Improving Barrier Insertion Loss

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by

Michael P. Valoski

ERRATA

On page 1, footnote 1, "Physical Agents Branch" should read "Physical Agents Division."

On page 9, paragraph 2, line 6, the word "increased" should read "decreased."

On page 13, paragraph 1, line 7, the word "bank" should read "band."

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U.S. Department of Labor
Ray Marshall, Secretary

Mine Safety and Health Administration
Robert B. Lagather, Assistant Secretary
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Michael P. Valoski [1]

ABSTRACT

This paper details two attempts at increasing barrier insertion loss by using two different systems of resonators attached to the edges of the barrier facing the noise source. The first system consists of quarter wavelength resonators and the second system consists of the quarter wavelength resonators containing fiberglass wedges. The system of quarter wavelength resonators was an attempt to achieve an acoustically soft edge condition. An acoustically soft edge condition theoretically can increase the insertion loss of a barrier up to 30 dB depending on the orientation of the noise source, receiver and barrier while a perfectly absorptive edge can increase the insertion loss when compared to a hard surfaced barrier up to 6 dB. The results indicate that both systems more closely approximate an absorptive edge condition than an acoustically soft edge condition. Noise control techniques developed in this report are most applicable to large stationary noise sources that contain pure tone components. Some examples of this type of noise sources in the mining industry are ventilation fans, power transformers, and vacuum pumps.

INTRODUCTION

Barriers have been used as a method of noise reduction for both stationary and mobile noise sources. For example, barriers have been used near ventilation fans and near construction sites where heavy equipment like that used in surface mining is being operated. When a barrier blocks the line of sight between the noise source and receiver, the receiver is in the shadow zone and the noise level reaching the receiver is reduced. In the bright zone the receiver is on a direct line of sight to the source and the strength of the received sound generally depends upon natural propagation from the source.

In general, barrier noise reduction is controlled by diffraction around the barrier and sound transmission through the barrier. There are suggestions in the literature which indicate that barrier insertion loss may be enhanced with certain structural modifications of the barrier edge.

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According to the Fresnel diffraction theory, as stated by Beranek,[2] only the region of the incident wavefield, which is close to the barrier edge, contributes significantly to the wavefield in the shadow zone of the barrier. In the case of the incident plane wave, a receiver in the shadow zone at a large distance from an infinitely long barrier will perceive the diffracted sound as a line source emanating from the barrier edge regardless of the source position. The strength of the diffracted sound is proportional to the strength of the incident sound at the barrier edge; that is, the greater the intensity of the sound at the barrier edge, the greater the intensity of diffracted sound.

According to Rawlins,[3] the theoretical maximum attenuation of a barrier is 50 dB with an acoustically soft edge condition (30 dB of this attenuation is due to the acoustically soft edge condition). Rawlins stated that pressure

