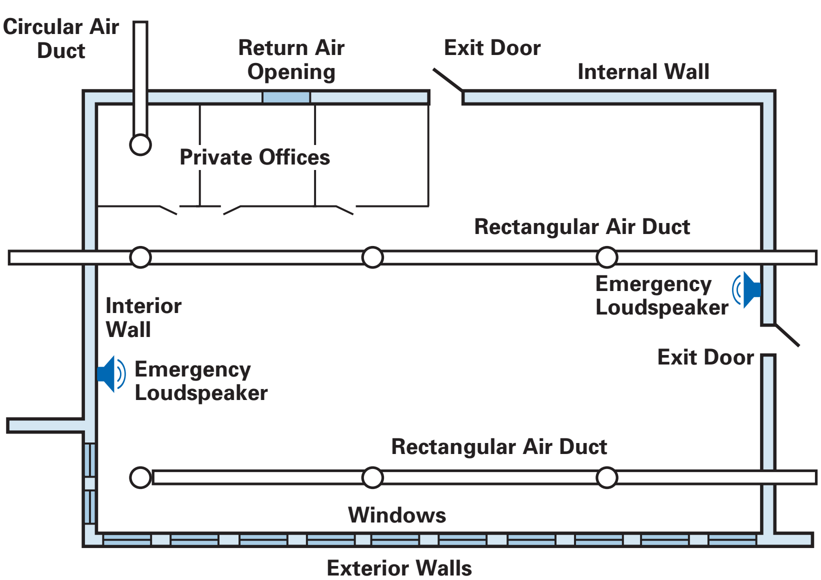


Figure 8-20

Often a potential customer may specify only a particular solution. After examining the room or the drawings, it is important to call attention to weaknesses of which the customer may not be aware. For example, an owner requested that a concrete wall be masked. On examination, it was found that the concrete slabs were separated by a one inch gap that had be filled with silicone adhesive. It would have been a simple matter to put a probe microphone through the gap, so a metal plate was recommended. These kinds of observations help to increase confidence in the vendor, even if it is not masking specifically. ***Figure 8-20*** shows the layout of a room to be secured against audio surveillance. Consider the perimeter envelope of the room as the location for listening devices. Windows, walls, doors, ducting, piping, ceiling plenums, raised floor cavities, and loudspeakers are all penetration points. There are two doors, one to the outside of the building. There is one return air opening in the ceiling above the closed offices; it must be protected. If a stub duct exists, apply the M2000-SM to the duct, if not, hang a M1000 masker nearby. All the walls extend to the structural ceiling and all piping that penetrates those walls are sealed, so no additional masking is needed for that case. However, the occupants of the closed offices want confidentiality from each other and from those in the open office area. Since these people are in the same SCIF, only Confidential Privacy is needed. M1000 maskers are applied at one watt over the closed offices and immediately outside their doors, with the three maskers in the closed offices tapped down to ½ watt. There are four air ducts that penetrate the room and four M2000-SM maskers are needed. There are twelve windows each of which requires a M2000-SM masker. There are two emergency loudspeakers in the room. It should be recommended that opti-isolators be applied. If not, then SM42T maskers should be attached to the wall next to each speaker and set to a low level. There is 110 feet of interior wall that requires masking. When protecting walls, determine whether the wall cavity is filled with fiberglass.

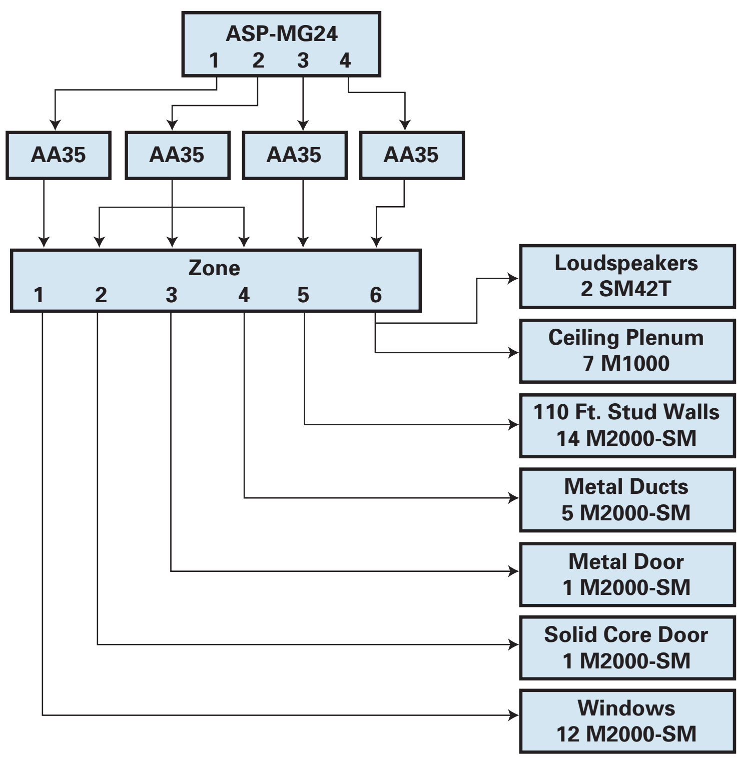


Figure 8-21

Such an examination provides the input data for the system design. The recommended design for the above room is shown in ***Figure 8-21***. Four different masking spectra are required so all four channels of the ASP-MG24 generator are used. The quantity of speakers is small enough to permit the AA-35 amplifiers to be used. Six zones are required. The ceiling plenum speakers and the internal loudspeakers are in the same zone to avoid extra equipment. The SM42T speakers should be tapped at ¼ watt.

8.8 Installation of Maskers

8.8.1 Windows

One M2000-SM masker must be installed for each window, and for each pane if the window is multi-pane. This applies for both single and double pane windows. If any pane is larger than five feet in either direction, two maskers need to be installed.

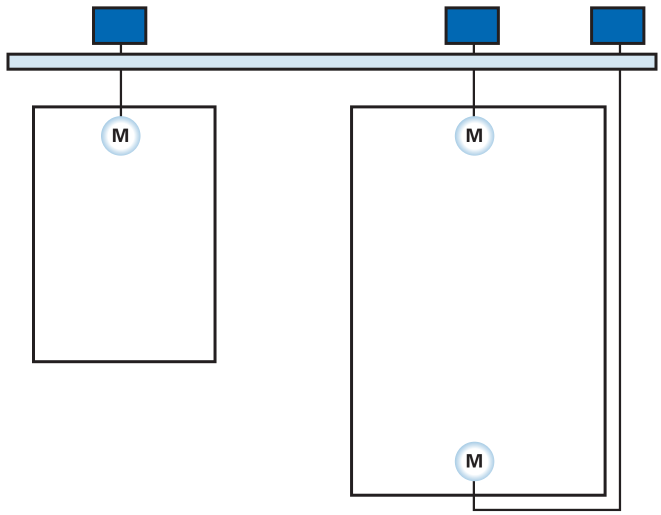


Figure 8-22

For one masker installation, it should be located two inches from the top of the window and in the center laterally as shown in ***Figure 8.22***. The connection to the transformer should be run along the window frame to the corner and then up to the ceiling plenum. The transformer should be placed in the ceiling plenum out of sight and wired for 1 watt on the 70V line.

For two masker installations, the second masker should be located two inches from the bottom of the masker and in the center laterally. The connection to the transformer should be run along the window frame to the corner and then up the frame to the ceiling plenum. The transformer should be placed in the ceiling plenum out of sight and wired for 1 watt on the 70V line. **NOTE**: If there are two nearby windows, and one has voice and masking while the other has only masking, and both masking signals are the same, it is possible to reduce the masking effect. To reduce this loss, install maskers in various positions on each window, centered around the recommendations noted above.

8.8.1.1 Normal Windows

These windows have a largest dimension of less than five feet so only one masker is required.

8.8.1.2 Large Windows

These windows have a largest dimension of five feet or greater, so two maskers are required.

8.8.1.3 Multi-Pane Windows

Each pane will vibrate in response to speech. If the pane is thick and small the vibration response is small and mostly above the speech frequencies so no masker may be necessary, unless amplified speech is used. If expense is of concern, the window washer, discussed in the section on walls, may be used to cover multiple panes otherwise one masker is required for each pane.

8.8.1.4 Double Pane Windows

Each pane is a partially independent vibrator; the interior pane response is higher than the outer pane. Double panes result in an STC rating that is higher than that for a single pane, so the transmitted sound is attenuated, reducing the ability for a directional microphone to detect speech, but does not preclude the effective use of laser microphones. As a result, double pane windows should be treated as if

8.8.2 Doors

Figure 8-23

If the door is found to be hollow-core (rapping identifies it), report that security with the door may be a problem for persons talking near the door. If acceptable, install a M1000 masker in the ceiling plenum immediately outside the door and connect it to the ceiling plenum zone.

If the door is solid core, attach a M2000-SM on the hinge side approximately 2 inches below are 2 inches in from the door frame. This is shown in ***Figure 8-23***.

Check to see of gasketing is provided around the door rim. Look for floor wipes at the door bottom. If a double door with no center post, recommend that a metal plate be installed to cover the gap.

If the door is a very high STC one, masking may not be needed. A simple speech test will determine whether the existing background sound on the unsecured side is sufficient to provide protection. To do this, stand 3 feet from the door, facing it, and speak at a conversational level.

8.8.3 Walls

An older method of protecting a wall was to insert a masking speaker in the wall cavity, or attached to the secure side, but projecting into the cavity. The weakness of this method is that it applies only the gypsum board walls with 3⅝ inch cavities.

A later method was to attach a vibration transducer to the wall on the secure side. One was attached with a screw. Because of the one-point contact, the gypsum inside the board settled and vibration levels decreased with time with consequent loss of protection. Another method was to use a piezoelectric crystal. Because of the required small size, the low frequency response was diminished.

The current method is to use a speaker coil vibrator such as the M2000-SM masker. The adhesive face has a high contact area so no settling of the gypsum occurs, and the masker can be adhered to almost any surface. It is simple to install and inspect, and does not require penetration of the gypsum board. The M2000-SM meets building codes so it can be placed above the suspended ceiling when needed (see below).

8.8.3.1 Brick or Cinder Block Walls

These walls are relatively massive so transmitted speech is low. It is difficult to use remote sensing since the material has high vibratory damping. It is more difficult to penetrate the material or affix devices because of the rough texture. Generally, these structures do not need sound masking.

8.8.3.2 Wood or Metal Stud Walls with Exterior Siding

These walls are less massive so speech is transmitted better. Although some walls of this type can be heavy, prudence dictates that they be protected. If not called for, masking should be recommended. The M2000-SM masker is recommended. The maskers should be placed between 6 and 8 feet apart, horizontally. To reduce the masking level in the secure room, the maskers can be placed immediately above the suspended ceiling. In that case the transformer taps should be set for 2 watts. If the masker is to be visible in the room, it should be placed at six feet high with the wire rising vertically up the wall so it can be inspected. In that case the transformer taps should be set for 1 watt.

