PROGRESS IN SOUND MASKING

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Introduction

Electronically generated sound masking has been around for over thirty years as a privacy tool and great progress has been made in its use. However, there are those who are still wedded to the *structural* solution for privacy. Those familiar with acoustics know that sound attenuation created by building structure is only one of three factors that play a role in creating that privacy. Yet many architects, and even some acoustical consultants, cling to structural solutions only. The glaring weakness of sound attenuation alone is that it is static, i.e., once installed it is usually difficult to alter and certainly almost impossible to change on a short term basis. The other two factors, the source and the background sound, are dynamic. Sound masking can be dynamic, i.e., the level can be set, either manually or automatically, at any time in any place. Another weakness of the sound attenuation approach in the design of offices is that the sound passing from one office to another will take multiple paths. Being a parallel path situation, if any one of the flanking paths is weak, the solution is weak. Specifications often go to elaborate, and expensive, extremes to eliminate weak flanking paths. All the flanking paths come together at the listener's ear, and this is where sound masking is effective. Another factor that once inhibited use of sound masking can be exemplified by the question "How can you make it quiet by adding noise?" Now, many end users understand that the quest for privacy supersedes the quest for quiet.

"It appears that the technological evolution of sound masking equipment and methods has not found its way fully into the marketplace, but the new products are showing signs of changing that."

Unfortunately, many current specifications, designs, and installations have yet to take advantage of the capabilities of newer masking systems. Further integration of sound masking into society will depend on these capabilities being used.

Secure applications

There is a need to protect facilities against deliberate listeners who may be using detection devices. The federal government has a document[1] that permits use of sound masking to protect conversations in their own facilities, such as in a Sensitive Compartmented Information Facility (SCIF), as well as those of government contractors. This is called *secure masking*. Generally, the room perimeter is protected, and this includes walls, windows, doors, ducts, piping, ceiling plenums and raised floor cavities. With the rise of economic espionage, commercial organizations are beginning to use secure masking to protect boardrooms, planning rooms, and research facilities. However, the sound masking equipment most often used in commercial facilities is inadequate.

It is well known that laser microphones exist and can detect from afar the minute vibrations of surfaces that are caused by local speech. The most obvious place for their use is on the window of a facility, but there are others. The structural solution is to have no windows, but this is not always acceptable to users. Unfortunately, windows face locations that are, most often, not under the control of the facility and the listener may have access to techniques that can recover signals buried in noise. For sound masking to provide protection, a vibration transducer must be attached to the window. Earlier, loudspeakers were placed in the ceiling above the window, but the required levels interfered strongly with room conversations. The signal applied to the transducer should be non-stationary (random) to inhibit signal recovery. Further protection is achieved by having the masking signal *layered*, i.e., other signals, such as music, voice babble, or simulated speech, should be added to and buried under the masking signal.

The structural solution for walls is a high sound transmission class (STC) rating. Although that rating was not designed for speech, a sufficiently high STC wall may be able to protect against voice recognition beyond the wall, but cannot protect against other penetration methods. For example, listeners may attach vibration sensors to the inner surfaces of a stud wall to detect the gypsum board vibration caused by room speech. A normal microphone, or the relatively unknown fiber optic microphone, may be placed inside the wall cavity. The wall itself offers no protection against these devices and the background level in wall cavities is quite low. Vibration maskers applied to the wall surfaces raises both the vibration masking level as well as the acoustical masking level, so if properly set they will handle all means of detection.

The structural solution for ducts is the addition of duct mufflers. They are expensive, increase system pressure drop, are difficult to install, and several may be required for each room. Again, because they are a static solution they *may* be able to protect conversations. The application of a vibration masker to the duct wall is a much simpler solution. It will raise internal sound levels sufficiently to protect against any sounds being transmitted through the duct.

Vibration transducers and non-stationary generators are commercially available.

Medical applications

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 the Health Insurance Portability and Accountability Act,[2] includes requirements for speech privacy associated with medical information. This legislation has provided an unprecedented opportunity to solve both the disturbance and privacy problems.