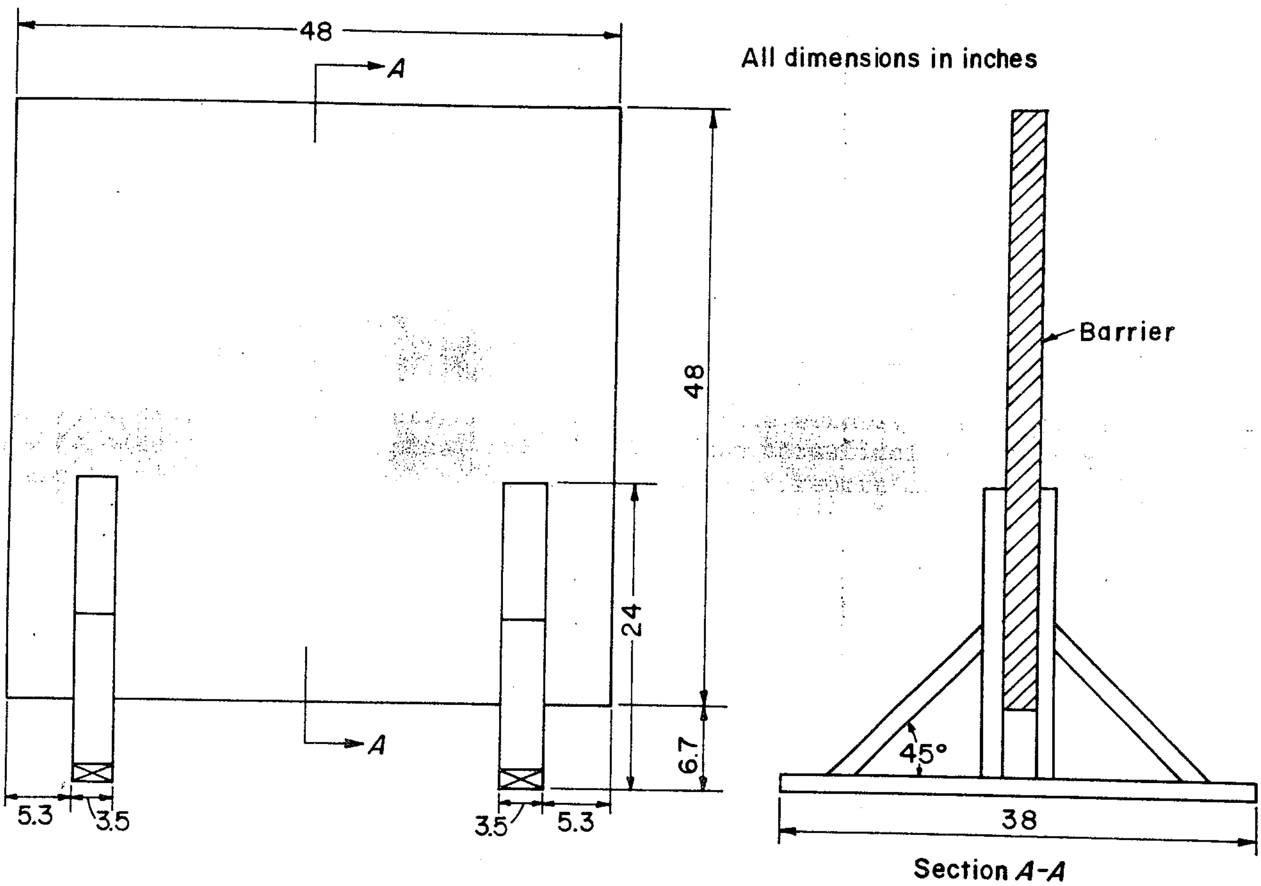

FIGURE 1. - Drawing of barrier without resonator.

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[2]Beranek, L. L. Noise and Vibration Control. McGraw-Hill Book Co., Inc., New York, 1971, pp. 164-193.

[3]Rawlins, A. D. Diffraction of Sound by a Rigid Screen With a Soft or Perfectly Absorbing Edge. Journal of Sound and Vibration, v. 45, 1976, pp. 53-67.

fluctuations approach zero for an acoustically soft edge condition.[4] The pressure fluctuations at the neck of quarter wavelength resonators also approach zero. This is the reason quarter wavelength resonators were chosen. The amount of attenuation, however, is dependent upon the source position. The specific purpose of this study is to determine if a quarter wavelength resonator system will approximate an acoustically soft edge condition.

A resonator is essentially a sealed cavity, having one entrance, that reduces sound pressure. A resonator reduces sound pressure levels only over a narrow frequency range. Figure 1 is a drawing of the plain barrier and figure 2 shows the barrier equipped with the simple resonator system. Figure 3 details the simple resonator system.

The experimental design required accurate initial and replicate positioning of a measurement microphone. A grid of microphone positions was specified on the floor of the anechoic chamber. Because of the practical difficulty in varying the vertical distance (height) of the receiver, the horizontal