8.8.3.3 Interior Walls with Wood or Metal Studs

These walls are less massive than cinder block, so speech is transmitted better. The M2000-SM maskers should be used. The maskers should be placed between 6 and 8 feet apart, horizontally. To reduce the masking level in the secure room, the maskers can be placed immediately above the suspended ceiling. In that case the transformer taps should be set for 2 watts If the masker is to be visible in the room, it should be placed at six feet high with the wire rising vertically up the wall so it can be inspected. In that case the transformer taps should be set for 1 watt.

8.8.3.4 Concrete Slab Walls

These walls are massive but have high stiffness, transmitting speech relatively well in vibration form. If furred out on the interior, maskers may not be required, but otherwise the M2000-SM maskers should be used. Most often the room length is greater than the slab width, requiring two slabs to butt together. During installation the installer should recommend a cover plate over the junctions between the slabs. The maskers should be placed between 8 and 10 feet apart, horizontally. To reduce the masking level in the secure room, the maskers can be placed immediately above the suspended ceiling. If the masker is to be visible in the room, it should be placed at six feet high with the wire rising vertically up the wall so it can be inspected. In both cases the transformer taps should be set for 1 watt.

8.8.3.5 Glass Block Walls

Glass block walls have reasonably high sound attenuation, but attachment of vibration maskers to each block is not financially feasible. So installation of the SM42T "wall washers" is recommended. If there is a suspended ceiling, the masker should be attached to the grid approximately two feet from the wall and pointed down towards the center of the window. They should be placed horizontally about 8 feet apart. If no suspended ceiling, they need to be hung in about the same positions.

8.8.3.6 Demountable Partitions

These partitions are intended to be moved periodically, so are lighter than any of the other walls. Most are thinner than fixed wall construction and have lower STC ratings. Since they are demountable, these ratings are further degraded by the fit at the suspended ceiling, the floor, and between the panels. Most are composed of gypsum board, so M2000-SM maskers should be used. The maskers should be placed between 6 and 8 feet apart, horizontally. To reduce the masking level in the secure room, the maskers can be placed immediately above the suspended ceiling. In that case the transformer taps should be set for 2 watts If the masker is to be visible in the room, it should be placed at six feet high with the wire rising vertically up the wall so it can be inspected. In that case the transformer taps should be set for 1 watt.

8.8.3.7 Glass Panel Interior Walls

Many conference rooms have glass-paneled walls that face an interior corridor. Glass panels have considerably lower STC ratings than other wall construction. A M2000-SM masker should be installed to each panel in the same way as is done for windows.

8.8.4 Ducts

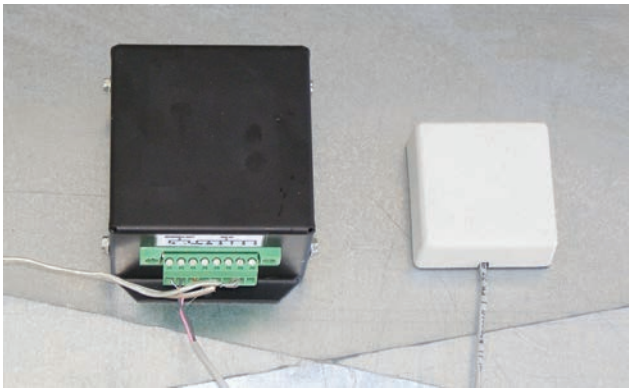


Figure 8-24

On rectangular metal ducts, both the transformer and the masker of the M2000-SM can be placed on top of the duct as shown in ***Figure 8-24***. Be sure that the duct surface is clean prior to attaching the masker. There are mounting holes on the transformer, so it can be screwed into the duct. The transformer tap should be set to 1 watt. The masker should be within 1 foot of the room perimeter.

On circular metal ducts, the transformer should be screwed to the duct. The masker does not attach to a curved surface, so must be attached with adhesive tape. The contact point is limited but is sufficient is the tap is connected to 2 watts. The masker should be within 1 foot of the room perimeter.

8.8.5 Ceiling Plenum

For plenum heights one foot high or higher, the M1000 masker should be installed. For smaller plenums, the M2000-LP should be used. If the maskers are located only at ceiling penetrations they should be set at 1 watt and placed near the opening but not blocking any air flow. If they are distributed evenly over the area, the maskers should be set at 1 watt and placed about one foot above the suspended ceiling.

8.8.6 Raised Floors

For cavities one foot high or higher, the M1000 masker should be installed. For smaller cavities, the M2000-LP should be used. If the maskers are located only at under floor penetrations they should be set at 1 watt. If they are distributed evenly over the area, the maskers around the perimeter should be set at 1 watt, but those placed centrally should be set at 2 watts.

8.8.7 Piping

Generally, liquid piping need not be protected. Empty conduit runs should be located and plugged with a cork or rubber stopper. Sound masking is not needed on conduit runs that are filled with wires.

8.8.8 Internal Loudspeakers

If an optical isolator was not called for, a SM42T masker should be installed immediately alongside the loudspeaker. It should be connected to a zone control to provide reduction in the masking level.

8.8.9 Computer Keyboards

Because protection for keyboards is seldom needed, there is no specific product to sound masking them. The existing M2000-SM is too large for this application. The only way to provide protection is to remove the transducer inside the masker housing and wire it directly to the transformer. The transformer should be placed on the floor under the desk and the transducer attached to a flat surface on the underside of the keyboard.

NOTE: For portable systems the placements of the maskers are the same. All maskers however will be connected directly to the GPN1200B one-channel generator so all will have the same spectrum and level.

8.9 System Equalization

In office masking systems, the criteria for performance is less stringent than for secure masking systems. The person equalizing can choose a specific masking spectrum from a database, from modeling, or from measurement of sound attenuation. In any case, he is able to verify the correctness of the equalization by making measurements in the affected area. In secure masking systems, the person equalizing can make such measurements only in a limited number of locations.

8.9.1 Methods

There are three ways these systems can be equalized, only one of which is practical:

1. *By Listening*. This method is the least acceptable and least accurate. For many locations, listening by ear may be adequate. Listening beyond doors or walls, or at remote air diffuser grilles, will indicate intelligibility for the casual listener. For other locations, such as walls, windows or pipes, listening with a vibration probe will indicate intelligibility. For some locations, such as windows, use of a directional microphone array is helpful. As changes in spectrum contour or level are made, the process must be repeated until intelligibility is lost. But not all locations need to be covered this way.

2. *By Voltage or Local Sound Level Measurements*. Atlas Sound has developed the database necessary to make this method the most practical. In the development of products for secure masking, many measurements have been made. As an example, when wall vibration maskers were tested, vibration probes were attached at various lateral and vertical positions around the masker location on both interior and exterior wall surfaces.

Using voice conversation at normal levels with and without masking, the probe outputs were downloaded into software from which the Privacy Index could be calculated. Similar tests were made within the wall cavity with a microphone. These tests evolved masker placement rules and generator masking spectrum contours, as well as voltages applied to the masker. Using these recommendations for equalizing the system allows reasonably correct proper settings to be done quickly. Listening tests should be conducted where feasible, but only as backup confirmation.

3. *By Direct Measurements*. This method is the most accurate, most time-consuming, but it is not possible for all cases (duct masking). Although the recommendations in the previous section tend to be conservative, there are cases where sufficient structural variations occur that would necessitate direct measurement and calculation of Privacy Index. These procedures are provided in Appendix C and apply to most of the critical locations.

8.9.2 Portable Systems

Set the MG1200B to Pink noise. Rotate MG1200B Low Pass Filter to **Flat**, then rotate clockwise to just to the right of vertical. This sets the masking spectrum contour. Set the amplifier output to 0.5 Volts if only windows are masked. Otherwise a compromise is necessary. If a sound level meter is available, place the microphone 8 inches from the MG2000-SM and adjust the amplifier until the meter reads 55 dBA.

8.9.3 Channel Assignments for Fixed Systems

The ASP-MG24 generator is used and the masking spectrum is set within it. Atlas Sound supplies a pre-set file called Securesound.xdat.

Open the ASP-MG24 program.
Yes to communicate to the program
Start/Login/OK
Device 1 (normal device)
Press **File Open** and choose *Securesound.xdat* file. This will set recommended spectrum and output levels

The inputs are assigned as follows

Input 1 (P1).	Music for layering
Input 2 (P2).	Second input for additional layering
Input 3 (M1).	Window Masking
Input 4 (M2).	Door Masking
Input 5 (M3).	Wall Masking
Input 6 (M4).	Loudspeaker Masking

The mixed outputs are assigned as follows:

Output 1.	Mixed P1 and M1
Output 2.	Mixed P1 and M2
Output 3.	Mixed P1 and M3
Output 4.	Mixed P1 and M4

P1 is connected to all four channels but muted. P2 is not connected and is also muted. Press the red **Mute** button to activate P1. The ***Figure 8-25*** shows what should be seen after the file is opened. Refer to Section 7.4 for details on use of the ASP-MG24.

If you are connected to the generator, the input and output bar graphs should show activity. The example above was taken when the connection was not made. The gain settings shown should result in about a 0.5 VAC output.

NOTE: Channel 4 is for loudspeakers. Some are plenum maskers above ceilings and some may be open to view to mask internal loudspeakers. If there are no plenum maskers, but loudspeaker maskers, set the channel 4 low pass to 3000 Hz. This can be done by pressing Mask EQ and changing the high cut from 7000 Hz to 3000 Hz.

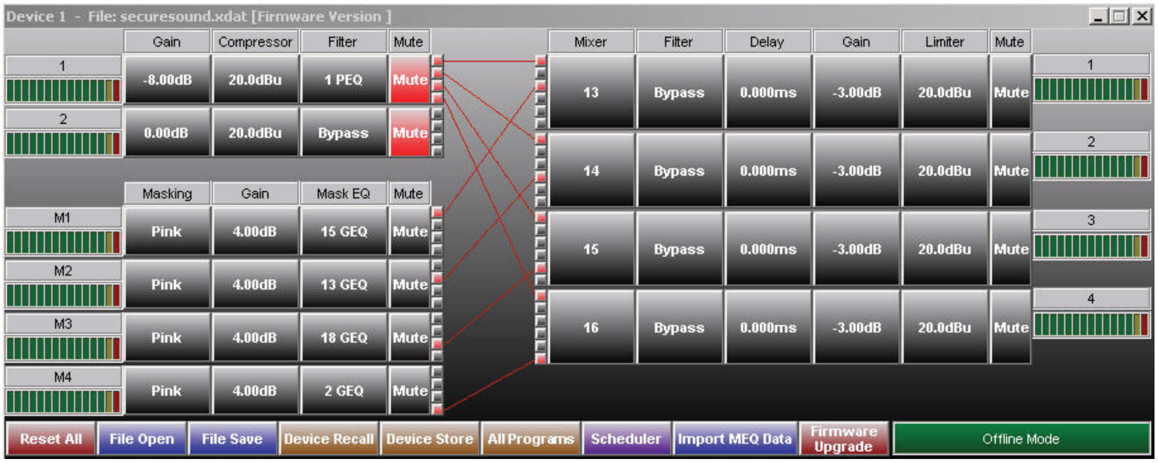


Figure 8-25

The recommendations below are provided in case your screen is not the same as shown.