There is an active group of acousticians helping hospital designers provide good acoustics in medical facilities. The structural solution is well in evidence with those complying with the law. For example, anyone visiting a pharmacy is asked to stand back six feet behind the yellow line. However, there is a glimmer of hope for a dynamic (masking) solution in hospitals.

Schieber[3] found that the amount and rate of increase in the sound level from a constant background was the main contributor to full awakening, or changes in the stages 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.[4] Suter[5] 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."* Griefahn[6] noted that the difference between the ambient and the single event levels should not exceed 8 to 10 dB.

A test was done in the patient room of a modern hospital. Night time hourly percentile levels were calculated and the results are shown in Fig. 1. As is usual, the door was kept open during the night. It is clear that there are several periods with levels sufficient to cause awakening in the patient.

Although masking has been applied in doctors' offices for over twenty years, nursing homes, pharmacies, hospitals and medical providers (public health authorities, life insurers, billing agencies, and service organizations) have yet to appreciate the effectiveness of sound masking. All standard commercial masking equipment can be used in medical facilities.

Speaker locations

There are criteria commonly used to insure that a masking system performs well. They are: (1) spectrum contour; (2) overall level; and (3) spatial uniformity of the overall level. Experienced professionals might include spectrum smoothness. In most cases, these criteria can be met successfully. However, it has been found that another criterion is needed to improve both performance and acceptability—*diffuseness of the masking sound field*. For those familiar with lighting this is similar to Equivalent Sphere Illumination, an accepted lighting criterion for reducing glare. A diffuse sound field reduces "acoustical glare" that, in practical terms, means that the source of the sound cannot be located. But it also means that listeners will accept higher masking levels. Most applications have speaker arrays above suspended ceilings but masking can be applied successfully in other locations. The criterion of diffuseness can be used to develop a hierarchy of preference for those speaker locations.

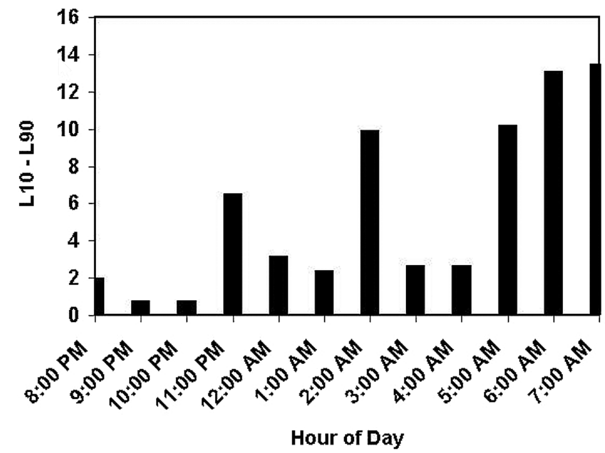

Fig. 1. A large difference between two important percentile levels in the patient room of a modern hospital will awaken patients. Significant awakening events occurred during the night time hours for this sample.

1. *Speakers under raised floors.* Because the loss of sound through a raised floor is considerably higher than that through a suspended ceiling, the amount of sound reaching the listener from other directions is relatively higher, resulting in a high degree of diffuseness. Field experience has shown that the diffuseness is sufficiently high that neither the source nor the direction of the sound can be identified.

2. *Speakers in a plenum above very high suspended ceilings.* The sound reaching the listener from above arrives from a broad range of angles improving diffuseness. Because it is still possible to determine that the sound is coming from above, it is rated second in preference.

3. *Speakers in an open ceiling plenum without a suspended ceiling.* The sound reaching the listener from above arrives from a broad range of angles improving diffuseness. Because it is possible to determine that the sound is coming from above and because the speakers can be seen, it is rated lower in preference.

4. *Speakers in a plenum above a normal height suspended ceiling.* This location has been the standard for many years. Because suspended ceilings are normally near nine feet high, the direction from which the masking comes can be identified, and diffuseness of the sound is reduced. With very high plenum depths the diffuseness is better.

