# Further Thoughts on Sound Masking
## Robert Chanaud, Ph.D.

The comprehensive book on sound masking entitled "*Sound Masking Done Right*" was published by Magnum Publishing in 2008. Since that time, advances have been made in understanding masking and some uses have strayed from the well accepted rules of application. This document contains eight interrelated articles on several of these subjects.

# ACOUSTICAL PRIVACY AND SOUND MASKING IN OFFICES

## Introduction

Persons desiring to add sound masking to their facility implicitly assume that the masking system installer will achieve the degree of privacy desired by his employees. Most often, however, the installer has been tasked only to add sound masking at some specific level. The contracting person must ask a basic question: ***How much acoustical privacy will my people have with sound masking?***

` In most cases, an honest answer would be: **I don't know**. The primary reason for this answer is that the installer does not have control of all the factors that result in acceptable privacy. *The relationship between sound masking and acoustical privacy is not straightforward*.

Specifications by consultants often go into detail requiring a specific masking spectrum over a broad range of frequencies but do not have a requirement to achieve a particular degree of acoustical privacy (see *Spatial Uniformity)*.

Sound masking in open offices is meant to cover a number of people, but acoustical privacy is a very personal interaction between two people; a person making sound, and a person inadvertently hearing it. There are three factors that determine the degree of privacy between them:

- The loudness and direction of the talker's voice and his or her activity sounds.
- How much of that sound is reduced enroute to a listener.
- How much of the sound reaching the listener is covered by the existing sound at the listener (masking).

> *Without knowledge of the first two factors it is not possible to claim* ***a priori*** *that a masking system will provide acoustical privacy with reasonable levels of sound masking.*

In short, the first two factors must be known before the third factor can answer the main question with any degree of precision. But even this addresses only speech privacy (see *Distraction Potential)*.

## Degrees of Speech Privacy

` Prospective owners seldom state what degree of privacy they want, so the contractor still has a problem even if the above factors can be defined. Standards have been developed that divide speech privacy into several degrees.

- **Secret Privacy** - speech is intelligible only to those for which it is intended, despite the attempt by deliberate persons to use listening devices.
- **Confidential Privacy**- speech is intelligible only to those for which it is intended, excluding unintentional casual listeners.
- **Normal Privacy** - speech is partially intelligible to unintentional listeners, but not enough to cause **distraction.**
- **Transitional Privacy**- speech is partially intelligible to unintentional listeners, but is enough to cause **distraction**.

- **No Privacy** - speech is fully intelligible to listeners, and enough to cause **complete distraction.**

## Determining Speech Privacy with Measurements

One approach to determining speech privacy is to use vocal speech intelligibility tests between two people. The impracticality of them for an office environment is clear. A second approach is to make several field measurements between workstation or closed office pairs with a broad band sound source and a high quality one-third octave band sound level meter. This determines the sound loss factor. Fortunately, the speech spectrum of people in an office environment is well known, so the voice level factor can be determined (see *Radius of Distraction*). With knowledge of the first two factors, one can computer model with various sound masking spectra to determine the desired masking. Calculations use the **Articulation Index** or **Privacy Index** to determine the degree of privacy. There are some weaknesses to this approach:

- The listener should have normal hearing.
- A statistically significant number of samples must be taken and suitably averaged.
- It implicitly presumes that the talker is speaking all the time (a worst case scenario).
- It does not address loss of privacy by other sounds.

See *Distraction Potential* for discussion of the last two items. It is clear that field measurements entail considerable effort to clearly define the relationship between sound masking and acoustical privacy.

## Early Guidance for Acoustical Privacy with Sound masking

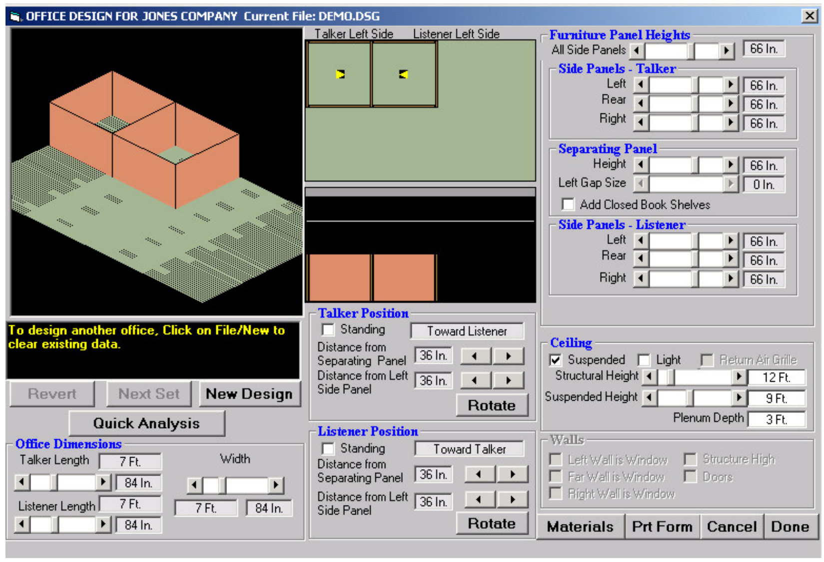
Over the last forty some years, measurements have been made of what was called *interzone attenuation;* the sound loss from one workstation, or one office, to another. With those measurements and estimates of normal speech spectra it was possible to define a masking spectrum through the use of the **Speech Privacy Potential (SPP).** It was defined in the GSA Public Buildings Service document PBS-C.1, 1972. That method used the **Noise Criterion Prime (NC')** rating to define and constrain the masking spectrum. Experience with this method suggested that levels higher than 47 dBA in open offices were not considered acceptable to most listeners, although some exceptions have been found. Levels higher than 45 dBA in closed offices were not considered acceptable. Levels lower than 42 dBA in open offices were considered non-performing. Since masking is not always used in closed offices, there seems not to be a lower limit for masking levels there. This early guidance at least defined the range of acceptable masking levels. It had a requirement for an **SPP** greater than 60 to provide what is now called Normal Privacy and not other degrees.

More recently, the earlier spectrum requirement has been replaced by a newer standard called **Room Criterion (RC)** and **Noise Criterion Balanced (NCB)** (ANSI S12.2-2008). This standard covers frequencies in the speech range and defines what is called a *neutral* spectrum, one that does not have too much low frequency or too much high frequency. The contour decreases at 5 dB per octave in the speech band of frequencies. The word "neutral" implies an acceptable spectrum. This standard places a restriction on the frequency distribution of the masking spectrum contour regardless of its level.

These developments have placed useful constraints on the level and spectrum of sound masking but still require field measurement of the sound loss factor if the masking is to achieve the desired degree of speech privacy. Since it is unlikely that measurements will be part of a specification for sound contractors, most facility managers now must wait until employees complain. Another approach is to model the office on a computer.

## Modeling Speech Privacy to determine the Sound Masking

With the publication of extensive data on the acoustical properties of office equipment, Atlas Sound developed an acoustical modeling program Called SCOPE (*Sound Conditioned Open Plan environment).* It includes a database of ceilings, furniture panels, carpets and other surfaces as well as various voice levels for men and women. A wide variety of open and closed offices can be modeled. The figure on the right shows an example of an open office workstation pair. The occupants can be placed in any position, and side walls can be added as well as a number of other factors, shown in the several boxes.




Once the design is created, the program analyzes the sound loss for up to 46 possible sound paths and creates a list starting with the weakest path (the critical path). The next step is to choose voice characteristics, background sound level, desired degree of privacy, and a masking spectrum from a data base of commonly used spectra. The program then designs a masking spectrum and level that satisfies the privacy criterion. If the level is unacceptable high, the critical path must be improved. A sample of workstation types can be examined in short order.

The program has several advantages:

- It can be used *prior* to the final design of an office space.
- It can readily determine whether the masking will create the desired degree of privacy with acceptable levels or where the weaknesses are, if it does not.
- It can be used to rapidly analyze a number of office designs.
- It can be used as a means of separating legitimate from illegitimate complaints.

One weakness of modeling is that it presumes the person is talking continually (the worst case scenario.). Fortunately, the level chosen is likely to be an upper bound on the required masking and initial installation recommendations can be used to handle that.

## The Final Privacy Test

Despite good estimates of privacy with a given sound masking spectrum, the final test is whether the environment is acceptable to the occupants. On initiation, a sound masking system should be set lower than final levels and then the levels should be slowly increased over days. It can be done automatically (ASP-MG24-TDB). This process can be used to advantage by the facility manager to point out that the privacy will improve with time. There may be a level that is acceptable to the employees that is lower than the design level.