8.9.4 Windows

8.9.4.1 Protection Against:

- Remote surveillance with laser microphones or directional array microphones
- Accelerometers or strain gauges in contact with window panes or frames.

8.9.4.2 Generator Settings

Page 1

Gain	*Compressor*	*Filter*	*Mute*
-8.00 dB	20.0 dBu	1PEQ	Red

Masking Channel 1

Masking	*Gain*	*MaskEQ*	*Mute*
Pink	+4.00 dB	15 GEQ	Black

Output Channel 1

Mixer	*Filter*	*Delay*	*Gain*	*Limiter*	*Mute*
14	Bypass	0.00 ms	-3.00 dB	20.0 dBu	Black

8.9.4.3 Voltage

Generator output: ½ to 1 Volt
Amplifier (or zone control) output: 1.9 Volts

8.9.4.4 Sound Level

In front of M2000-SM: 55 dBA at 8 inches

8.9.5 Doors

8.9.5.1 Protection Against:

- Remote surveillance with laser microphones or directional array microphones on outer surface of door.

- Accelerometers or strain gauges in contact with outer surface of door
- Microphones within cavity of hollow core door (door not recommended).

8.9.5.2 Generator Settings

Page 1

Gain	*Compressor*	*Filter*	*Mute*
-8.00 dB	20.0 dBu	1PEQ	Red

Masking Channel 2

Masking	*Gain*	*MaskEQ*	*Mute*
Pink	+4.00 dB	13 GEQ	Black

Output Channel 2

Mixer	*Filter*	*Delay*	*Gain*	*Limiter*	*Mute*
13	Bypass	0.00 ms	-3.00 dB	20.0 dBu	Black

Output 1: –3.00 dB

8.9.5.3 Voltage

Metal Doors. Amplifier (or zone control) output: 10.5 Volts
Solid Core Doors. Amplifier (or zone control) output: 10.5 Volts
Very High STC Doors. Amplifier (or zone control) output: 5.0 Volts
Roll Up Doors. Amplifier (or zone control) output: 5.0 Volts

8.9.5.4 Sound Level

Near side: In front of M2000-SM: 56 dBA at 8 inches
Far side: In front of M2000-SM: 45 dBA at 8 inches

8.9.6 Stud Walls, Brick, Cinder Block or Concrete Walls with Furring and Demountable Partitions

8.9.6.1 Protection against:

- Remote surveillance with laser microphones or directional array microphones on exterior surfaces
- Accelerometers or strain gauges in contact with exterior surfaces.
- Accelerometers or strain gauges in contact with interior surfaces of wall cavities.
- Normal or fiber optic microphones within wall cavities

8.9.6.2 Generator Settings

Page 1

Gain	*Compressor*	*Filter*	*Mute*
-8.00 dB	20.0 dBu	1PEQ	Red

Masking Channel 3

Masking	*Gain*	*MaskEQ*	*Mute*
Pink	+4.00 dB	18 GEQ	Black

Output Channel 3

Mixer	*Filter*	*Delay*	*Gain*	*Limiter*	*Mute*
15	Bypass	0.00ms	-3.00 dB	20.0 dBu	Black

8.9.6.3 Voltage

Generator output: ½ to 1 Volt
Amplifier (or zone control) output: 1.0 Volt

8.9.6.4 Sound Level

Near side: In front of M2000-SM: 55 dBA at 8 inches
In cavity: Near M2000-SM: 48 dBA

8.9.7 Concrete or Brick Walls

8.9.7.1 Protection against:

- Remote surveillance with laser microphones or directional array microphones on exterior surfaces
- Accelerometers or strain gauges in contact with exterior surfaces.

8.9.7.2 Generator Settings

Page 1

Gain	*Compressor*	*Filter*	*Mute*
-8.00 dB	20.0 dBu	1PEQ	Red

Masking Channel 3

Masking	*Gain*	*MaskEQ*	*Mute*
Pink	+4.00 dB	18 GEQ	Black

Output Channel 3

Mixer	*Filter*	*Delay*	*Gain*	*Limiter*	*Mute*
15	Bypass	0.00 ms	-3.00 dB	20.0 dBu	Black

8.9.7 3 Voltage

Generator output: 1.0 Volt
Amplifier (or zone control) output: Variable

8.9.7.4 Sound Level

Near side: In front of M2000-SM: 55 dBA at 8 inches

8.9.8 Glass Block Walls

8.9.8.1 Protection against:

- Remote surveillance with laser microphones or directional array microphones on exterior surfaces
- Accelerometers or strain gauges in contact with exterior surfaces.

8.9.8.2 Generator Settings

Page 1

Gain	*Compressor*	*Filter*	*Mute*
-8.00 dB	20.0 dBu	1PEQ	Red

Masking Channel 4

Masking	*Gain*	*MaskEQ*	*Mute*
Pink	+4.00 dB	2GEQ	Black

Output Channel 4

Mixer	*Filter*	*Delay*	*Gain*	*Limiter*	*Mute*
16	Bypass	0.00 ms	-3.00 dB	20.0 dBu	Black

8.9.8.3 Voltage

Generator output: ½ to 1 Volt
Amplifier (or zone control) output: Variable

8.9.8.4 Sound Level

Near side: In front of M2000-SM: 55 dBA at 8 inches

8.9.9 Interior Glass Panel Walls

8.9.9.1 Protection against:

- Remote surveillance with laser microphones or directional array microphones
- Accelerometers or strain gauges in contact with window panes or frames.

8.9.9.2 Generator Settings

Page 1

Gain	*Compressor*	*Filter*	*Mute*
-8.00 dB	20.0 dBu	1PEQ	Red

Masking Channel 4

Masking	*Gain*	*MaskEQ*	*Mute*
Pink	+4.00 dB	2GEQ	Black

Output Channel 4

Mixer	*Filter*	*Delay*	*Gain*	*Limiter*	*Mute*
16	Bypass	0.00 ms	-3.00 dB	20.0 dBu	Black

8.9.9.3 Voltage

Generator output: 1 Volt
Amplifier (or zone control) output: 1.9 Volts

8.9.9.4 Sound Level

Near side: In front of M2000-SM: 53dBA at 8 inches

8.9.10 Rectangular or Circular Metal Ducts

8.9.10.1 Protection against:

- Normal or fiber optic microphones within duct
- Accelerometers or strain gauges in contact with outer surfaces of duct

8.9.10.2 Generator Settings

Page 1

Gain	*Compressor*	*Filter*	*Mute*
-8.00 dB	20.0 dBu	1PEQ	Red

Masking Channel 4

Masking	*Gain*	*MaskEQ*	*Mute*
Pink	+4.00 dB	2GEQ	Black

Output Channel 4

Mixer	*Filter*	*Delay*	*Gain*	*Limiter*	*Mute*
16	Bypass	0.00 ms	-3.00 dB	20.0 dBu	Black

8.9.10.3 Voltage

Generator output: ½ to 1 Volt
Amplifier (or zone control) output: 6.5 Volts

8.9.10.4 Sound Level

In front of M2000-SM: 53 dBA at 8 inches

8.9.11 Fiberglass Ducts

8.9.11.1 Protection against

Normal or fiber optic microphones within duct

8.9.11.2 Generator Settings

Page 1

Gain	*Compressor*	*Filter*	*Mute*		
-8.00 dB	20.0 dBu	1PEQ	Red		

Masking Channel 4

Masking	*Gain*	*MaskEQ*	*Mute*		
Pink	+4.00 dB	2GEQ	Black		

Output Channel 4

Mixer	*Filter*	*Delay*	*Gain*	*Limiter*	*Mute*
16	Bypass	0.00 ms	-3.00 dB	20.0 dBu	Black

8.9.11.3 Voltage

Generator output: ½ to 1 Volt
Amplifier (or zone control) output: 1.9 Volts

8.9.11.4 Sound Level

In front of SM42T: 45 dBA at 8 inches

8.9.12 Ceiling Plenum

8.9.12.1 Protection against:

- Normal or fiber optic microphones within the ceiling plenum of the room
- Normal or fiber optic microphones within the ceiling plenum of other rooms when the walls do not extend to the structural ceiling (open plenum).
- Accelerometers or strain gauges attached to light fixtures or other metallic ceiling surfaces such as air diffusers.

8.9.12.1 Generator Settings

Page 1

Gain	*Compressor*	*Filter*	*Mute*		
-8.00 dB	20.0 dBu	1PEQ	Red		

Masking Channel 4

Masking	*Gain*	*MaskEQ*	*Mute*		
Pink	+4.00 dB	2GEQ	Black		

Output Channel 4

Mixer	*Filter*	*Delay*	*Gain*	*Limiter*	*Mute*
16	Bypass	0.00 ms	-3.00 dB	20.0 dBu	Black

8.9.12.1 Voltage

Generator output: ½ to 1 Volt
Amplifier (or zone control) output: 1.9 Volts

8.9.12.1 Sound Level

At 48 inches high: 47 dBA at 48 inches high

8.9.13 Raised Floors

8.9.13.1 Protection against:

- Normal or fiber optic microphones beneath the floor
- Accelerometers or strain gauges attached to the floor grid floor panels, or metallic surfaces such as air diffusers.

8.9.13.2 Generator Settings

Page 1

Gain	*Compressor*	*Filter*	*Mute*
-8.00 dB	20.0 dBu	1PEQ	Red

Masking Channel 4

Masking	*Gain*	*MaskEQ*	*Mute*
Pink	+4.00 dB	2GEQ	Black

Output Channel 4

Mixer	*Filter*	*Delay*	*Gain*	*Limiter*	*Mute*
16	Bypass	0.00 ms	-3.00 dB	20.0 dBu	Black

8.9.13.3 Voltage

Generator output: ½ to 1 Volt
Amplifier (or zone control) output: 10.5 Volts

8.9.13.4 Sound Level

Above a nearby masker: 47 dBA at 48 inches above the floor

8.9.14 Piping

8.9.14.1 Protection against:

- Normal or fiber optic microphones at far end of empty wiring conduit
- Accelerometers attached to dry sprinkler pipes, beams or columns.

8.9.14.1 Generator Settings

Page 1

Gain	*Compressor*	*Filter*	*Mute*
-8.00 dB	20.0 dBu	1PEQ	Red

Masking Channel 4

Masking	*Gain*	*MaskEQ*	*Mute*
Pink	+4.00 dB	2GEQ	Black

Output Channel 4

Mixer	*Filter*	*Delay*	*Gain*	*Limiter*	*Mute*
16	Bypass	0.00 ms	-3.00 dB	20.0 dBu	Black

8.9.14.1 Voltage

Generator output: ½ to 1 Volt
Amplifier (or zone control) output: 1.2 Volts

8.9.14.4 Sound Level

In front of SM2000-SM: 45 dBA at 8 inches

8.9.15 Internal Loudspeakers

8.9.15.1 Protection against:

High gain AC voltage sensors attached to loudspeaker wiring.