5. *Speakers mounted face-down in a suspended ceiling.* Because the listener is in the direct sound field of the speakers, diffuseness is considerably reduced, so the source of masking can be identified acoustically, and in some cases, visually. Shadowing of the masking can occur with higher open office furniture panels. Although this is the least desirable location for a masking speaker, it can be beneficial when the plenum above is very small.

Determining the amount of diffuseness for each location would make an interesting study. When choices are available, the above hierarchy is recommended. Masking speakers for any of the above locations are currently available, including those that fit into a small plenum or floor cavity. Most masking systems can accommodate the required difference in spectrum contour and overall level.

Task masking

The advent of vibration maskers for security masking has opened the door for localized masking in commercial offices, typically open office workstations. Placement of the masker under a work surface, behind a tack board, on a panel, or behind a picture, can provide privacy for an occupant with local control. Although the author had a panel mounted masking system in his workstation for several years, there seems not to be any current interest in this application by furniture manufacturers. However, there are personal speaker maskers that can be used for this application. One furniture manufacturer sells panel-mounted speaker maskers, but they are intended for area masking.

The masking spectrum

A required masking spectrum is defined in almost all sound masking specifications. In the poorer ones, it is given in octave bands as opposed to the one-third octave band recommended by the American Society for Testing and Materials (ASTM).[7] There is ample evidence that one spectrum is not optimum for all applications. The author has used Privacy Index[7] in lieu of Articulation Index because users feel comfortable with the analogy between the degrees of privacy associated with it and school grades. Figure 2 shows the range of Privacy Index resulting from a variety of commonly used masking spectra in open offices. The overall level for each spectrum was 47 dB(A). It is clear that the spectrum *contour* for an open office is critical. To determine the best one for a given application, a computer modeling program was developed that creates a masking spectrum complementary to the sound attenuation spectrum of the given design. This kind of modeling minimizes the amount of masking required to achieve a given degree of speech privacy. It is recommended that the spectrum should be tailored to the specific project, not the one saved from previous projects as is found in too many specifications. Many modern masking generators have multiple sources and equalizers, so they are capable of handling a wide range of spectrum contours.

The quest for spatial uniformity

Achieving spatial uniformity of the A-weighted sound masking level 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 is determined by the scale of the measurement. As one makes the ruler smaller, the minor irregularities of the coastline are 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 but also significant changes in the spectrum contour, demonstrating practical limits to the uniformity requirement.

One 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 the small level changes within a workstation or closed office are seldom noticed. This suggests that measurements of spatial uniformity be restricted to the aisles of open offices, at occupant locations in closed offices, or in corridors.

The problem with all this is that the actual quest is for *spatial uniformity of speech privacy*. Because closed offices have very similar sound attenuation characteristics, both quests generally merge there. In open offices, however, the various panel heights and the possible proximity to vertical reflecting surfaces means that spatial uniformity of masking may not provide spatial uniformity of privacy. Zoning in open offices is the best means for solving that problem.

System zoning

Most masking system designs have insufficient zoning. A zone control changes the overall masking level created by a

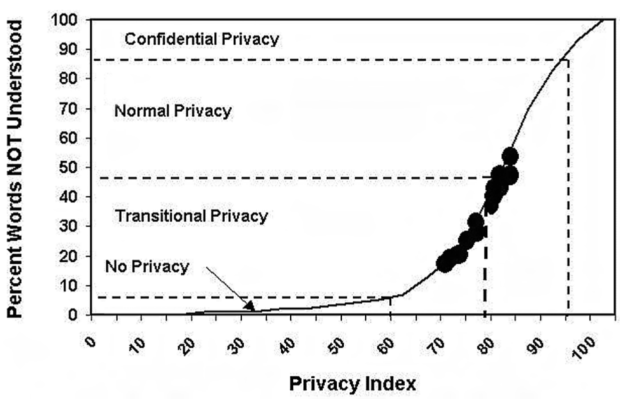

Fig. 2. The Privacy Index achieved by various masking spectra in an open office can vary significantly. This strongly suggests that the masking spectrum contour is important in open offices.