The final test of success is lack of legitimate complaints. Legitimate complaints result from cumulative distractions that finally result in annoyance and then to a complaint Complaints can be based on several factors. A legitimate one is from persons with hearing loss that has been given more privacy than others. Turning off a local speaker is not a solution; the person should be moved to another area. Persons with vision loss use acoustical cues to navigate in offices; masking can destroy those cues; they should be moved also.

Another compliant is damage to a person's hearing or welfare caused by alleged excessive masking. There is no evidence that reasonable levels of masking cause hearing damage. Other complaints can be based on non-acoustical factors, such as unhappiness with the temperature, the management, etc. These are not indications of masking system failure.

## Recommendations

- ***Owners should define the desired degree of privacy for contractors.***
- ***Contractors should be given access to office plans prior to design of the sound masking system.***
- ***Contractors should be responsible for operation and training of the masking system, and not the privacy results.***
- ***When possible, modeling should be done to determine the value of sound masking.***

# SPATIAL UNIFORMITY OF SOUND MASKING

The uniformity of sound masking levels can be important in offices, although it is only one of several factors that contribute to successful systems. There is one important question: **Will uniformity of sound masking provide uniformity of acoustical privacy?**

See *Acoustical Privacy and Sound Masking* for the relationship between them.

> *Uniformity implies that a person moving from one area to another will not detect changes in the background sound. To a lesser extent, uniformity within a workstation is also desirable. Deviations from uniformity might occur for various reasons; they are generally localized and randomly distributed. There are situations where deliberate non-uniformity is introduced in order to match the sound level in one area with that in another; it is called* ***soundscaping.***

Uniformity is generally not an issue in closed offices, but uniformity in open offices can be. ASTM E1573-09 addresses uniformity of sound masking in open offices. Consultant specifications most often require that levels be uniform over an area. For example, they may require a specific masking spectrum contour and may allow only limited spatial level variations, such as +/- 2 dB, in each frequency band or in overall A-weighted level. If these requirements are met, masking sound levels should be essentially uniform over the measurement area. Often in specifications the area is not defined. However, there are further requirements:

- During office design, areas of very similar office structure should be designated as separate *zones*.
- The spectrum frequency contour and the desired overall level for each zone should to be defined (see *Acoustical Privacy and Sound Masking*).
- Level measurements over a zone should be made with 1/3 octave band filters to detect sharp spectrum deviations.
- A-weighted levels should be measured in aisles between workstations by an extended walk though at standing height for spectrum uniformity.
- Masking level measurements should be made at seated height in workstations for level uniformity..
- The A-weighted levels should all be within +/- 2 dBA of each other.
- Persons with vision or hearing handicaps should be placed in separate areas.

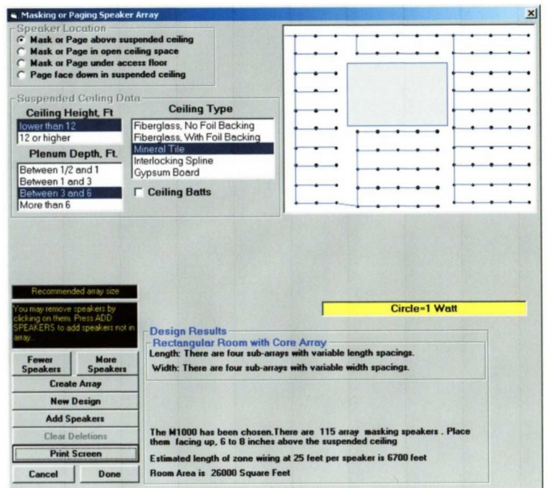
If these requirements are met, spatial uniformity of masking is generally achieved and uniformity of acoustical privacy is likely to be achieved if the workstation arrangements are consistently the same in a zone.

## Assisting masking uniformity with proper speaker arrays

Proper speaker spacing helps to insure reasonably uniform masking levels in open offices. Proper spacing is a compromise between close spacing resulting in excessive uniformity and excessive costs and more open spacing with less uniformity and less expense. There are a number of factors that determine the best spacing. These are listed below.

| Speaker Location | Important Factors |
|---|---|
| **Above Suspended Ceiling** | Suspended ceiling height |
| | Plenum height |
| | Ceiling material |
| | Presence of plenum sound absorption |
| **In an Open Ceiling** | Structural ceiling height |
| | Presence of plenum sound absorption |
| **Under a raised floor** | Cavity height |

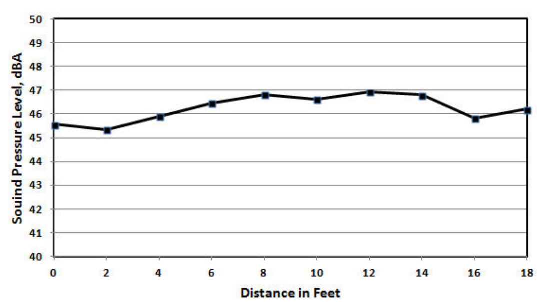
Atlas Sound has a program called **SPEAKER LAYOUT** that expedites the creation of speaker arrays. Entering the room geometry and the factors listed above, results in a speaker array considered an optimum balance between cost and performance. The user chooses the shape and dimensions of a zone to be masked, then chooses the vertical location of the masking speakers. The program then quickly creates a speaker array for the space that can be printed with location details for each speaker. An example is shown in the figure on the right for an office with a central elevator core. A manual layout for an office this size one would take considerable time. This is just one tool to assist in spatial uniformity.




## Examples of spatial uniformity in Open Offices

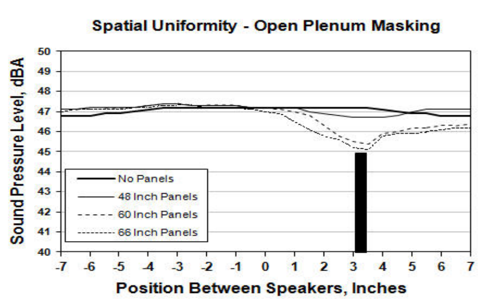
### Plenum Masking

The figure on the right shows an example of the A-weighted masking level measured in an open office aisle area. The speaker array in the plenum was a 15 foot square and the ceiling height was 9 feet. A person passing through that aisle would experience less than a 2 dB variation. None of the employees that used that aisle said they detected no level changes when questioned. Measurements for this case were made at seated height.




### Open Plenum Masking

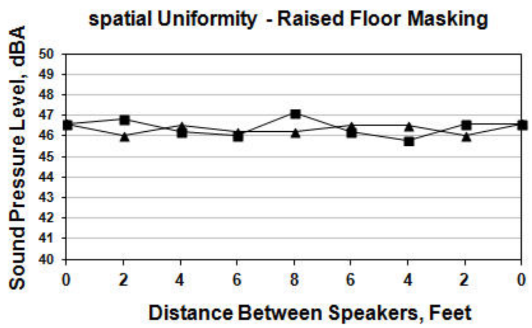
The figure on the right shows examples of the A-weighted masking level at seated height when the masking speakers are placed in an open plenum with no suspended ceiling. The speaker array was a 14 foot square. The speakers were pointed up and their bottoms were 12 feet high. The heavy solid line is the level with no panels; the other lines represent the



level for three heights of workstation panels.  These panels were absorptive so the levels near the panels was reduced.  Typically, people are three feet from the panel so the level reduction is less significant.

**Under Floor Masking**

The figure on the right shows two examples of the A-weighted masking level at seated height with no panel systems.  The speaker array in the cavity was a 16 foot square. The cavity height was 6 inches and M1000LP low profile speakers were used (see *Under Floor Masking)*.




**Direct Field Masking**

See *Direct Field Masking*.

## Recommendations

- ***Follow the requirements listed above.***
- ***Use software to create speaker arrays.***

# UNDER FLOOR SOUND MASKING

When given an option for locating sound masking speakers, the prospective owner should ask the question: ***What is the best location for the speakers to provide the most acceptable masking?***

Possible locations are:

- In the plenum above a continuous suspended ceiling'.
- In the plenum above a discontinuous suspended ceiling ("clouds").
- In an open plenum without a suspended ceiling.
- Face-down in a suspended ceiling.
- **Under a raised floor.**

## Introduction

For many years sound masking speakers have been placed in the plenum above a suspended ceiling. In some designs, the suspended ceiling was discontinuous so the tiles were referred to as "clouds". In some offices, the suspended ceiling was completely absent, so the structural ceiling was visible and speakers were placed in the open plenum. In each of these cases, rules for positioning the speakers and tuning the sound spectrum and level were developed. (Download "*Sound Masking Done Right"* from the Atlas Sound web site). These three locations are commonly available and are used to create successful sound masking systems. More recently, face-down masking speakers in suspended ceilings have been used. (see *Direct Field Sound Masking)*.