8.9.15.1 Generator Settings

Page 1

Gain	*Compressor*	*Filter*	*Mute*
-8.00 dB	20.0 dBu	1PEQ	Red

Masking Channel 4

Masking	*Gain*	*MaskEQ*	*Mute*
Pink	+4.00 dB	2GEQ	Black

Output Channel 4

Mixer	*Filter*	*Delay*	*Gain*	*Limiter*	*Mute*
16	Bypass	0.00 ms	-3.00 dB	20.0 dBu	Black

8.9.15.1 Voltage

Generator output: 1 Volt
Amplifier (or zone control) output: 0.5 Volts

8.9.15.1 Sound Level

In front of SM42T: 45 dBA at 8 inches

8.9.16 Computer Keyboards

8.9.16.1 Protection against:

Nearby microphone

8.9.16.1 Generator Settings

Page 1

Gain	*Compressor*	*Filter*	*Mute*
-8.00 dB	20.0 dBu	1PEQ	Red

Masking Channel 4

Masking	*Gain*	*MaskEQ*	*Mute*
Pink	+4.00 dB	2GEQ	Black

Output Channel 4

Mixer	*Filter*	*Delay*	*Gain*	*Limiter*	*Mute*
16	Bypass	0.00 ms	-3.00 dB	20.0 dBu	Black

8.9.16.1 Voltage

Generator output: 1 Volt
Amplifier (or zone control) output: 1.9 Volts
NOTE: The vibrator must have been removed from the housing.

8.9.16.1 Sound Level

Above keyboard: 43 dBA at listener ear position

Appendix A
SOUND RATINGS

Acousticians have developed many ways to define speech privacy and describe room acoustics. Some are still being used despite the fact that they have been superseded, and are insufficiently precise for the use intended. This appendix may be useful for people involved in masking systems who are not familiar with acoustical terminology. Most of the ratings are discussed only briefly, outlining their advantages and disadvantages. The reader is referred to the references that define the ratings for more specific information.

A.1 Sound Attenuation Ratings

These ratings are an attempt to describe how much sound is lost from one location to another with just one number. Some are more useful than others, but none can be used alone to describe privacy.

A.1.1 Sound Transmission Class (STC and FSTC)

STC is a rating of the loss (attenuation) of sound it passes through a solid material and is most commonly used to describe the loss through walls and workstation furniture panels in open offices (3.1.3). It varies from 0 (no loss) to higher values. The actual value is loosely related to the amount of sound loss in dB. After careful preparation of a partition in a laboratory, the STC is determined when all other sound paths have been blocked. It is a measure of the performance of a partition in isolation from other factors, so cannot be used directly in determining the overall sound loss in an actual room. However, the higher the rating, the higher is the sound loss. This rating has several weaknesses. It covers the ⅓ octave band frequencies from 125 Hz to 4000 Hz, which is not the same as those for speech intelligibility. It is a graphical technique in which a specified frequency contour is fitted to the measured data and that contour is not closely related to speech intelligibility. It allows for “deficiencies,” so that certain frequency bands may be acceptable although they do not meet the contour requirements. If those deficiencies occur at important speech frequencies, the value of the rating is diminished.

The ⅓ octave band sound attenuation data are published for most tests on walls, but not for furniture panels. The published STC rating for a particular partition should be considered the best that can be accomplished. The performance of an installed partition will always be less than what is published. Acousticians have subtracted 5 to 7 from the rating to estimate the performance of an installed partition. Field STC (FSTC) is a way of determining the actual performance of a particular room, and takes into account all other sound paths (flanking paths) as well as the actual performance of the partition.

In summary, STC [10] has a number of limitations for use in modern applications:

1. It is a graphical technique but can be computerized.
2. It permits “deficiencies” so its accuracy is limited.
3. It is not weighted for speech.
4. It is “normalized” for the characteristics of the receiving room.
5. It requires the average of several measurements at standardized distances.

6. The rating is of a partition in isolation from flanking paths, so it represents the best possible value.

A.1.2 Noise Isolation Class (NIC), Noise Isolation Class Prime (NIC′)

NIC is similar to STC in that the same methods are used [3,4,5]. It is a field measurement of the sound loss of a partition. It suffers the same weaknesses as STC when used for speech privacy. NIC′ is similar to NIC except that the range of frequencies used for the rating has been reduced to 125 to 2000 Hz [15].

A.1.3 Noise Reduction Coefficient (NRC)

NRC is a rating of the sound lost on reflection from a surface, such as a workstation panel, a wall, or a ceiling. Although it is used widely, it is a true anachronism in that it lacks sufficient accuracy to be useful. NRC is determined in a laboratory reverberation chamber and so is useful for very reverberant spaces, which most offices are not. The rating varies from 0 (complete reflection) to 1 (no reflection). NRC has several great weaknesses. Persons unfamiliar with acoustics tend to think that if a sound is not reflected, it has been absorbed (no longer sound). Very little sound is reflected from an opening suggesting an NRC =1, but the sound has not been absorbed and the person on the other side of the opening hears it clearly. Some furniture panel manufacturers have convinced customers that high NRC panels are best. This is not the case (3.1.3). In some panel systems, the panel material is primarily fiberglass so little sound is reflected (high NRC), but that is because most of it is transmitted to the person in the next workstation.

The method for determining NRC was developed for reverberant spaces where the sound to be absorbed comes from all directions (random incidence). In open offices, the sound of concern is reflected from a material and reaches the listener from a specific angle (specular incidence). There is a difference between these two types of incidence, but few tests have been made to quantify it.

NRC	Attenuation dB	Human Response	Typical Application
0.1	0	None	Concrete, wall board
0.5	3	Barely noticeable	Standard mineral tile ceiling panels
0.7	5	Noticeable	Acoustical furniture and wall panels. high performance mineral tiles
0.9	10	Very noticeable	Fiberglass ceiling panels
1.0	Infinite	-	Not achievable

Table A-1

Another weakness is that NRC does not include the entire range of frequencies for speech nor does it weight those frequencies for speech intelligibility. The rating is an arithmetic average of the sound loss in the octave bands 250 500, 1000, and 2000 Hz in terms of numbers between 0 and 1. Since most of us think linearly, this rating can create underperforming materials. As seen in ***Table A-1***, NRC=0.5 provides for only a 3 dB loss, which is typical of mineral ceiling lay-in panels. An NRC=0.9 provides a 10 dB loss, which is typical of fiberglass ceiling panels. The large improvement in performance is not reflected in NRC.

The table shows the non-linear relationship between the rating and the actual loss in dB. Unfortunately, the test measurements are made in dB (logarithmic) and converted to sound absorption coefficients (linear) with a consequent loss of accuracy and then one must convert it back to dB for design purposes (as is done in the table above). Worse yet, the linear ratings are rounded to the nearest 0.05. For high NRC the round-off alone can change the sound attenuation estimate by 1 to 2 dB, small but potentially significant. (2.5).

The test procedure permits ratings greater than one, a physical impossibility. How does one correct such numbers to realistic ratings and then translate to dB?

A.1.4 Articulation Class (AC)

AC is a rating of the loss of sound between two locations [6]. Like STC, it varies from 0 (no loss) to values in the hundreds. The improvement incorporated into this rating is that it weights the various frequencies in the same way as speech intelligibility and does not allow for "deficiencies." It is generally restricted to evaluating open office furniture systems [7], but it is readily applicable to other uses. The addition of an arbitrary multiplier of 10 reduces its meaning to the layman so the Speech Weighted Loss has been added to drop that multiplier (A.1.6). The equation is:

$$AC = \sum_{i=200}^{5000} TL_i * W2_i$$

TL_i is the sound attenuation from the sound source to the measurement point and $W2_i$ is the speech weighting factor (A.4).

A.1.5 Ceiling Attenuation Class (CAC)

CAC is a rating of the sound loss between two rooms when the major path is through a ceiling plenum [11]. It varies from 0 (no loss) to high values. Its major value is in the design of closed offices. Like AC, it incorporates speech intelligibility weighting and does not allow for "deficiencies.". It is a useful rating for the design of closed offices (3.2.3).

A.1.6 Speech Weighted Loss (SL)

SL is a rating of the loss of speech between two locations. It is not standardized. It can vary from 0 to high values. See A.1.7 for its derivation. The equation is:

$$SL = \sum_{i=200}^{5000} TL_i * W3_i$$

TL_i is the sound attenuation from talker to listener, and $W3_i$ is the speech weighting factor (A.4). Multiply SL by 10 to get Articulation Class.

A.1.7 Effective Speech Weighted Loss (ESL)

ESL is a rating of the loss of speech that incorporates the added effect of sound masking. It is not standardized. It can vary from 0 to high values. It can be considered as the attenuation of a fictitious partition that would give the same speech privacy without masking as the actual partition would give with sound masking. The difference between ESL and SL is the beneficial effect of sound masking in sound attenuation terms. The difference represents how much more sound attenuation of the structure would be required if sound masking were not used. The difference often runs about 6 dB. For a closed office, that difference would imply the need to *double* the mass of the partition. For an open office, a panel 60 inches high would have to be raised to 72 inches. One needs to compare the cost of these structural changes with the cost of sound masking. The derivation is (see next page):

$$TL_i^{'} + BS_i = TL_i + MS_i$$

$$TL_i^{'} = TL_i + (MS_i - BS_i)$$

$$ESL = \sum_{i=200}^{5000} TL_i^{'} * W3_i$$

TL_i is the actual sound attenuation, TL_i' is the fictitious sound attenuation, BS_i is the existing background spectrum, and MS_i is the masking spectrum.

A.2 Noise Ratings

A.2.1 Noise Criterion (NC)

NC is a rating of a sound spectrum in one-octave bands and may be used to evaluate the acceptability of the background or masking sound in various non-industrial environments [54]. Since the frequency range is 63 to 8000 Hz, the rating may not correctly represent sound masking (See Figure A-1). It is a precursor to the NCB rating. It is not standardized, but has been in common use for many years and the General Services Administration used a modified form of it in their standards for masking sound [14, 15].

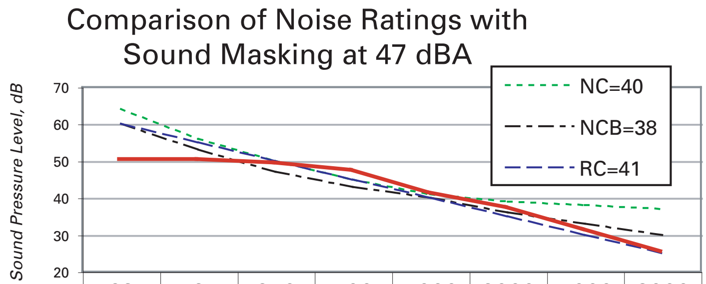
A.2.2 Noise Criterion Balanced (NCB)

NCB is a rating of a sound spectrum in one-octave bands and may be used to evaluate the acceptability of the background or masking sound in various non-industrial environments [17]. The rating contours differ from the older NC contours. The rating range is from 15 to 65 and is not calculated outside this range. A table of recommended ratings can be compared with the actual rating to determine the acceptability of the sound spectrum. The rating also includes an evaluation of the contour of the spectrum. If the low frequencies are much higher than the mid frequencies, the letter R (Rumble) is affixed to the rating. If the high frequencies are much higher than the mid frequencies, the letter H (Hiss) is affixed to the rating. Both letters can be included in the rating. If neither R nor H appears, the letter N (Neutral) is affixed. Neutral is the desired spectrum shape for this rating.