group of speakers, but not the spectrum contour. Zones have several functions, one of which is noted in the previous paragraph. They also permit adjustments for differences in the acoustical environment of the speakers, such as plenum depths, suspended or structural ceiling heights, when the additional expense of a separate channel is not warranted. Zone controls also give the user some personal control over the system and the controls should be stepped so changes do not detune the system. A rule of thumb, when higher degrees of privacy have been achieved, is that a change of 3 dB equates to a nine point change in the Privacy Index. (See the steep part of the curve in Fig. 2.) This change is enough to alter the degree of privacy; thus level steps should be on the order of 1 to 2 dB. Several manufacturers now have zone controls in the form of separate autotransformers, amplifier input controls, or centralized digital controls that meet this requirement.

Initial ramp function

A common adage says "Everyone is for progress; it is change they hate." There is considerable change when employees enter a new facility. To greatly reduce the impact of sound masking on these individuals, several modern masking systems include an initial ramp function that will increase the levels automatically from background to final over many days. This function is in series with other gain controls.

Power ramp function

The above concept also applies when power to the masking system is lost. To avoid the abrupt onset of sound masking, a few systems now include a function that will raise the level slowly over several minutes.

Programmed level control

Most masking specifications ignore the time factor even though the need for privacy is a function of time. Employees need to communicate at times, to be private at other times, but always to retain a sense of community with their fellow employees. During night, or early morning hours, occupancy is very low. During those hours, employees need to be aware of the presence of others, and security guards need wide aural horizons. In the early work hours, social aspects are most important and then transition to a need for privacy occurs and finally, near the end of the workday, the social aspects again prevail. One example of this effect is that complaints about excessive masking in fixed level systems often occur in early morning or late afternoon and this strongly suggests the need for temporal variations of masking level.

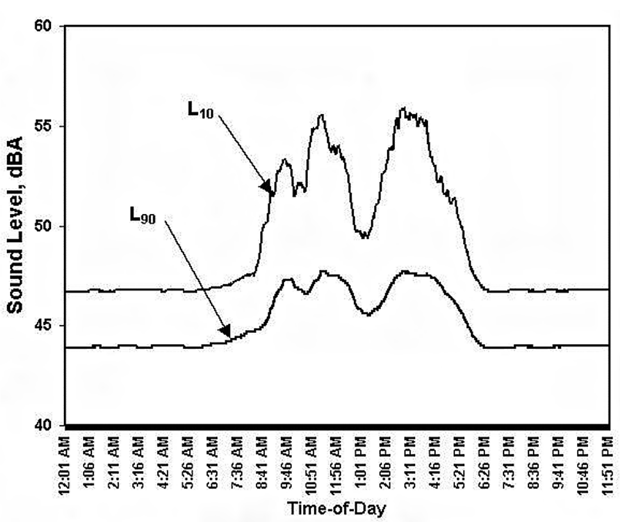

Fig. 3. A sample of the two important percentile levels found in a busy open office with 44 dB(A) sound masking is shown. Significant potential distractions occur during work hours despite the presence of sound masking.

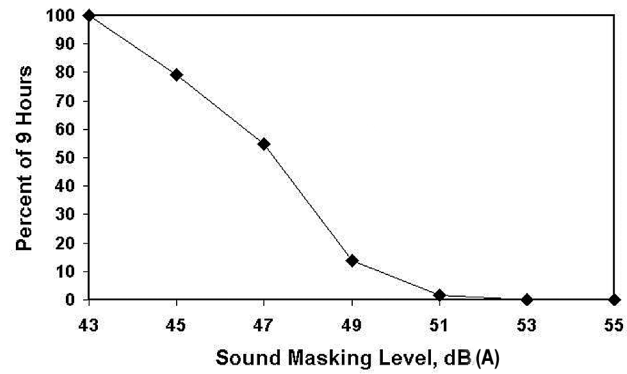

Fig. 4. The duration of exposure of an employee to acoustical distractions as a percentage of the workday for several masking levels is strongly influenced by the masking level. It is based on the criterion that L10-L90 is greater than 5 dB.