In the 1980's, raised floors migrated from computer rooms to office spaces, providing another possible location for sound masking speakers. To the author's knowledge, the first such installation was done in the early 1980s at a government office in Florida. The speakers were placed on the structural floor under a twelve inch high raised floor, prior to the raised floor being completed. The installation process was much quicker and simpler than for placement above a suspended ceiling. Because the sound transmission loss of a raised floor is much higher than that of a suspended ceiling, higher levels of sound within the cavity were required to achieve acceptable masking levels in the room above. The masking spectrum contour used for plenum masking supplications was found not to be applicable so it was modified to achieve the desired level and spectrum at the employee level above.

The remarkable and unexpected result was that the source of the masking sound was impossible to locate. As a result, the masking levels above were more uniform than that for all other masking speaker locations. Also, the sound field was exceedingly ***diffuse***. A diffuse sound field is one where the sound comes from so many directions it is not possible to locate the source. For a fuller discussion of sound diffusion see the section below.

## Cavity Depth Issues

Although most ceiling plenums are sufficiently deep to accept standard sound masking speakers, there are some that are quite shallow and require low profile speakers. The same is true for raised floors. When the cavity is 12 inches or greater, the Atlas M1000 speakers work well. For smaller cavities, the Atlas M2000-LP low profile speaker is used.

## The Masking Spectrum

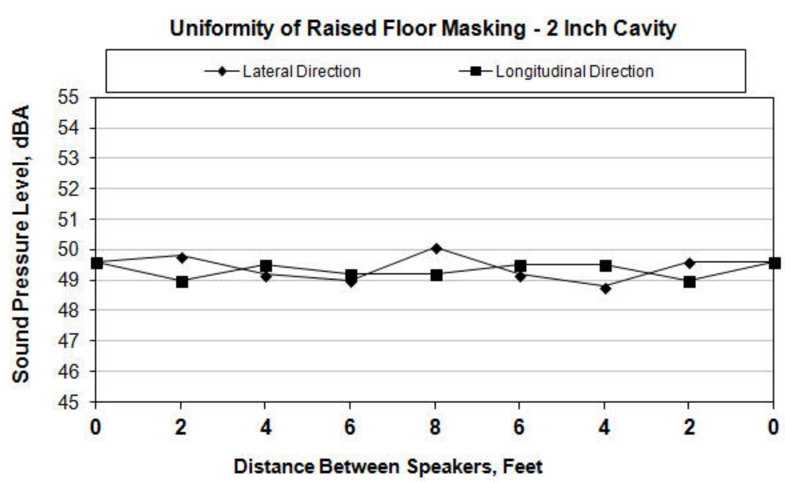
The masking spectrum desired in workstations above a raised floor is determined by the sound spectrum under the floor. Unlike plenum speakers, the change in level and spectrum contour is so large that a different base acoustical spectrum is required. To handle under floor applications, the Atlas ASP-MG24 and ASP-MG24TDB masking generators store a base electrical spectrum for under floor applications that provide an office acoustical spectrum that is near that recommended by standards. The initial spectrum is approximately correct and only small changes in spectrum and level are required.

## Spatial Uniformity

The spatial uniformity exceeds the uniformity of masking speakers located in any other position. The results of tests done by Dynasound (see reference below) are given in the table below. The standard deviation for the several important spectra was determined over a number of positions in each test and in a number of tests. The deviations were exceedingly small.

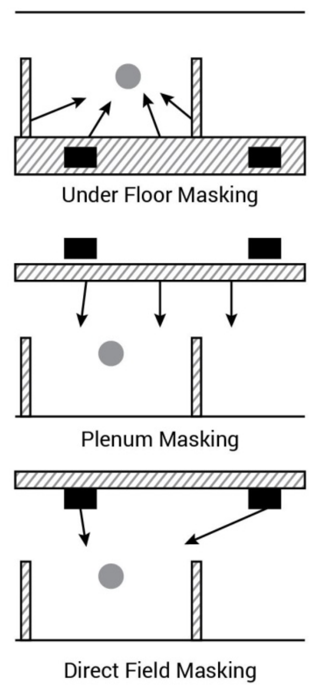
| Freq | 500 | 630 | 800 | 1000 | 1250 | 1600 | 2000 | 2500 | 3150 | 4000 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.5 | 0.3 | 0.3 | 0.2 | 0.6 | 0.5 | 0.6 | 0.3 | 0.3 | 1.5 |
| 2 | 0.6 | 0.7 | 1.0 | 0.5 | 0.7 | 0.4 | 0.3 | 0.7 | 0.4 | 0.1 |
| 3 | 0.9 | 0.8 | 0.5 | 0.4 | 0.3 | 1.0 | 0.6 | 0.8 | 0.4 | 1.0 |
| 4 | 0.4 | 1.3 | 2.0 | 0.3 | 0.9 | 0.6 | 0.3 | 0.5 | 1.3 | 1.4 |
| 5 | 0.7 | 0.5 | .5 | 0.3 | 0.3 | 0.6 | 0.6 | 0.3 | 0.1 | 0.6 |
| 6 | 0.9 | 0.5 | 1.1 | 0.6 | 0.2 | 0.5 | 0.6 | 0.7 | 0.5 | 0.8 |
| 7 | 1.2 | 0.7 | 1.0 | 0.4 | 0.3 | 0.4 | 0.6 | 0.7 | 0.8 | 1.7 |

A graphical example of this uniformity is shown in the figure on the right (made by Dynasound). There was a 16 foot square foot speaker array. Low profile speakers were placed in a shallow cavity. A traverse was made, 48 inches high, before the furniture system was installed. It was made both laterally and horizontally. The 8 foot position was the center of the array for both directions. Such uniformity is very difficult to achieve in speaker arrays at other locations. Comparison with other locations is given in a companion article entitled *Spatial Uniformity*.




## Diffusion

Diffusion of sound masking is seldom mentioned in the literature, but has a significant influence on both performance and acceptability. It is best appreciated by reference to lighting system design. Engineers use *Equivalent Sphere Illumination* and *Visual Comfort Probability* to define the acceptability of lighting designs. The more diffuse the lighting, the less the glare, and the more acceptable the visual environment. This concept applies also to sound. An example of a nearly diffuse sound field is the outdoor ambient we experience every day. It is not normally possible to identify a direction to a specific source and most of us are not even aware of its existence. In the office environment, under floor masking is highly diffuse so it is not possible to identify the source of sound. The figure on the right below shows a simplistic sketch of the directions masking sound impinges on a workstation occupant. With under floor masking, it appears that the higher sound levels in the cavity can cause undetectably minute vibrations of the furniture panels and even the room walls which then reradiate sound from a number of directions. Plenum masking is less diffuse; a listener can usually determine that the sound is coming from above but cannot identify a specific source (if the system is well designed). Sound shadowing is minimized. Direct field sound masking has *no* diffuse characteristic and is equivalent to a glare light source. A listener is perfectly capable of pointing at the source.




Subjectively, diffuse masking sound in an office always appears subjectively quieter and thus is more acceptable at the same overall level as masking from other locations.

## Recommendations

**Whenever possible, use under floor masking in preference to any other speaker location.**

## Reference


Anon, "The Acoustical Issues and Benefits of Raised Access Floors", Tate Access Floors and Dynasound, May 2006

# ADAPTIVE SOUND MASKING

Activity sounds, both voice and non-voice, will vary in level throughout the workday in an office. A prospective owner should ask the question: **Is it beneficial for the level of a sound masking system to continually adapt to the changing activity sounds?**

## Handling Activity Level Changes

The three important factors in achieving acoustical privacy are: (1) the sound level of talkers or their activity sound; (2) the sound loss enroute to a listen; and (3) the sound level of the masking or background. Item 1 can vary with time, but item 2 cannot, so item 3 has to be varied in time if item 1 varies to maintain the desired degree of privacy.