A.2.3 Room Criterion (RC)

RC is a rating of a sound spectrum in one-octave bands and may be used to evaluate the acceptability of the background or masking sound spectrum in various non-industrial environments and is similar to, but not the same as, the NCB rating [17]. The rating range is not limited as with NCB. A table of recommended ratings can be compared with the actual rating to determine the acceptability of the sound spectrum. It also includes an evaluation of the spectrum contour. If the low frequencies are much higher than the mid frequencies, the letter R (Rumble) is affixed to the rating. If the high frequencies are much higher than the mid frequencies, the letter H (Hiss) is affixed to the rating. Both letters can be included in the rating. If neither R nor H appears, the letter N (Neutral) is affixed. Neutral is the desired spectrum contour for this rating.

Figure A-1 compares this rating with a typical sound masking spectrum at 47 dBA. The lower frequencies of the rating contours are not applicable to sound masking. The NC rating allows more high frequency content than is recommended; the RC and NCB spectra fit reasonably well. In any case, the above ratings may be calculated from the chosen masking spectrum, but it is recommended they not be used to define it (3.1.7).



	63	125	250	500	1000	2000	5000	8000
NC=40	64	56	50	45	41	39	38	37
NCB=38	60	53	47	43	40	36	33	30
RC=41	60	55	50	45	40	35	30	25
Masking	50	50	49	47	41	37	31	25

Octave Band Center Frequency, Hz

Figure A-1

A.2.4 Noise Criterion 40 (NC40)

NC40 is a rating of a sound spectrum in ⅓ octave bands and is used to evaluate the acceptability of the background or masking sound spectrum in an open office environment [15]. It is a frequency-limited version of the Noise Criterion rating using the NC=40 contour. It had been used extensively in the past for federal government and large corporate projects.

A.3 Privacy Ratings

A.3.1 Articulation Index (AI)

AI is a rating of speech intelligibility taking into account the relevant factors: the speech spectrum, the sound attenuation spectrum between talker and listener, and the background or masking spectrum at the listener [12]. It presumes the listener has normal hearing. It is an older rating but is still being used since it compares favorably with the newer Speech Intelligibility Index [16]. The Articulation Index can be written:

$$\mathrm{AI} = \sum_{i=200}^{5000} \mathrm{SNR_i} * \mathrm{W1_i}$$

$$\mathrm{SNR_i} = \mathrm{VS_i} - \mathrm{TL_i} - \mathrm{MS_i}$$

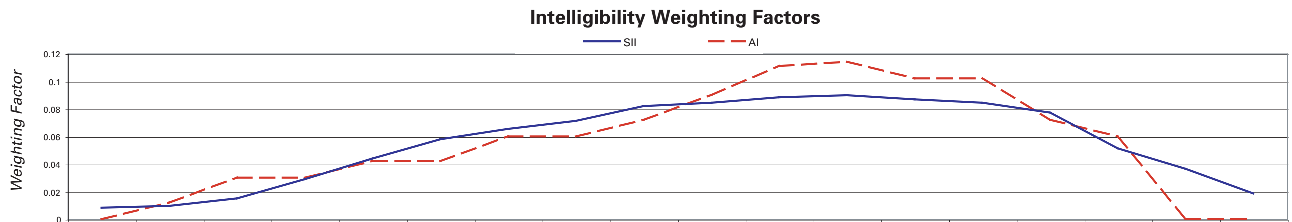
SNR_i is the signal-to-noise ratio in each ⅓ octave band from 200 to 5000 Hz. VS_i is the speech spectrum, most often that specified by ASTM [1]. TL_i is the sound attenuation spectrum between talker and listener and MS_i is either the sound masking or background spectrum. The intelligibility weighting factors, $W1_i$, are given in section A.4. AI must be between 0 and 1, so the following constraints apply:

$$\text{If } SNR_i < 0 \text{ then } SNR_i = 0$$
$$\text{If } SNR_i > 30 \text{ then } SNR_i = 30$$

These constraints express the fact that intelligibility in a band cannot be less than nothing, nor greater than full understanding.

A.3.2 Speech Intelligibility Index (SII)

SII is a rating of speech intelligibility taking into account all relevant factors similar to Articulation Index [16]. This rating is defined in a newer standard and is more comprehensive than Articulation Index. The weighting factors for SII are given in A.4. ***Figure A-2*** shows the differences between the AI and SII weighting factors. AI weights the important bands more than SII. However, ***Figure A-3*** shows the high degree of correlation between the two ratings. The frequency bands most important for speech intelligibility for both ratings are near 2000 Hz, so sound masking must have sufficient level in bands near this frequency. Because the ratings compare favorably, ASTM and most specialists use AI for office masking applications.



	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000
SII	0.0083	0.0095	0.015	0.0289	0.044	0.0578	0.0653	0.0711	0.0818	0.0844	0.0882	0.0898	0.0868	0.0844	0.0771	0.0512	0.0364	0.0185
AI	0	0.012	0.03	0.03	0.042	0.042	0.06	0.06	0.072	0.09	0.111	0.114	0.102	0.102	0.072	0.06	0	0

One-Third Octave Band Center Frequency, Hz

Figure A-2

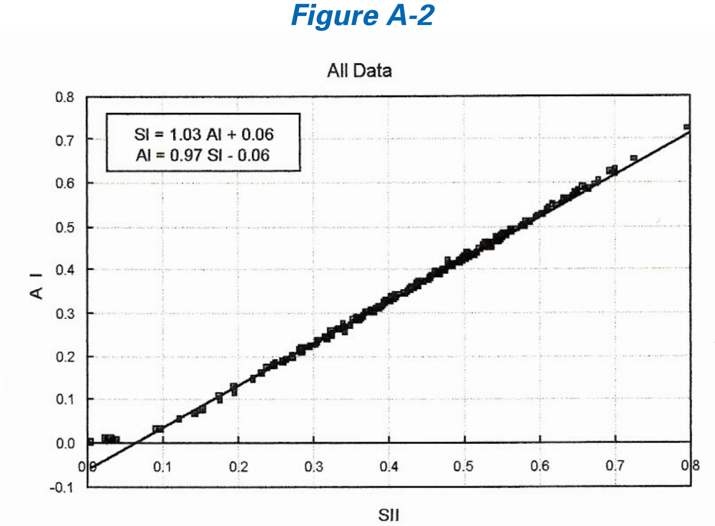


Figure A-3

A.3.3 Privacy Index (PI)

PI is a rating of speech privacy, instead of speech intelligibility [1]. The relationship of the objective rating, PI, to speech intelligibility is non-linear (2.5). By comparing degrees of privacy in terms of PI with school grades, laymen feel more comfortable with this rating than AI. It runs from 0 (no privacy) to 100 (no intelligibility); the relationship with other ratings is given below:

$$PI = 100 * (1 - AI)$$

$$PI = 100 * (1.06 - 0.97 * SII)$$

A.3.4 Estimated Privacy Index (EPI)

This rating approximates the more exact calculations in the above privacy ratings. It is derived from Articulation Index by removing the constraints on the signal-to-noise ratio. If they are removed, then the terms can be separated (see next page):

$$AI = \sum_{i=200}^{5000} VS_i * W1_i - \sum_{i=200}^{5000} TL_i * W1_i - \sum_{i=200}^{5000} MS_i * W1_i$$

Multiplying by 30 we get:

$$30 * AI = \sum_{i=200}^{5000} VS_i * W3_i - \sum_{i=200}^{5000} TL_i * W3_i - \sum_{i=200}^{5000} MS_i * W3_i$$

Define the following terms:

$$VSR = \sum_{i=200}^{5000} VS_i * W3_i$$

$$SL = \sum_{i=200}^{5000} TL_i * W3_i$$

$$MSR = \sum_{I=200}^{5000} MS_i * W3_i$$

where VSR is the speech weighted voice rating, SL is the speech weighted loss (A.1.6), and MSR is the speech weighted masking rating. Using the relationship between Articulation Index and Privacy Index, the Estimated Privacy Index is:

$$EPI = 100 * [1 - (VSR - SL - MSR) / 30]$$

Using ASTM values [1] the voice rating (VSR) for normal levels is 56. The range of MSR for acceptable masking spectra is 27 to 34. (39<dBA<48). Background spectra are MSR=25.

This index can tell the masking system designer approximately how much sound attenuation (Speech Weighted Loss) will be required for acceptable levels of privacy with reasonable levels of sound masking (3.1.3).

For freedom from distraction (PI=80), the SL must be at least 16.

For confidentiality (PI=95), the SL must be greater than 20.

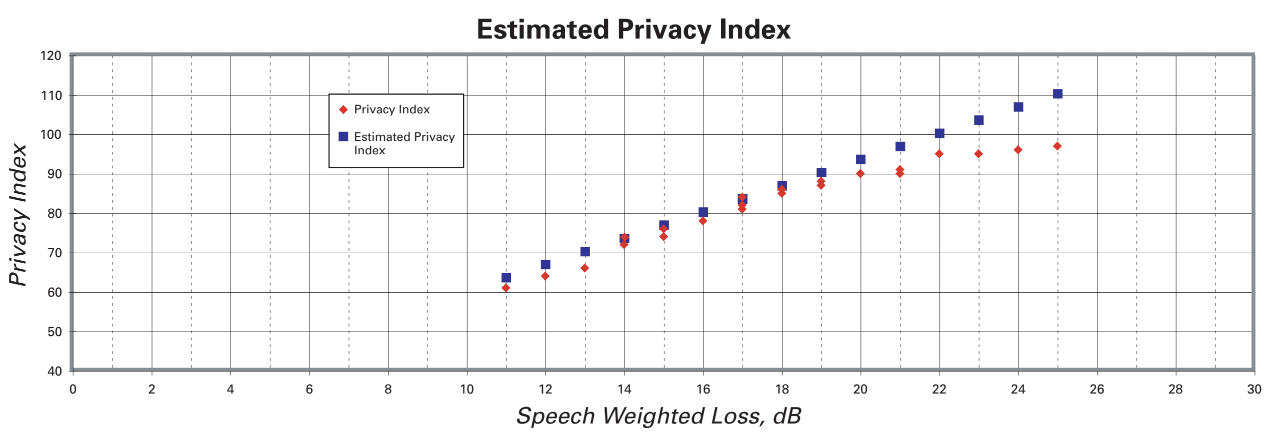


Figure A-4

The range of validity for EPI is shown in ***Figure A-4***. This graph was generated with a decreasing signal-to-noise ratio by using a normal level male voice and increasing values of transmission loss with sound masking at 47 dBA. It is clear that EPI can be useful for open offices where the constraints on Privacy Index are seldom applied, but is valueless for closed offices.

A.3.5 Speech Transmission Index (STI)

STI is a rating of speech intelligibility. It requires the use of a special sound source for measurement so that with proper instrumentation, the rating can be calculated immediately, unlike the other ratings such as PI that require several separate measurements. A review of the original paper [56] suggests that the rating is applicable to AI values greater than 0.2, which reduces its utility for high degrees of speech privacy.