The earliest patent for this function was issued in 1978[8] and now a number of manufacturers have what may be called a programmed level control function that will automatically change overall masking levels with time. The installer can program the generator for a range of levels in hourly increments over any day of the week, no increment of change ever being greater than 1 dB. Typically, there is one level rise and one level decrease during the day. 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. The total 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 so the change is often only 5 dB, i.e., the gain increases from –10 dB to –5 dB. This feature is best implemented in clock-based digital signal processing systems where the required versatility is controlled by software and is quite simple to program. Programmed level control has been used successfully for over twenty-five years, but few specifications include it.

Adaptive level control

The weakness of programmed level control is obvious—the installer must predict how much activity sound there is going to be during any hour of any day. Adaptive level control is a further refinement, although it requires more thought about how much privacy is needed.

The basic structure of such a system is as follows. A spatially diverse set of microphones is placed in a room and overall level data are mixed and sent to the generator. The data are converted to one second Leq values and a running level histogram is constructed. The histogram data are converted to a running percentile table. The L_{10} and L_{90} (or L_{99})

levels are abstracted and the difference between them is compared with a difference criterion. If the level difference is greater than the criterion, the masking level is raised slowly. If the level difference is less than the criterion, the masking level is lowered. Generally, the rate of decrease is less than the rate of increase.

To develop some feel for what that criterion should be and what masking levels are required to control distractions, we looked at a typical day in a busy office. Figure 3 shows the L_{10} and L_{90} values for a twenty four hour period in an open office with a suspended ceiling and with sound masking at a fixed level of 44 dB(A).

At the present time, it is considered reasonable to set the level difference criterion at 5 dB. Figure 4 shows the total exposure time for the data in Fig. 3 as a percentage of the workday for several levels of sound masking in an open office. Levels of 45 dB(A) and above provided a significant reduction in the amount of time one was exposed to distractions. Raising the level from 43 to 47 dB(A) would have provided a 45% reduction in exposure. The figure suggests that a level of 49 dB(A) would be required to provide good privacy at all times. Most professionals consider that level excessive and unacceptable to occupants.

Most dissatisfaction with the acoustics of a work environment is an accumulation of distractions both in time and in the degree of severity. A metric such as dB-Minutes, (similar to that used by the Occupational Safety and Health Administration)[9] would add in that factor.

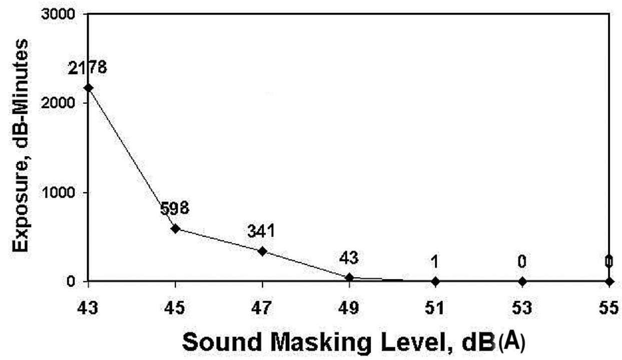

Fig. 5. When both the intensity and duration of exposure of an employee to acoustical distractions is expressed as dB-Minutes for several masking levels, the impact on employees is changed. It is based on the criterion that L_{10}-L_{90} is greater than 5 dB.

Figure 5 shows the data in terms of the number of dB-Minutes greater than the criterion. Although the percentage of time a listener would be exposed to distractions was significant at 45 dB(A), this graph indicates that the severity of that exposure was 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 is inadequate. Since we are concerned with cumulative effects, consider an average workday exposure. 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 that too much masking adds little benefit while increasing the likelihood of not being accepted by employees.