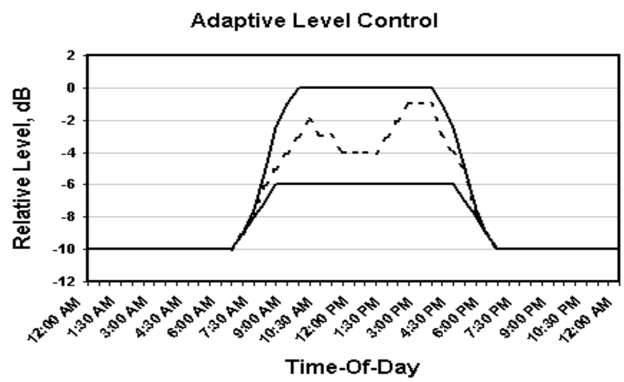
Most activity sound is related to office occupancy. Most often, activity levels are reasonably constant during the workday when occupancy is high, but in some offices it can be intermittent. Activity levels are always lower before and after work hours when occupancy is lower. During work hours, employees desire acoustical privacy to do their tasks while outside work hours they need a sense of community and less privacy. (Download "*Sound Masking Done Right*" from the Atlas Sound website) Since work hours are reasonably well defined, it is possible to separate the workday into two parts: work hours and non-work hours. During work hours activity levels are likely to be unpredictable so the requirements to maintain privacy are variable. During non-work hours, activity levels diminish and privacy may not be of as much concern.

The initial means of separating the workday into two parts was to manually turn the masking system off after work and back on in the morning. Later, a timer performed the On/Off function. The abrupt level change in sound level was highly noticeable since not all employees came and went at the same time. The need to vary masking levels and slowly was recognized and a US patent for a *programmed level controller* was issued in 1977 (4,052,720). The output of the masking generator was controlled by an internal clock. Early versions allowed the level to rise slowly from a low nighttime level over a specified number of hours early in the work day. Masking levels usually remained constant during the majority of the workday and then decreased slowly after work hours. Later versions permitted independent smooth hourly level changes for each day of the week. Current versions of these controllers permit numerous and highly variable time-vs.-level histories to be stored and used in different office zones (Atlas Sound ASP-MG24-TDB).

The essential weakness of this concept was recognized at the time the patent was issued and a patent disclosure was written for an *adaptive level controller*. Essentially, this design would listen to the activity sounds in an office and adjust the sound masking level to maintain the desired degree of privacy. Several hurdles had to be overcome. The social hurdle was that the sound sensor must not carry the entire speech spectrum to avoid being a "bugging device". A technical hurdle was how to separate the activity sounds from the masking sound. This was handled by calculation of percentile levels; the activity sounds being the more infrequent higher percentiles ($L_{10}$) while the masking being the more constant lower percentiles ($L_{90}$ or $L_{99}$). A practical hurdle was how to distribute the detecting devices. High activity sounds in one area of an open office might result in excessive and unacceptable masking levels in another area. At the time, the technology was not available at reasonable cost, and since the advantages of adaptive masking were not obvious, no patent application was submitted. However, in 2006, a US patent (7,460,675) was issued for an adaptive system and that system now exists (SoftdB SmartSMS-Net). If the main question is answered affirmatively, a second question is: **Is *an adaptive level controller preferred over a programmed level controller?***

Much of the additional cost of an adaptive system is associated with the purchase and installation of sound detection equipment. In offices, acceptable masking levels create a Radius of Distraction (**RofD**) of about 16 feet (see *Radius of Distraction*). That radius is the distance beyond which employees have Normal Privacy from a person talking. On this basis, for an adaptive system to properly cover an office, it would seem reasonable to space the microphones in a rectangular array of about 20 feet in every separate zone. For a 20,000 square foot open office, 50 microphones would provide uniform coverage. Clearly, such spacing is impractical on a cost basis, and it is likely that the existing system has fewer sensors. The detected sound is converted to a variable voltage, suitably averaged, and then analyzed. The generator then transmits a changed masking level to the zone as needed. This process requires two wire systems for each zone.

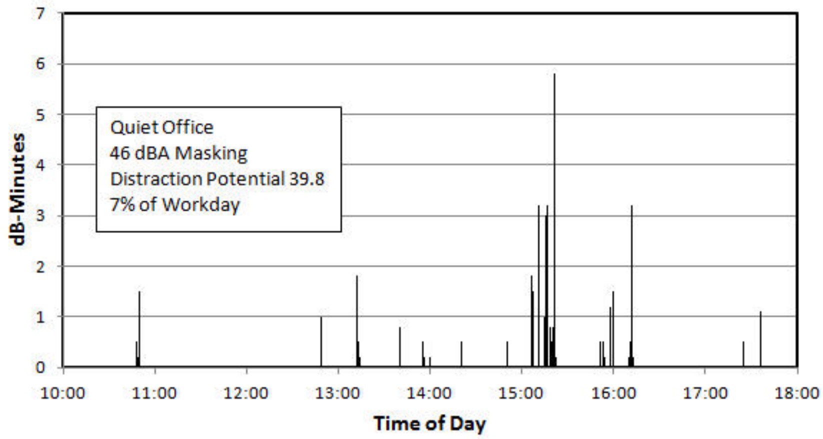
The original patent disclosure envisioned a hybrid system with both types of controllers such as shown in the figure on the right. The solid lines represent programmed level controls that act as limits on adaptive levels. During the workday, the adaptive levels (dashed lines) would respond to the changing activity levels. The programmed limits could be preset for various hours and days. Such a system would limit response to fire alarms at any time or evening vacuum cleaner sounds. The author is not aware if the existing system has these features.




## Work Hour Measurements

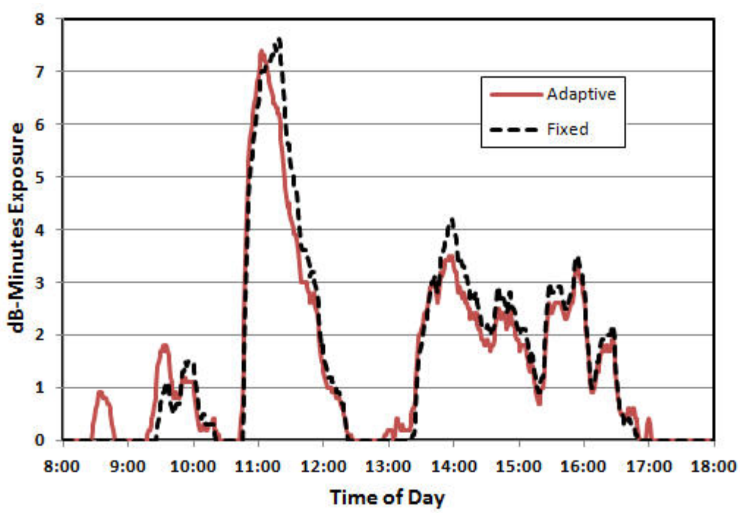
Although speech privacy is discussed most often, the primary issue for occupants is freedom from distractions, either speech or other sounds Distraction has two factors; the magnitude of the distraction and how often it occurs (see *Distraction Potential*). A means for determining this is to collect minute to minute time histories of sound levels and compute level statistics such as $L_{10}$, the activity sound, and $L_{99}$, the masking sound. Time histories taken at one minute intervals in offices over work hours were analyzed. The figure below shows the time history of distraction exposure in **dB-minutes** with an adaptive masking system in operation. The table below summarizes the exposure in comparison with that resulting from a fixed sound masking level during work hours. The **Distraction Potential** is the sum of the dB-minutes over the workday. The other data are the time a listener is exposed during the workday in minutes or percent of the workday.

In this example, it is clear that the office was a relatively quiet one with few distractions except for mid afternoon. The results strongly suggest that an appropriate fixed masking level during work hours achieved the same reduction in distraction as the adaptive system.




| | Adaptive Masking | Fixed masking 45 dBA | Fixed Masking 46 dBA |
|---|---|---|---|
| Distraction Potential | 54 | 87 | 50 |
| Minutes of Exposure | 50 | 59 | 35 |
| Percent of 8 Hr Work Day | 10% | 12% | 7% |

Another set of one-minute level data were analyzed for an office that might be considered a busy one. The results are shown the figure below as a line graph rather than a column graph. The dB-minutes for both adaptive and fixed masking levels during work hours are displayed, and follow each other closely. There were several times when the adaptive masking was slow to respond, resulting in more exposure than for the fixed masking. There were times when the adaptive masking responded appropriately resulting in less exposure than with fixed masking.