A.3.6 Speech Privacy Potential (SPP)

SPP is a rating of speech privacy used by the General Services Administration [15]. The equation is:

$$\mathrm{SPP} = \mathrm{NIC}' + \mathrm{NC}40$$

The sound attenuation is expressed in terms of NIC′ (A.1.2) and the sound masking is expressed in terms of NC40 (A.2.4). Ratings above 60 are considered to create Normal Privacy in open offices.

A.3.7 Speech Interference Level (SIL)

SIL is a rating that expresses how much a background sound interferes with conversational speech. It is the arithmetic average of the sound pressure levels in the 500, 1000, and 2000 Hz one-octave bands. It is not used for masking applications. The formula for it is:

$$SIL = (L_p(500) + L_p(1000) + L_p(2000))/3$$

L_p is the sound pressure level in the octave band.

A.4 Weighting Factors for Ratings

The various ratings that use ⅓ octave band data have different weighting factors, some of which are related. These are shown in Table A-2.

Frequency	$W1_i$ (AI)	$W2_i$ (AC) =300*$W1_i$	$W3_i$ (SL) =30*$W1_i$	$W4_i$(SII)
160	0.0000	0.00	0.000	0.0083
200	0.0004	0.12	0.012	0.0095
250	0.0010	0.30	0.030	0.0150
315	0.0010	0.30	0.030	0.0289
400	0.0014	0.42	0.042	0.0440
500	0.0014	0.42	0.042	0.0578
630	0.0020	0.60	0.060	0.0653
800	0.0020	0.60	0.060	0.0711
1000	0.0024	0.72	0.075	0.0818
1250	0.0030	0.90	0.090	0.0844

1600	0.0037	1.11	0.111	0.0882
2000	0.0037	1.14	0.114	0.0898
2500	0.0034	1.02	0.102	0.0868
3150	0.0034	1.02	0.102	0.0844
4000	0.0024	0.72	0.072	0.0771
5000	0.0020	0.60	0.060	0.0512
6300	0.0000	0.00	0.000	0.0364
8000	0.0000	0.00	0.000	0.0185
Sum	0.0333	10.00	1.00	1.00

A.5 Histograms and Percentile Levels

Percentile levels are used to describe transient sounds by showing the percent of time each level of sound occurs. The percentiles are derived from a level *histogram*. Typically, the histogram shows samples of the energy averaged A-weighted sound level collected over a short time period, such as one second. A histogram is a table with level bins, normally of integer values. Each sample is added to the bin that matches its level. The samples are collected over a specified time period, such as one hour. There would be 3600 one second samples added to the table after one hour of collecting. Many instruments are able to create multiple histogram tables, e.g. 24 one-hour tables for an entire day.

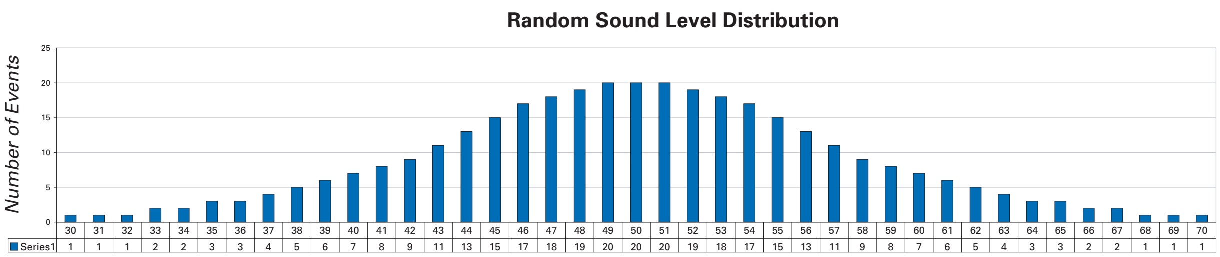


Figure A-5

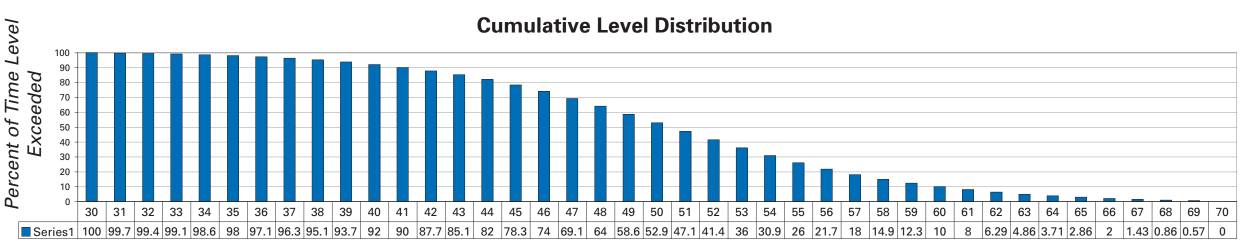


Figure A-6

The table can be graphed as a *level histogram*. ***Figure A-5*** shows the histogram for stationary random noise. The levels vary from 30 to 70 dBA. The vertical axis indicates the number of times a particular level occurred during the data collection period. Either the table or graph can be used to create percentile levels for the data collection period. A percentile level answers the question: What percent of the time is a specific level exceeded? All the samples must be summed from the maximum level downward, and then divided by the total number of events. This gives you the fraction of samples exceeding the specific level that can be converted to a percentage. ***Figure A-6*** shows this operation for the data in Figure A-5. The lowest level of 30 dBA is exceeded 100 percent of the time, while the highest level of

70 dBA is never exceeded. The symbol for each is L_{100}=30 dBA and L_0=70 dBA. Only certain percentiles are calculated in practical applications. Several are often calculated to create a percentile level graph.

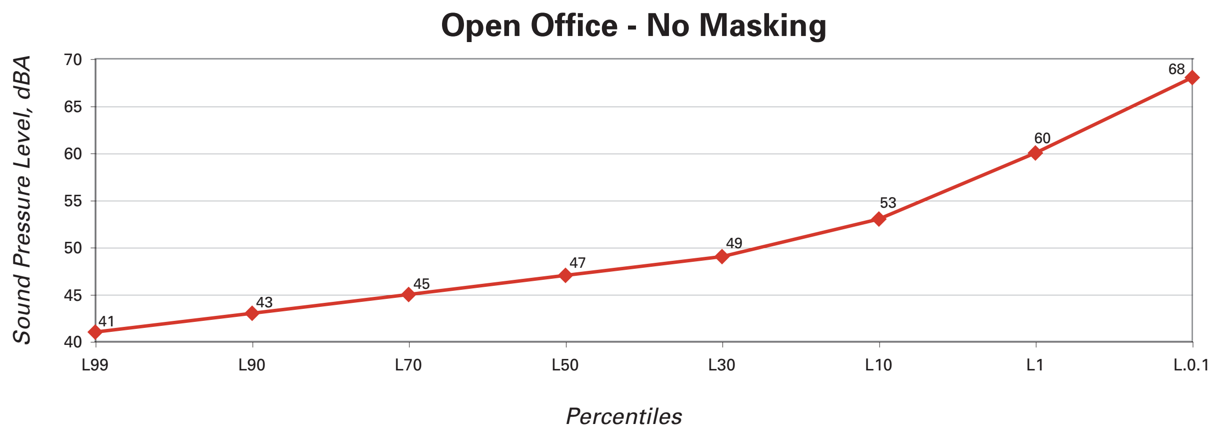


Figure A-7

It is common to have the sound level on the vertical axis and the percentile level on the horizontal axis. Data were collected in an actual office without sound masking and several percentile levels are shown in ***Figure A-7***. This graph shows that the lowest level was near 41 dBA and the highest level was near 68 dBA, a large difference. The lowest level was set by the steady air handling system. The highest level was some transient, such as a person talking loudly. It has been established that the extremes are not always useful, particularly since they can vary considerably. Research [23] has suggested that L_{90} be used to describe the lower or background levels while L_{10} be used to represent the higher percentiles of transient sounds (in this case traffic noise). By using percentiles, the steady background or masking sound can be separated from the transient activity sounds. The difference between them serves as an objective descriptor of the potential for distraction. In the example of ***Figure A-7***, about 10 percent of the time the levels were 10 dB above the background. It is useful to define a *Percentile Level Difference* (LD=L_{10} – L_{90}).

What difference is enough to cause distraction? That question has yet to be answered. It is common practice by acousticians to agree that a rapid 10 dB rise (a doubling of loudness) is sufficient to cause immediate distraction from a task. It implies that the level rose from one value to another in a short time period, regardless of percentile levels. In the office, very high levels occur infrequently and distraction is rather an accumulation of numerous smaller transients over a longer period. Percentile levels can be effective in defining the magnitude of potential distractions for this situation. It is likely that the threshold value of LD for distraction is less than 10. One objective for a masking system would be to keep LD at or below a specified threshold (5.5.3).

Appendix B
MASKING SYSTEM DESIGN CHECKLIST

These data are used for designing a sound masking system, for estimating the success of adding sound masking, for estimating the required level of masking.

B.1 Open Offices

Structural ceiling construction

- Ceiling Plenum Height (inches)
- Suspended Ceiling Material
  - Manufacturer's Name, Model and NRC rating
- Office Furniture
  - Manufacturer's Name and Model, STC and NRC ratings
  - Panel Heights
  - Workstation size
- Dimensions of smallest open area.
- Estimate the background sound level with the walkway test (See below)

B.2 Closed Offices

- Structural ceiling construction
- Ceiling Plenum Height (inches)
- Suspended Ceiling Material
  - Manufacturer's Name, Model and CAC rating
- Wall Materials
  - Type of wall construction and STC rating
- Existence and location of ceiling air returns
- Door construction
  - Solid or hollow core

B.3 Drawings

Obtain drawings of areas requiring privacy so that zones can be defined. Furniture plans for office offices are preferred.

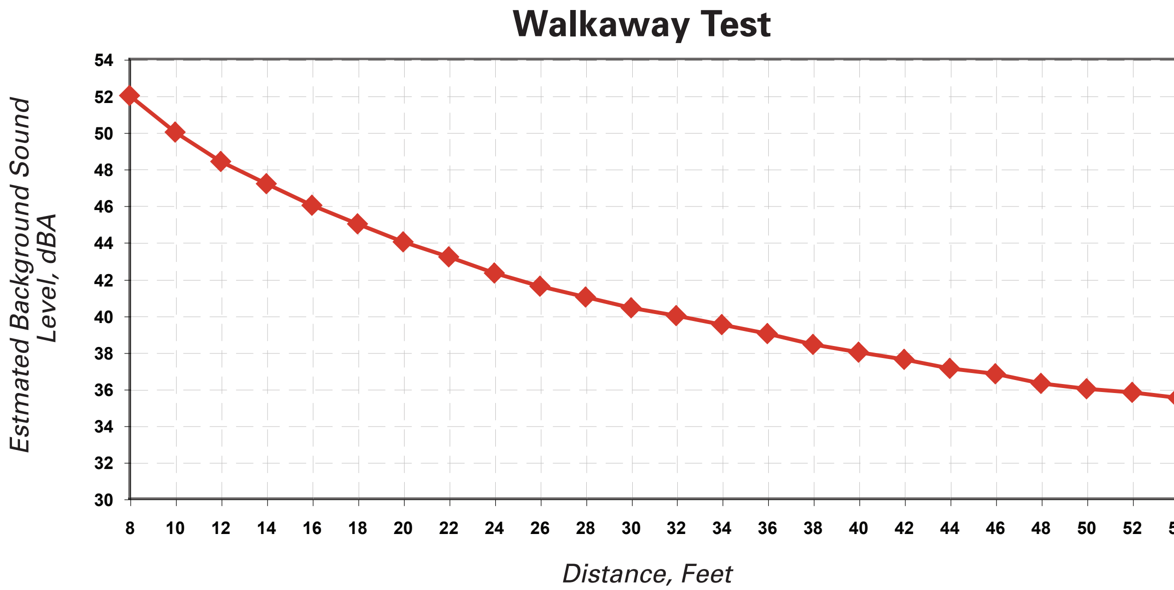
B.4 Estimating Background Sound Level with a Walkaway Test

Step 1. Find an open area where there are not nearby walls (not a hallway), an open office aisle is excellent. Normally the area will have a 2x4 suspended ceiling grid which will be the ruler.