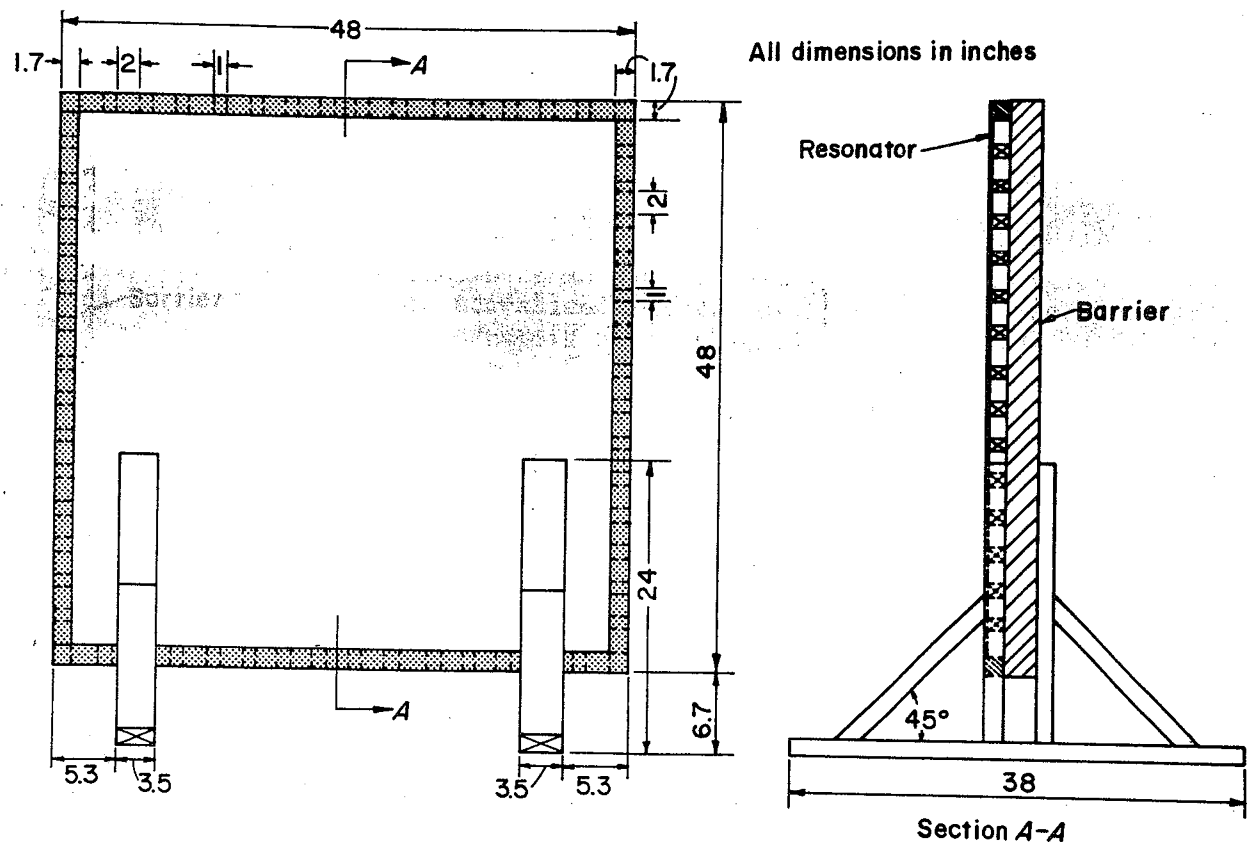

FIGURE 2. - Drawing of barrier with resonator.

[4]An acoustically hard or soft surfaced barrier implies perfect reflection of sound waves. In this case of the acoustically soft edge condition, the reflected waves are 180° out of phase and complete destructive wave interference occurs.

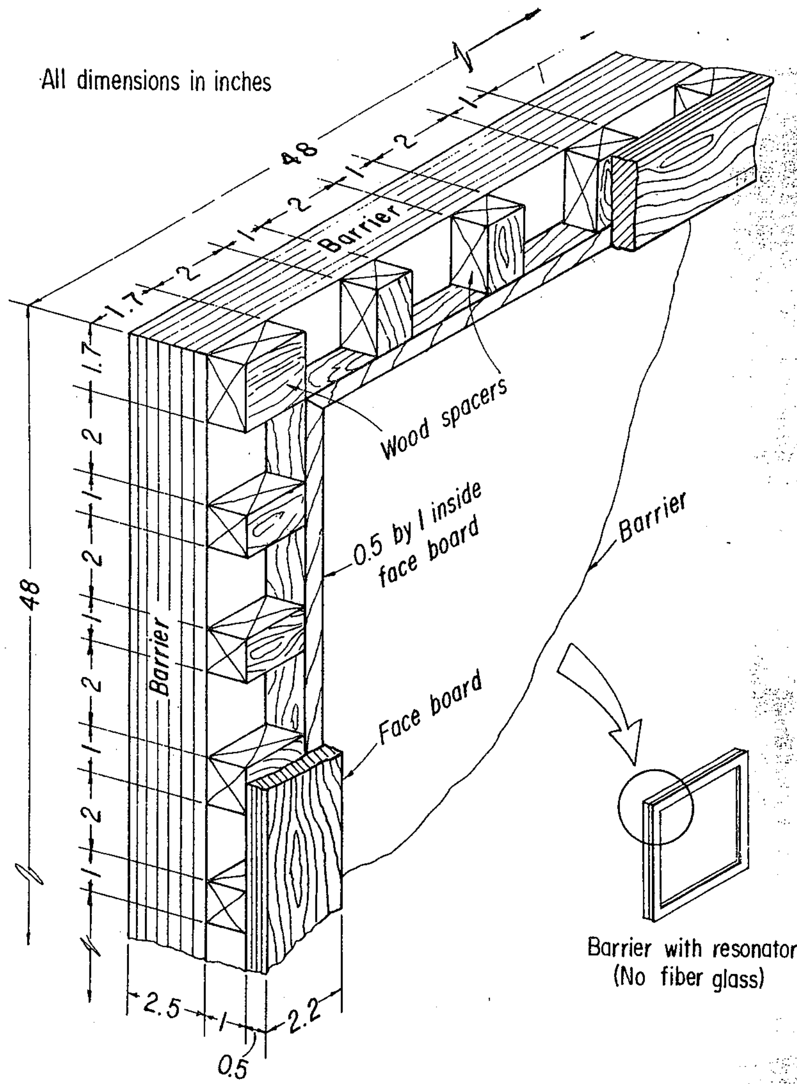

FIGURE 3. - Sectional enlargement of barrier with simple resonator.