The table below summarizes the comparison. It seems clear that this office had considerably more activity sound, and required higher levels of masking to provide freedom from distraction. However, the comparison showed that both methods resulted in a similar Distraction Potential.

| | Adaptive Masking | Fixed masking 47 dBA |
|---|---|---|
| Distraction Potential | 861 | 905 |
| Minutes of Exposure | 424 | 357 |
| Percent of 10 Hr Work Day | 71% | 60% |

## Recommendations

- ***Programmable level controlled systems are recommended over fixed level systems and over adaptive systems for most offices.***
- ***Adaptive systems are best applied in offices in where unexpected and large changes of activity sound might occur during the workday.***
- ***Adaptive systems are best applied to offices with suspended ceilings and are difficult to install in open plenum ceilings or under raised floors.***
- ***An adequate number of activity sound sensors is required.***

# TUNING OF SOUND MASKING SYSTEMS

***Correct tuning or equalization of a sound masking system is just as important as the products used.***

Early systems had two deficiencies in this regard. Generators were sent to installers with a pink noise electrical spectrum with little guidance on the tuning process. Often installers were unfamiliar with proper tuning of the masking system, resulting in rejected systems. It is important to ask the question: ***Does the installer have experience in the correct tuning of a masking system?***

Correct tuning is a direct benefit to the occupants of the office but requires additional time for the installer. There are several steps to make the tuning process generate acceptable sound masking:

- The product should be capable of being equalized in 1/3 octave bands.
- The installer must be familiar with how tuning is done and have the proper sound meters.
- The masking spectrum should meet the privacy objectives of the owner.

Most, but not all, modern systems meet the first requirement (see *Direct Field Masking*). Any system that does not have the capability of spectrum and level changes in 1/3 octave bands should not be used. Good systems have the capability to set different spectrum contours and overall levels in multiple zones. There are methods to assist with the second requirement. The third requirement is more difficult (see *Acoustical Privacy and Sound Masking*).

## Assisted Manual Tuning

Manufacturers can oversee the installation, or perform the equalization themselves. They can provide training for installers. Both methods are presently being used by the major manufacturers, but many smaller systems are sold directly to installers with no support. Atlas Sound addresses this problem in two ways. Their major products not only meet the first requirement, but also have built-in initial spectra and levels for the three major speaker locations: above suspended ceilings, in open ceilings, and under raised floors. One click sets an approximately correct initial spectrum which later can be fine tuned to provide the desired spectrum with only small adjustments. Atlas Sound has a comprehensive training program available to installers on the concepts of privacy and use of their products, including equalization.

## Pre-Tuning and Automatic Tuning

There are systems that provide only one masking spectrum for open offices. Levels may be changed, but the spectrum contour remains the same despite the large variations that occur in open office furniture systems (see *Direct Field Sound Masking*). These systems are claimed to be *pre-tuned*. This bypasses the task of equalization, so is attractive to installers. This concept may be useful in smaller open offices or closed offices, but in larger open offices with a variety of furniture systems and workstation sizes, they should not be used.

There are products that have been claimed to be capable of performing tuning automatically to an *optimum* spectrum and level. Optimum here must be interpreted to mean acceptable acoustical privacy. One company claims that their software has a self-tuning technique that takes into account the specific acoustic characteristics of the workspace and the existing background sound. Without knowledge of the specific relationships between each employee pair, measurement of reverberation time and background sound level cannot provide the desired acoustical privacy, but only an approximation to the desired masking spectrum.

## The General Problem with Tuning

All of the above tuning methods can create a specific masking spectrum, but they do not address the third requirement. An installer may be required to meet a masking specification and a requirement for uniformity of level (see *Spatial Uniformity*). Unfortunately, the responsibility for matching the masking to the privacy goals of the owner is often left with the installer and not the specification writer or the owner's representative. Too frequently, the matching is not done.

## Recommendations

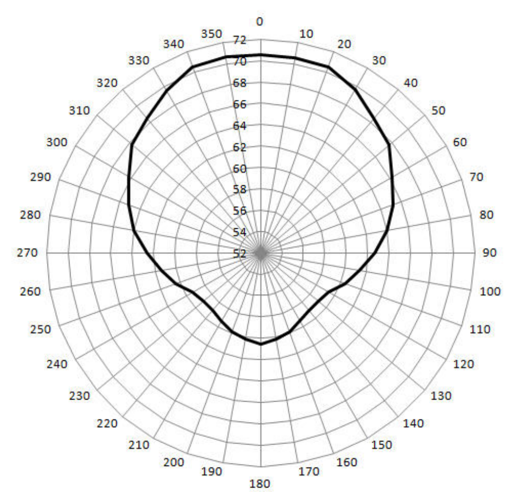
- ***Tuning a masking system is a critical operation for a successful system.***
- ***A knowledgeable installer is required to provide accurate tuning***
- ***Pre-tuning or automatic tuning does not guarantee acoustical privacy.***
- ***There is no substitute for on-site tuning of a masking system.***

# RADIUS AND AREA OF DISTRACTION IN OPEN OFFICES WITHOUT FURNITURE PANELS

When people talk it is possible for those not involved to be distracted. In closed offices, the sound loss is generally sufficient so that those outside the room are not distracted. In open offices, however, the structure of the room determines how much distraction is caused by conversations. If the office has high separating panels, the sound loss can be sufficient to avoid distracting neighbors when a masking system is installed. Many modern offices have low or no panels, so distraction of close neighbors is inevitable. The question here is: **How far away do neighbors have to be in order to avoid distraction in an open office without furniture panels?**

The key factors in answering that question related to speech are: (1) how loud people talk; (2) in what direction they talk; (3) how much speech is lost enroute to a listener; (4) the level of the background sound; and (5) the definition of freedom from distraction. The various levels and directivity of the human voice are discussed below. The major factors in sound loss are: the distance, the ceiling absorption, and floor absorption. Since the acoustical properties of these two surfaces are knowable, it is possible to use the data in calculations. Similarly, the level and spectrum of the background or masking sound can be chosen in calculations. Since distance is the defining factor, Thomas Koenig of Dynasound developed the concept of **Radius of Distraction (RofD)**. He defined the radius as the *maximum* distance beyond which listeners have **Normal Privacy,** an Articulation Index of less than 0.2 or a Privacy Index greater than 80. These are commonly accepted indices among the acoustical consultant industry and they can be used as the criterion in a calculation.

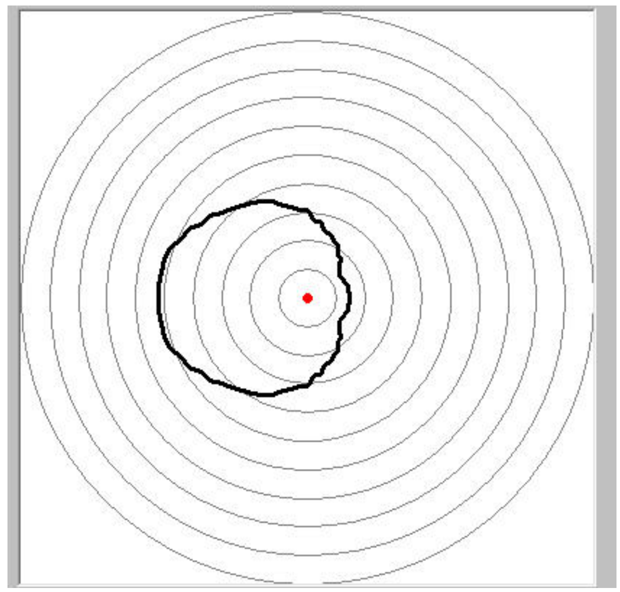
## Directivity of the Human Voice




The human voice is highly directional, so in a completely open environment it plays a significant role in setting the **RofD.** Since speech intelligibility is strongly dependent on the frequency distribution of the voice at every angle, it is necessary to have detailed spectral information on the human voice. Such data are available and were used to develop the results discussed below. The figure on the right is an example of the A-weighted level of the human voice at various angles to show the strong directivity of the voice in an open environment. The level when the voice is directed at a listener is nearly 10 dBA louder than when the voice is directed away. Essentially, a talker facing a listener requires the listener to be about three times further away for privacy than for a talker facing away. For example, if the radius is 15 feet when the talker is facing way, the maximum distance (**RofD)** is about 45 feet when the talker is facing the listener.

## Influence of Voice Directivity on Speech Intelligibility

Since all of the acoustical factors can be made available, it is straightforward to model on a computer. In all the examples below, there were no panel systems. The three free paths, direct, ceiling reflection, and floor reflection, determine the sound level at the listener. The floor was covered with wear resistant carpet, the ceiling was 9 feet high and both talker and listener were seated at 48 inches height. The talker was facing horizontally. Several choices of ceiling tile could be chosen in the software as well as a variety of background/masking levels and voice levels.