Step 2. Have one of the employees stand at one point facing you and read some text material at a conversational voice level (that which might be used on the telephone). There is a tendency for that person to project to reach you, and that must be avoided.

Step 3. You and your client should face the person talking and slowly back up until you have difficulty understanding the speech. Use the number of ceiling tiles as the ruler and determine the distance in feet.

Step 4. Consult the chart to determine the approximate A-Weighted sound level.



Appendix C
CALCULATING PRIVACY INDEX

C.1 Introduction

C.1.1 Why Calculate Privacy Index?

In offices, it is seldom practical to make detailed measurements of the privacy provided by a sound masking system. The vast number of acoustical interactions in even small offices makes it a long and time-consuming prospect. As specialists gain more experience, setting up and adjusting the system to increase user acceptability is just as important as detailed measurements. However, there are circumstances where such measurements are valuable.

1. If a specification calls for the installer to do such measurements.
2. If an existing office looks marginal for sound masking to create privacy.
3. If facility managers need objective data to offset unreasonable complaints or justify the expense by showing the improvement provided by masking.
4. If privacy needs to be demonstrated in secure facilities at locations where listening tests cannot be performed (e.g. windows).

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C.1.2 Procedures

Privacy Index can only be calculated from a series of measurements, since it incorporates all relevant factors for speech privacy. For normal masking systems, the acoustical version is used. For secure facilities, where speech may be in vibration form, the second method must be used. Note that Privacy Index (A.3.3) is a rating between a specific talker and a specific listener and must be repeated for a multiplicity of situations. To collect the necessary data, a ⅓ octave band Real Time Analyzer with a random incidence microphone is necessary. To create the test sound, a source with directional characteristics similar to the human voice is necessary [61]. A tripod should be used to mount the sound source, normally 48 inches high for seated talkers.

C.2 Acoustical Privacy Index

The equations for Articulation Index and Privacy Index (A.3.1, A.3.3) are:

$$AI = \sum_{i=200}^{5000} SNR_i * W1_i$$

$$SNR_i = VS_i - TL_i - MS_i$$

$$TL_I = SS_i - RS_i$$

$$PI = 100 * (1 - AI)$$

The transmission loss spectrum (TL_i) has to be determined from two measurements, so a total of four spectrum measurements is indicated. It is both common and acceptable to choose the standard voice spectrum (VS_i) available from ASTM as one factor. The source spectrum (SS_i) must be measured at the location of the speaker, while the received spectrum (RS_i) and masking spectrum (MS_i) must be measured at the listener location, but not at the same time.

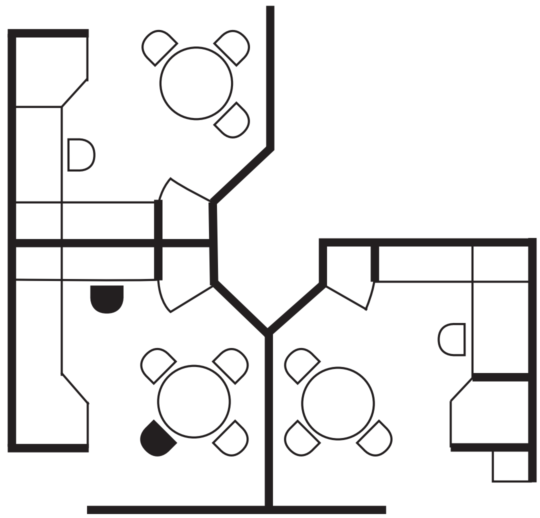

Figure C-1

Since there are many combinations of talker/listener positions even in one workstation pair, it is best to choose a worst-case situation such as shown in *Figure C-1*. The sound source (dark symbol) should face the upper workstation at seated height. Although the talker may seldom be in this position, it will be the one creating the worst privacy for the other parties. The listener should be at the most used position; in this case, at a workstation near the talker (open symbol). For a second test, placing the sound source (dark symbol) at the table, and facing across it, would be the worst-case for the listener in the workstation to the right. Since the normal position of the listener is likely to be at a worksurface further from the talker, the worst-case measurement should be from the talkers table to the listeners table.

Step 1: The source spectrum (SS). The sound source, mounted on a tripod, should be faced horizontally at seated height (48 inches) and pointed in the desired horizontal direction. It should be powered by a broadband random generator/amplifier. The spectrum should be as near pink (flat ⅓ octave band spectrum) as possible with an overall level of between 70 and 80 dBA, but since it will be used for difference measurements, it need not be exactly pink. It is preferred to make this measurement in an anechoic environment but such rooms are hard to come by. Further, one may have to determine the spectrum in the field. In that case, the source should be at least fifteen feet from all sound reflective vertical surfaces and over a carpeted floor. To minimize the destructive interference of the floor reflection, measurements should be made at 2, 3, and 4 foot distances along the speaker axis. Arithmetically averaging the three spectra will tend to strongly reduce the interference, which is below the frequencies important for speech anyway. Using software (e.g. Excel), the averaged spectrum can be stored and retrieved so source spectra need only be entered once.

Step 2: The received spectrum (RS). With the sound source on and the sound masking off (to avoid interference), the microphone should be placed at the listener's position, 48 inches high. To avoid body reflections, the microphone may be placed on another tripod, or held at arm's length at an angle not along the sound path.

S*tep 3: The masking spectrum (MS).* With the sound source off and the sound masking on, make a measurement at the same received position.

Step 4: Calculate Privacy Index. There is enough data to calculate Privacy Index. If the intention is to use these measurements to develop a masking spectrum, or evaluate one, it is best to make a number of these measurements spatially over the zone of interest rather than make several measurements in each of few workstations. One of the benefits of entering the data into the modeling program is that it permits calculation of Speech Weighted Loss (A.1.6), so the reason for any deficiency can be determined.

To minimize the tedium of these measurements, the source can be set up in one workstation, then rotated to make received measurements in all surrounding workstations. In many cases, four or five measurements can be made relatively quickly.

C.3 Vibration Privacy Index

The previous equations implied that all spectra were acoustical, but the same technique can be used for vibration spectra. In this case the masking spectrum is in vibration form but the transmission loss is the difference between a reference sound spectrum and the vibration response spectrum of a surface. The equations are:

$$SNR_i = VS_i - TL_i - VMS_i$$
$$TL_i = SS_i - VRS_i$$
$$SNR_i = (VS_i - SS_i) + (VRS_i - VMS_i)$$

VMS_i is the vibration masking spectrum measured on the surface and VRS_i is the vibration response spectrum measured on the surface caused by the sound source. By rearranging the terms, the two sound spectra can be grouped together and the two vibration spectra can be grouped together. The vibration measurement system need not be calibrated as long as the frequency bandwidth and level sensitivity is sufficient. These equations can be used for both windows and walls where vibration detectors are likely to be used.

Step 1: The source spectrum (SS). The same sound source spectrum as used for acoustical Privacy Index may be used. The overall level should be at least 80 dBA.

Step 2: The received spectrum (VRS). With the sound source on and the sound masking off (to avoid interference), the vibration detector should be placed at the listener position on the surface.

Step 3: The masking spectrum (VMS). With the sound source off and the sound masking on, make a measurement at the same received position on the surface.

Step 4: Calculate Privacy Index. There are enough data to calculate vibration Privacy Index.

Appendix D

COLLECTING AND DOWNLOADING DATA FROM CERTAIN REAL TIME ANALYZERS

The masking/paging equalization program, MEQ, has the ability to accept spectrum downloads from several real time analyzers. Each is addressed in this appendix separately. Data can be downloaded from the Bruel & Kjaer Model 2250 in the MEQ program but no instructions for meter use are available.

D.1 The Larson-Davis Model 824A

The Model 824A meets all standards. It is more versatile than one needs for sound masking applications and can be confusing to operate, so detailed procedures for making sound measurements are given here:

D.1.1 Equipment Needed

- Larson-Davis Model 824A Sound Level Meter
- Larson-Davis Model PRM902 Preamplifier
- Larson-Davis Model 2540 Random Incidence Microphone
- Larson-Davis Model CAL200 Acoustic Calibrator
- Power Converter with output of 9VDC and 500 mA
- Larson-Davis rechargeable battery packs (2 recommended) or 3 AA batteries (with adequate spares) Useful life: 2 hours
- Larson-Davis access software (optional)
- Larson-Davis cable from LD824 to computer serial port

D.1.2 Equipment Setup

1. Put 3 AA batteries in rear of meter.

2. Attach 2540 microphone to PRM902 preamplifier.

3. Attach PRM902 to meter. Line up red dots.

D.1.3 Check/ Set Date

NOTE: Data files are stored by date/time so it is a good idea to set the correct time.

1. Press Power button (turn on meter).

2. Press TOOLS button.

3. Scroll Down to Clock/Timer. Hit center Check Key.

4. If Date and time are incorrect:
   a. Hit Left/Right Keys to go to "Time-a" window. Hit Check Key.
   b. Scroll to "Current Time." Hit Check Key.
   c. Use Up/Down arrows to set hour (24 hour clock). Hit Right Key.
   d. Use Up/Down arrows to set first digit of minutes. Hit Right Key.

e. Set second digit of minutes. Hit Right Key.
f. Use Up/Down arrows to set first digit of seconds. Hit Right Key.
g. Set second digit of seconds. Hit Check Key.
h. Scroll down to “Current Date.” Hit Check Key.
i. Use Up/Down arrows to set month. Hit Right Key.
j. Use Up/Down arrows to set day. Hit Right Key.
k. Use Up/Down arrows to set year. Hit Check Key.
l. Scroll down to “Weekday.” Hit Check Key.
m. Select the current day of the week. Hit Check Key.
n. Hit Power Key until power monitor screen returns.

D.1.4 Set Calibration

NOTE: Always set the calibration prior to measurements!

1. Turn on meter.

2. There is a small slide switch near calibrator On button. It should be positioned closest to the On button. This will set it for 94.0 dB at 1000 Hz.

3. Put CAL200 calibrator on microphone.

4. Turn on Calibrator and listen for tone. It will turn itself off automatically, so if you are slow you will need to restart it.