The above data are helpful as input to the programmed level control, but are limited to being samples. An adaptive masking system responds to the unique events of each minute of each day. By continually tracking the disturbance potential, the severity of the impact is lessened further. One beneficial feature of adaptive masking is that it responds to *all* transient sounds, so it will handle unexpected or exterior sounds, such as roadway or aircraft traffic. At the present time only one adaptive system is available.

Improved equalization methods

Most masking specifications permit a range of levels in any one or one-third octave band, typically it is +/- 2 dB. This permits up to 4 dB difference in contiguous bands. Experience has shown that although the spectrum contour is very important in open offices, it is just as important for the contour to be *smooth*. Newer systems permit a relatively smooth version of the chosen spectrum contour to be created in a short time.

Most sound masking generators are supplied with no high or low pass filter settings, and flat band pass filter settings. The source is pink noise. Standard methods require the person equalizing to make a set of spectrum measurements in the area of interest, average them, and then compare the results with a desired spectrum. The needed corrections are entered with a mechanical slider or a software slider. In practice this method is iterative and time consuming, considering that large systems may have multiple channels of equalization.

The first improvement is that modern masking systems permit initial spectra to be pre-set. The user can create pre-set spectra by saving and recalling a file created on a previous project. One manufacturer has created pre-set files for the three most common masking speaker locations: above a suspended ceiling, in an open ceiling, or under a raised floor. In both methods, a reasonably correct initial masking spectrum can be set. Since every building is acoustically unique, a pre-set spectrum is close but is not likely to contain the corrections needed to offset the acoustical impedance variations created by the environment into which the speaker looks. Therefore, a set of masking spectrum measurements is still required. But instead of hand calculating the required corrections and tediously entering them into the generator channel, there now are better ways to accomplish this task.

First, it is necessary to choose the desired masking spectrum. The modeling software mentioned above can be used to generate that spectrum. It may be chosen from the editable database of spectra, it can be developed from modeling the sound attenuation of the facility, or it can be developed from actual sound attenuation measurements. Modeling is the shortest method and has proven to be reasonably accurate, despite the inability to solve the wave equation.

Second, it is necessary to determine the actual masking spectrum by measurement. A set of spatially diverse spectra must be collected. These data may be saved to an Excel file, or to a file that the equalization software is capable of reading, or can be downloaded directly to the equalization software. The software then calculates the corrections needed to match the two. The corrections can be entered manually into the equalizer, or they can be saved to a file that later is to be read by the generator software.

There are a few systems that have this capability. One manufacturer uses a hand-held computer with a microphone and a wireless connection to the generator, so that equalization is real time. In each case, the equalization is rapid and the spectrum is smooth and very close to that desired.

Conclusions

It appears that the technological evolution of sound masking equipment and methods has not found its way fully into the marketplace, but the availability of new products are showing signs of changing that. Increased understanding of the relationship between disturbance potential (measurable) and distraction (hard to measure) will permit manufacturers to develop systems that improve privacy dynamically. **AT**

References for further reading

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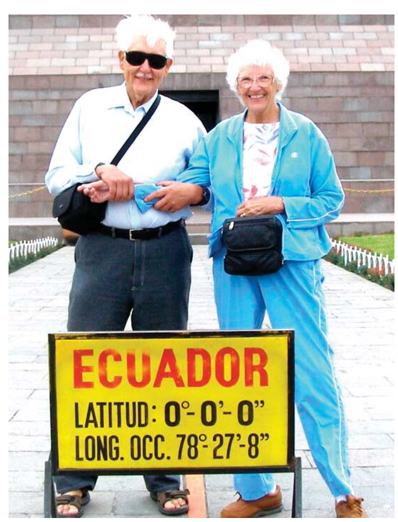

Dr. Robert Chanaud has been involved with acoustics since 1958 and sound masking since 1972. He has written a manuscript on sound conditioning offices and has recently completed a manual on sound masking.

Photo: Robert Chanaud and his wife, Jo.