The figure on the right shows an example of the distances and directions at which Normal Privacy is achieved. A common NRC=0.55 ceiling tile was used with a normal male voice, and a masking spectrum at 46 dBA that meets the standards. Each circle in the figure represents an increment of 5 feet. Behind the talker the radius was less than 10 feet, while direcly in front of the talker the **RofD** was near 26 feet. At right angles to the talker the radius is about 15 feet. The impact of voice directivity is aboundnatly clear. Tthe impact on all surrounding persons is discussed below.

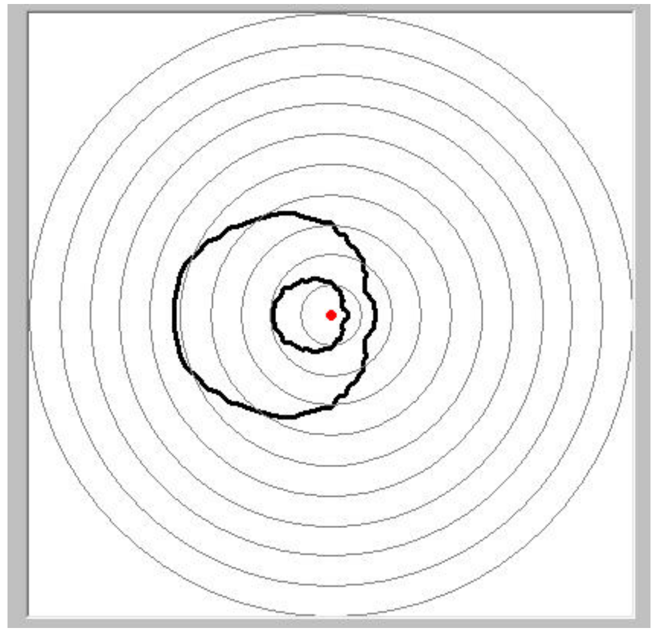
## Influence of Voice Level

There are several accepted levels of voice that are used in an office environment: casual, normal, and raised. *Casual* is characterized by telephone use or a privileged conversation. *Normal* is when the person wishes to project his or her voice a short distance such as at a meeting. *Raised* is characterized by conflict resolution situations. These levels apply to both male and female speakers and the spectra have been measured (ASTM E1130 – 08).

The male normal voice level might be considered the worst case, since the raised voice is normally restricted to closed rooms. The table below shows the results for five talker levels with the talker directly facing the listener (**RofD** or worst case). The calculations were made with an Atlas masking spectrum at 46 dBA and with a 9 foot high ceiling with a NRC-0.55 mineral tile. Although the impact is worst for a talker facing a listener, there is impact on all the surrounding persons. The simplest way to account for that is to define an **Area of Distraction (AofD)**. It is the total area under the contour in square feet.

| Voice Level | Male Casual | Male Normal | Male Raised | Female Casual | Female Normal |
|---|---|---|---|---|---|
| RofD, Feet | 10 | 25 | 56 | 9 | 22 |
| AofD, Square Feet | 115 | 873 | 4153 | 85 | 640 |

First, it is clear that raised voices should *never* be used in open offices that do not have furniture panels; the impact is enormously greater than that for normal level voices. Even at normal voice levels and with acceptable masking levels (less than 48 dBA), the longest distance is still quite far. For example with panels 48 inches high or lower, and with workstations on six foot centers, Normal Privacy would be achieved at about four workstations away, Sound masking is often asked to bail out a noisy office, but this situation is asking too much of masking. Experience has shown that a **RofD** near 15 feet has been found to be acceptable, so male casual voices, such as those used in call centers, can be handled with reasonable masking levels. To show the enormous benefit of lowered voices, the figure on the right shows a comparison of the male normal voice and the male casual voice. The **AofD** reduction is significant! Female voices are even less intrusive.



## Influence of Ceiling Sound Absorbing Materials

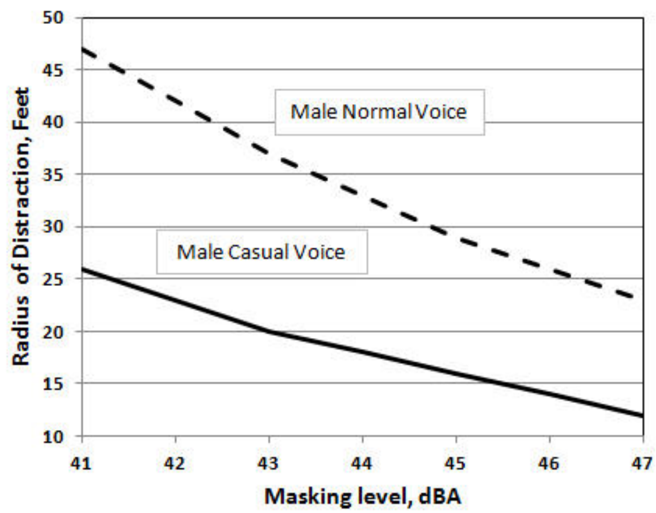
In open offices with workstations having separating panels of significant height, the ceiling materials play an important role in providing privacy. ***Is it worth providing highly absorptive and more expensive ceilings when there are no panels?*** The table below shows the beneficial effect of ceiling sound absorption for a 9 foot high ceiling and with a sound masking level of 46 dBA for two male voice levels.

| Voice Level | Ceiling NRC | 0.05 | 0.55 | 0.75 | 0.90 |
|---|---|---|---|---|---|
| Male Normal | RofD, Feet | 29 | 26 | 26 | 25 |
| Male Normal | AofD, Square Feet | 1125 | 873 | 854 | 787 |
| Male Casual | RofD, Feet | 10 | 10 | 9 | 9 |
| Male Casual | AofD, Square Feet | 130 | 115 | 110 | 106 |

It is clear that the direct path from talker to listener is so dominant in an open office without furniture panels there is little benefit in using high NRC tiles; lower cost mineral tiles (NRC=0.55) are adequate.

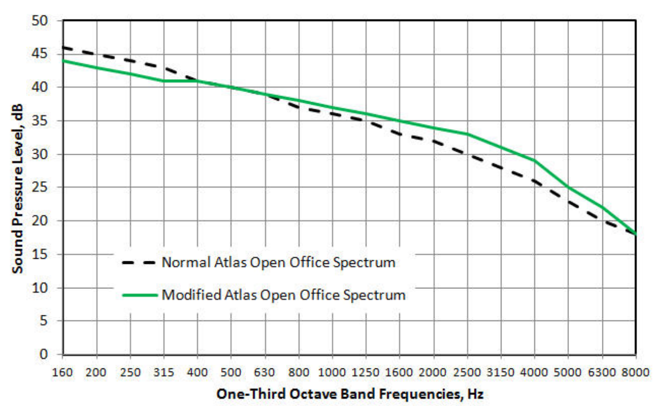
## Influence of the Masking Sound Level

With only a low level of air conditioning sound, around 38 to 39 dBA, the **RofD** is huge for the male normal voice. This strongly suggests that sound masking is needed in open offices without furniture panels. **How much sound masking is needed to reduce the RofD to an acceptable distance?** The figure on the right shows the influence of various levels of a masking spectrum that meets standards and for two male voice levels. It is clear that the upper acceptable limit of sound masking level is needed for male normal voice levels. Using the 15 foot criterion established many years ago, masking levels near 45 to 46 dBA meet that criterion for male casual voice levels.