5. Press TOOLS button.

6. Scroll Up/Down to Cal Level. Hit Right Key.

7. Scroll Up/Down to change the three number bins so they read 94.00. Hit Check Key.

8. Scroll Up/Down to Calibration. Hit Right Key.

9. Question: “Calibrator Active” Answer: “Yes.” Hit Check Key.

10. Scroll Up/Down to Change. Hit Right Key.

11. Watch screen. It should home in at ~94.0 dB.

12. Question: “Reset required” Answer: “Yes.” Hit Check Key.

13. Question: “High Range” Answer: “No.” Hit Check Key.

14. Hit Power Key until power monitor screen returns.

D.1.5 Clearing Memory

NOTE: The meter stores a very large, but finite, number of files. We recommend you clear the memory of the files already stored, so you can start with file 1 as the first measurement. You may wish to download the existing files prior to clearing memory.

1. Turn on meter.

2. Press TOOLS button.

3. Scroll Down to Memory. Hit Right Key.

4. Scroll Up/Down to Purge Files. Hit Check Key.

5. Question: “Purge Files” Answer: “Yes.” Hit Check Key.

D.1.6 Making Measurements for Download

1. Remove Calibrator.

2. Turn on meter.

3. Press VIEW button.

4. Scroll Down to RTA. Press Right Key.

5. Scroll Up/Down to RTA Leq. Press Right Key.

6. Scroll Up/Down to Tabular. Press Check Key.

7. Press Run/Stop button to start data collection.

8. Wait at least 10 seconds for averaging. Press Run/Stop. If any extraneous noise occurred during time period (talking, PA etc) do again.

9. Manual Recovery
   a. Scroll Left/Right to see ⅓ octave band level at 160 Hz.
   b. Copy level into data sheet. Scroll right and copy levels to 8000 Hz.

10. Automatic Recovery
    a. Press DATA button.
    b. Scroll Up/Down to Store File. Press Check Key.
    c. Check file number (if not sure). The meter assigns a number to each file which you need to know.
    d. Press DATA button.
    e. Scroll Up/Down to Recall File. Press Check Key.
    f. On upper right is small number set usually 1x where x is total number of files added. The latest store would be x.

D.1.7 Making Measurements of Sound Masking Spectra

NOTE: This includes adjusting the meter graph scales.

1. Turn on meter.

2. Press VIEW button.

3. Scroll Down to SLM. Press Check Key.

4. Scroll Up/Down to Gain +xx

5. If you want to show lower sound levels, press Right Key *quickly*.
   a. Gain will increase in 10 dB steps to 50.

6. If you want to show higher sound levels, press Left Key *quickly*.
    a. Gain will decrease in 10 dB steps to 0.

7. If you want to adjust the range of levels shown, press Check Key *quickly*. Even double click. You will be in the SLM/RTA menu.

8. Press Check Key again. You will see the graph entitled Adjust Graph. The graph has 5 major divisions and 50 minor divisions.

9. Press Up/Down Keys to adjust lowest level of graph in 1dB steps.

10. Press Right/Left Keys to adjust range (Scale).
    a. 1 means each minor division is 1 dB (50 dB total range)
    b. 1/2 means each minor division is ½ dB (25 dB total range)
    c. 1/4 means each division is ¼ dB (12.5 dB total range)

11. You may have to adjust the level key to get the desired lowest level.
    a. Press Check Key to exit.
    b. Press View Key to start graph.
    c. Press Down Key to RTA.
    d. Press Right Key. Press Down Key to RTA Leq.
    e. Press Right Key.
    f. Scroll to Spectrum.
    g. Press Run/Stop Key to start graphing.

D.2 The Goldline Model DSP30

The DSP30 is a multi-purpose real time analyzer. The cost of the instrument is significantly less than the Model 824A. This section of the note describes the detailed procedures for making sound measurements with it.

D.2.1 Equipment Needed

- Goldline CVOW software
- DSP30 Real Time Analyzer with microphone
- Knowledge of the directory of the equalization program. You will have to do a copy/paste operation.

D.2.2 Making Measurements and Storing Them

1. Turn on the unit

2. Set Scale (Button 1) to 3 or 5 dB per step to more easily see the spectrum.

3. Set Weight (Button 2) to Flat

4. Set Decay (Button 3) to Slow

5. Set the Level+ (Button 8) or level- (Button 0) until the spectrum shows. .

6. When you are in the correct room position press Store (Button 7) and then a number key 1 to 6 to store to that memory. Press RTA to resume next measurement. You can store up to 6 measurements.

7. When all are stored, press Option/.Sum+ (Button 1) at the same time. Then press all the buttons that relate to the measurements you just made. You have now averaged all the data taken so only one spectrum needs to be sent to the program.

D.2.3 Transferring the Data to a File

1. Connect the DSP30 to your computer with the serial cable.

2. Open the CVO software and run it.

3. With the current file being the average spectrum, press Capture Plot.

4. Press File/Save, give the file a useful name as Proj234.txt.. MAKE SURE you choose ASCII text as the file type. Save the file to the Folder where the equalization software is located, so the program can find it easily.

5. The equalization program later will pick it up and use it.

D.3 The Phonic PAA3

The PAA3 is a multi-purpose real time analyzer. This section of the note describes the detailed procedures for making masking sound measurements with it.

D.3.1 Equipment Needed

- PHONIC software (paa.exe)
- PAA3 Real Time Analyzer with microphone
- Power supply if not used with battery.
- USB cable to connect to computer.

D.3.2 Step by Step to Set up for Measurement

1. Turn Power on
   Hold down Left Button until screen shows (Enter button)
   Enter again

2. Scroll to SETTING
   Enter

3. Scroll to WEIGHTING
   Enter

4. Scroll to FLAT
   Enter

5. Scroll to ESC
   Enter

6. Scroll to RANGE
   Enter

7. Scroll to 30 – 90 dB

8. Scroll to ESC
   Enter

9. Scroll to RESP TIME
   Enter
10. Scroll to 1 Sec
   Enter

11. Scroll to ESC
   Enter

12. Scroll to MAXLEVEL
   Enter

13. Scroll to RESET
   Enter

14. Scroll to ESC
   Enter

15. Scroll to SPL/LINE

16. Scroll to SL
   Enter

17. Scroll to ESC
   Enter

18. Set up complete
   Meter screen should show and running

D.3.3 Step by Step Masking Measurements and Storing

You may make up to 10 measurements and store them.

NOTE: Memories cannot be cleared in this meter so you must remember to which memories you are storing data.

NOTE: If you store more than one memory, they must be in sequence, as recovery will require knowing the start and end records and will recover all records in between.

With the meter running and all ⅓ octave bands (160 Hz to 8000 Hz) showing above the line. If not, raise the masking level until they do.

When ready to store, do not move the meter as it continues to run while doing the next steps.

1. Enter

2. Scroll to MEMORY
   Enter

3. Scroll to STORE
   Enter

4. Scroll to Desired Memory Number
   Enter

5. Scroll to YES
   Enter (you will be on ESC)
   Enter
6. Scroll to ESC
   Enter

7. Scroll to ESC
   Enter

8. Make the next measurement or turn off meter (Hold down power button)

D.3.4 Saving Data to a File

1. Connect the meter to your computer with the USB cable.

2. Turn it on.

3. Open the PHONIC software and run it.

4. Go to File/Online. If properly connected the meter will show activity and the memories will be displayed.

NOTE: This a good time to review the memories used for the measurement. Look for blank spaces in those memories. If there are you will have to make more measurements and over-write the bad ones.

1. Go to File/Save File.

2. Choose the directory PHONIC/PAA3 as the location (That is where the paa3.exe file is located)

3. Give the file a name and press SAVE.

Index

Q

R

S

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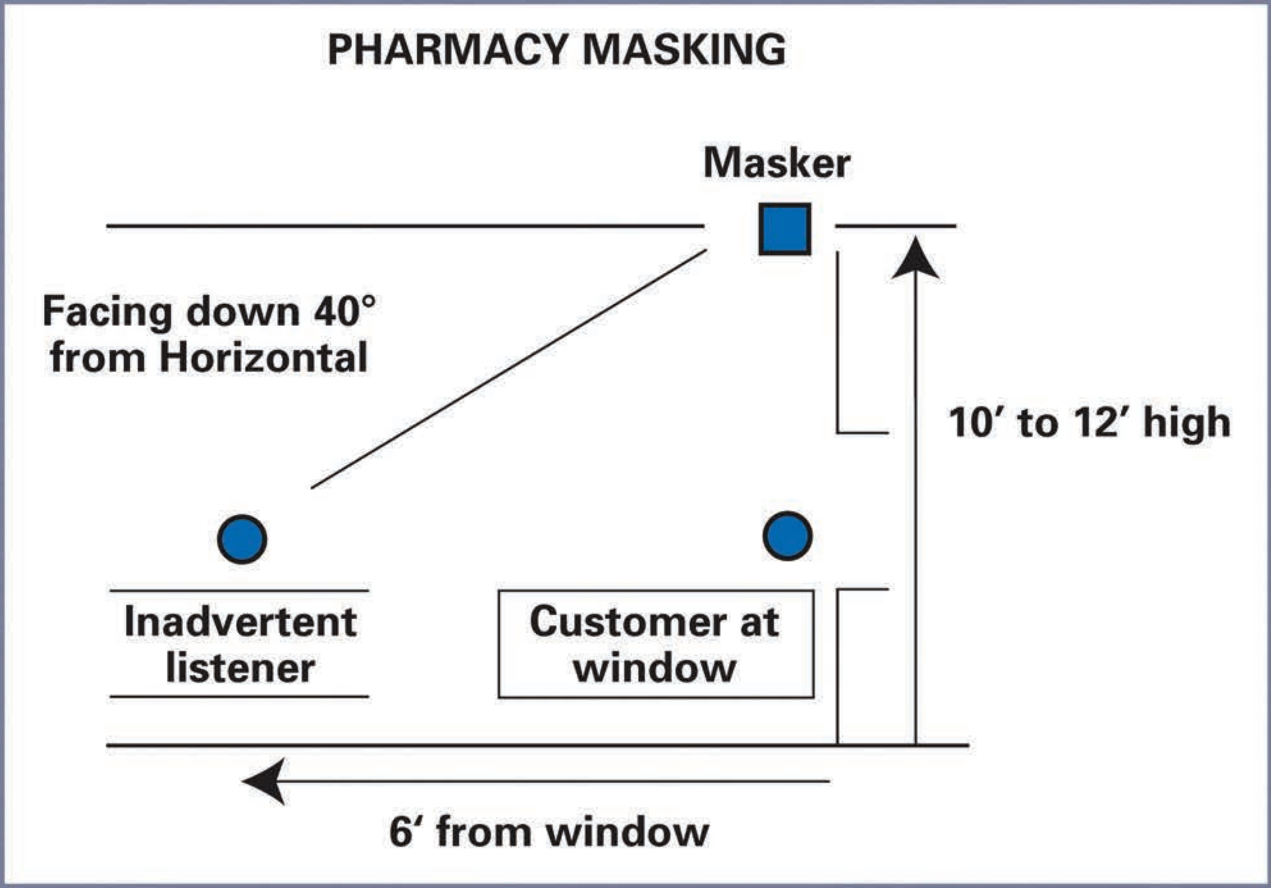

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