## Influence of the Masking Sound Spectrum

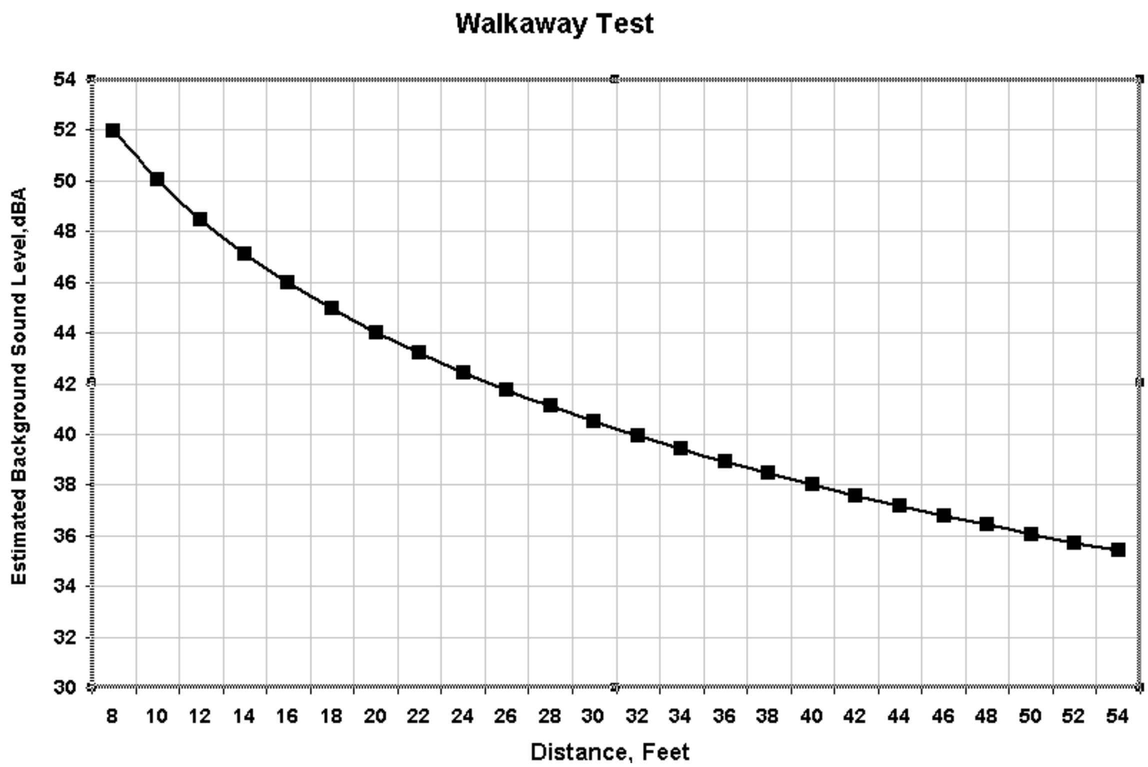
The Atlas sound masking spectrum can be found in the Atlas manual *"Sound Masking Done Right"* and can be downloaded from their site. It can also be found in the Wikipedia article on sound masking. This spectrum has been used successfully for a number of years. It was based primarily on the presence of workstation panels of acoustically significant height. With the loss of those panels, it was important to determine whether the spectrum contour needed revision. A number of spectra were tested in the model. Using **RofD** as the criterion, it was found that only a slight modification to the standard spectrum was marginally beneficial. The two spectra are shown in the figure and in the table below. All other spectra created larger **RofD**.




| Frequency | 160 | 200 | 250 | 315 | 400 | 500 | 630 | 800 | 1000 |
|---|---|---|---|---|---|---|---|---|---|
| Standard | 46 | 45 | 44 | 43 | 41 | 40 | 39 | 37 | 36 |
| Modified | 44 | 43 | 42 | 41 | 41 | 40 | 39 | 38 | 37 |
| Frequency | 1250 | 1600 | 2000 | 2500 | 3150 | 4000 | 5000 | 6300 | 8000 |
| Standard | 35 | 33 | 32 | 30 | 28 | 26 | 23 | 20 | 18 |
| Modified | 36 | 35 | 34 | 33 | 31 | 29 | 25 | 22 | 18 |

## Estimating the RofD in an Existing Office

The Radius of distraction can be estimated by the use of a "walkaway test". A standing male reads a text at casual voice level facing a standing listener, while the listener backs away slowly until he or she has difficulty understanding what is said. That distance can also be used to estimate the level of the background sound with use of the figure below.




The **AofD** can be estimated with use of the formula: $A = 1.3 * R^2$. For example, if the distance is 20 feet, The **AofD** = 1.3*400 or 520 square feet. This can be used to estimate how many people might be distracted.

## Recommendations

- ***Casual male or female voice levels should be encouraged in open offices with no separating panels.***
- ***Ceiling tiles with NRC values near 0.55 are sufficient for most open offices with no separating panels.***
- ***The RofD in an existing office can be determined with a walkaway text.***

# DISTRACTION POTENTIAL

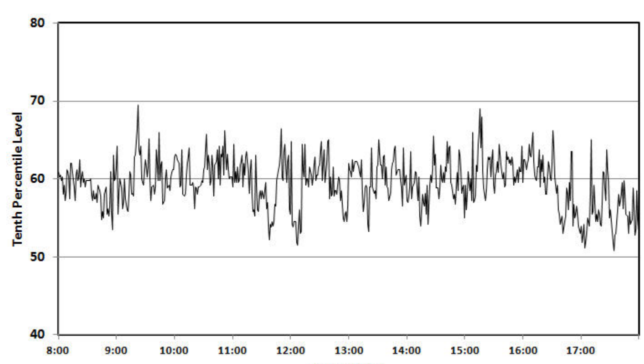
The major emphasis on the use of sound masking in offices is to create acoustical privacy for employees. With the use of **Articulation index, Speech Intelligibility Index or Privacy Index** it has been possible to define various degrees of *speech* privacy: Secret, Confidential, Normal, Transitional, and None. This metric is commonly used as a criterion for offices, but it is important to ask two questions. **How much acoustical distraction is caused by non-speech sounds? What is the relationship between degrees of privacy and acoustical distraction?**

Although speech in both open and closed offices is important, other sounds also can be important. Activity sounds such as coughing, sneezing, telephone ringing, copier printing, and drawer slamming are but a few sources of distraction. Excessive use of speaker phones, paging, or radios, although speech related, are not included in the above indices. Research has determined that sound processing is *obligatory* on the part of a listener so *any* intruding sound must be part of the potential for distraction.

When the above indices are used as a privacy criterion, it is prudent to look at the worst case where a talker is facing a listener and speaking continuously. Relying on this approach can result in excessive use of sound masking. The Occupational Safety and Health Administration have addressed a similar situation associated with hearing loss. They developed the ***Time Weighted Average*** which takes into account the level *and* duration of the noise exposure over the workday. This concept can be adapted for use in evaluating distraction in an office. It may be expressed in ***dB-Minutes*** of exposure; the level of any sound during a one minute interval over a specific threshold. The cumulative exposure is sum of the dB-minutes over an entire workday; I call it ***Distraction Potential (DP)***. **What is a distraction Threshold?** Since most occupants are not aware of level changes less than 3 dB, but are clearly aware of changes nearer to 10 dB, it seems reasonable to consider that if a transient sound level rises 5 dB, or more, above the background or masking level, it has potential to distract. This would require that minute-to-minute level data be collected over an entire workday. A highly accurate means of evaluating such data would be to track the level that is exceeded 10 percent of the time (tenth percentile level, $L_{10}$) and the ninetieth or ninety-ninth percentile level ($L_{90}$ or $L_{99}$) during the measurement period. If the $L_{10}$ is greater than 5 above the $L_{90}$, or $L_{99}$, distraction is likely to occur and the excess is recorded as dB-minutes. Fortunately, some time-level histories are available so that the above procedure can be used.

## Typical Activity Sounds

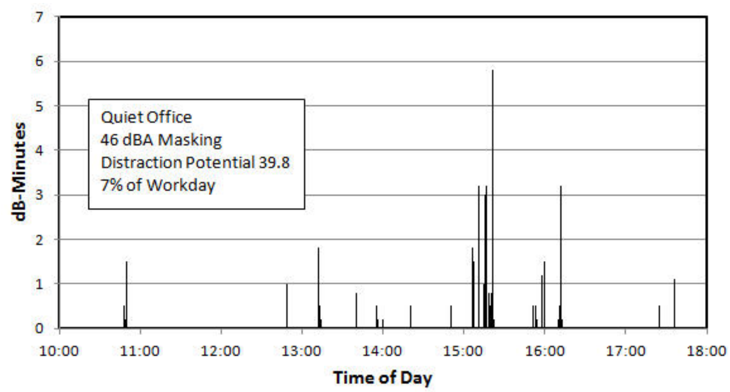
An example of activity sound in an office is shown in the figure on the right in the form of tenth percentile levels in one minute intervals. Since close-in speech can reach 70 dB, the levels appear to be the composite of numerous voices and other sounds. The important



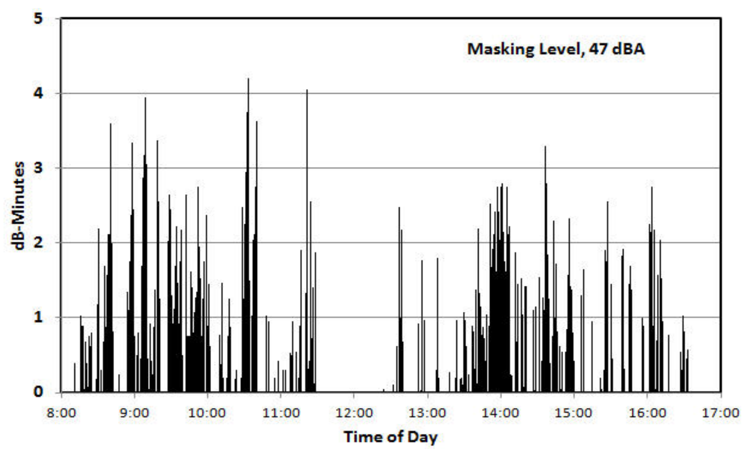
point is that activity sounds can vary as much as 10 dB; enough level changes to potentially cause distractions, and the variability can occur over the entire workday.

## dB-Minutes in Quiet and Noisy Offices

The dB-minutes for the time-level history in one office were calculated and are shown in the figure on the right for normal work hours. The reference for the exposure was not a variable background level, but a fixed masking spectrum that meets the standards and with a level of 46 dBA. So the measure was ($L_{10}$-46-5). Potential distractions occurred only 7% of the workday. Except for the mid-afternoon rise in activity, it must be considered to be a "quiet" office and one in which sound masking would provide an adequate amount of acoustical privacy.



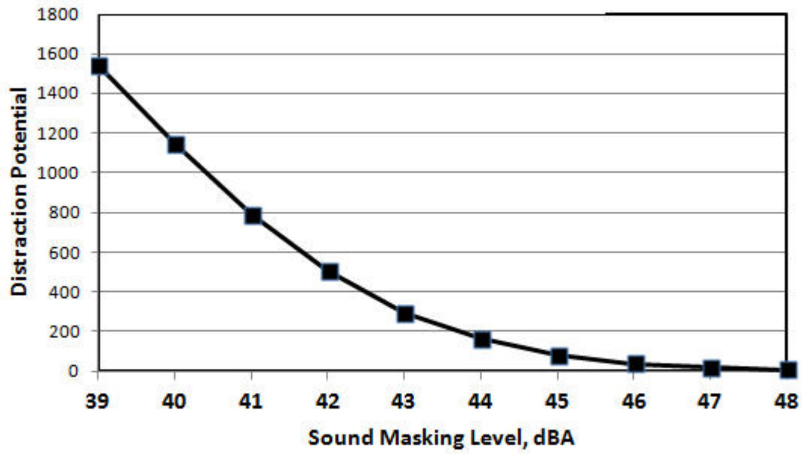

An example of a very active office is shown in the lower figure on the right. For this case, the sound masking level was 47 dBA. Potential distractions occurred during the entire workday (except for lunch hour). One must consider this a "noisy" office and one in which sound masking may *not* provide an adequate amount of acoustical privacy.

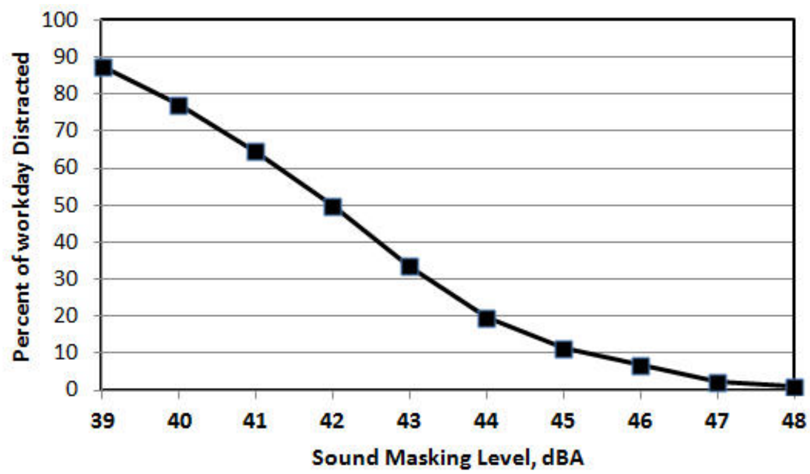



It is important to note that these data make no distinction between speech and other sounds.

## Influence of Sound Masking on Distraction Potential for a Quiet Office

The **Distraction Potential** for the "quiet" office is shown in the figure on the right for several levels of sound masking. At the present time there is no body of measurements that permits one to state that a satisfactory office has a **DP** below a certain number. However, it is clear that acceptable levels of sound masking significantly reduce the magnitude of the distractions. Perhaps a more informative approach is look at the percent of the workday that distractions occur. The lower figure on the right shows that acceptable levels of sound masking have significant impact on the amount of time an employee is exposed to potentially distracting sounds.

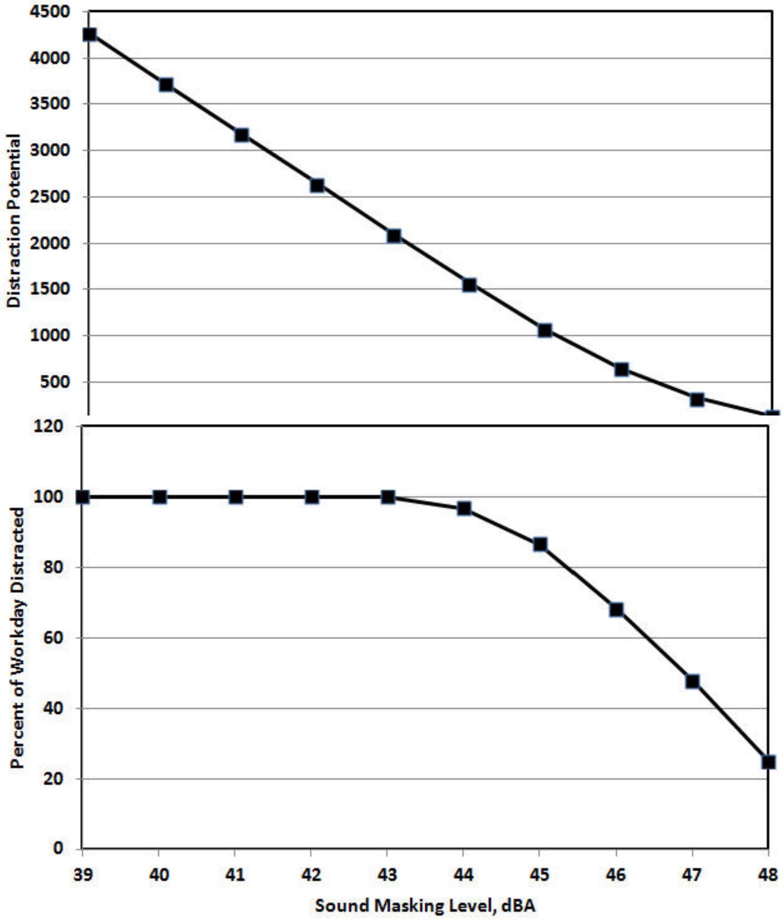



One conclusion for this case is that without sound masking, distractions would have occurred over most of the workday. Often masking levels are set at 47 dBA and in this case it is likely that 45 dBA would be acceptable to employees. This kind of analysis resulted in the development of the slow timed rise feature in Atlas products for the initiation of a masking system. The final level might have been chosen to be 47 dBA, but when 45 dBA was reached employees might consider their privacy acceptable.

## Influence of Sound Masking on Distraction Potential for Noisy Offices

The **Distraction Potential** for *several* "noisy" offices was calculated for normal work hours and the result for several sound masking levels and is shown in the figure on the right. Once again, the reduction in distractions caused by the addition of sound masking is clear. Note that the magnitude of **DP** is considerably higher than that for a "quiet" office.




A more informative graph is shown in the lower figure on the right which shows the percent of the workday that distractions might occur. Here it is clear that low levels of sound masking do not alleviate the continuous nature of the distractions, despite reduction of the severity. Only when the masking level exceeds 45 dBA is there any reduction in the percentage of the workday that distractions occur. Although any level of sound masking above the background can reduce the severity of distractions, a certain level is required to reduce the percent of the workday that an employee is distracted. It is clear that levels of sound masking near the upper limit of acceptability are required to provide any significant reduction in potential distractions.

## Transition from Distraction to Annoyance to Complaints

The above results identify the two factors in noise disturbance: level and duration. The results do not indicate whether one factor may be more important than the other. That remains for future research.

Numerous articles have pointed out that distractions reduce productivity and increase costs for the employer. The local facility manager has the job of handling complaints resulting from annoyance at acoustical distractions. This becomes both a technical and administrative problem. Failure to meet privacy needs is often the result of unrealistic privacy expectations on the part of the owner..

**Recommendations**

- **It is important to separate the severity of distractions from their duration.**
- **Consider the acoustical impact of sounds other than speech. Separate any that can be placed outside of an open office.**
- **Contractors should be given access to office plans prior to design of a sound masking system.**
- **When possible, modeling should be done to determine the value of sound masking.**