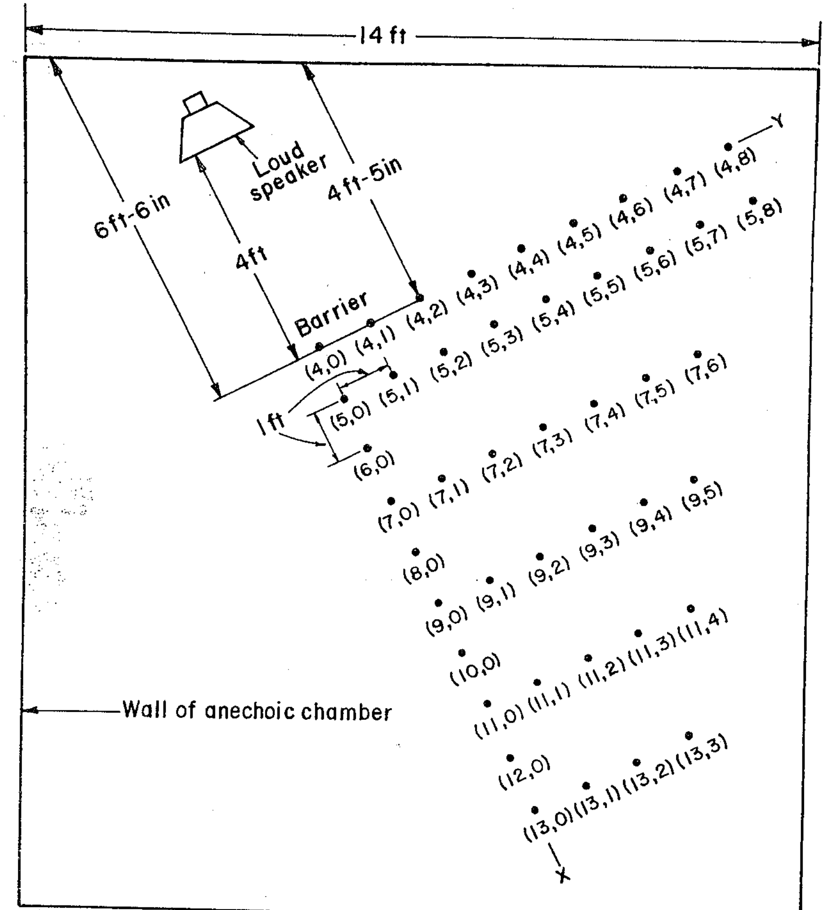

FIGURE 4. - Schematic of microphone positions in anechoic chamber.

distance was changed. According to Maekawa,[5] the sound waves are diffracted the same by any edge of a barrier (provided the edge conditions are identical); therefore, a change in horizontal distance should correspond to a change in vertical distance. A schematic of the microphone positions and their distance relationships to the loudspeaker and barrier can be found in figure 4. The loudspeaker was positioned in the corner of the anechoic chamber so the maximum distance from the barrier could be used. Also, the mounting brackets for the speaker were attached to the ceiling from previous experiments.

The diaphragm of the loudspeaker was positioned parallel to the barrier. The microphone was positioned so that its diaphragm was parallel to the speaker's diaphragm and at the same height as the center of the speaker. This arrangement permitted easy calculation of the path length difference to determine if the barrier would provide any attenuation and, via the calculations, provide an insight into the effectiveness of the barrier. The barrier consisted of five sheets of ½-inch thick plywood, measuring 4 feet by 4 feet, nailed together. The reason for such a massive barrier was to have a large sound transmission loss so the sound measured at the microphone positions would be the result of diffraction, not sound transmission through the barrier.

A system of resonators was attached to the four edges of the barrier on the side facing the source. Detailed drawings of the barrier and resonator system are presented in figures 1, 2 and 3. A resonator was nailed to the four edges. The sound waves would, therefore, be modified in the same manner by each edge.

PROCEDURE

Figure 5 shows the instrumentation used to perform the measurements. A pistonphone was used to calibrate the precision sound level meter to ±0.1 dB prior to every measurement session. The microphone was attached to a ring stand via a laboratory clamp and positioned on the grid utilizing a plumb. Sound pressure level measurements were conducted at each grid position; a reference position was chosen. Sound pressure level measurements at the reference position were made at discrete frequencies between 100 and 8,000 Hz. Data were recorded for both pure tones and for one-tenth octave band pink noise. An electronic switch was utilized to switch between pure tones and one-tenth octave band pink noise. The one-tenth octave bands had center frequencies corresponding to the pure tone frequencies. One-tenth octave band pink noise was used to help overcome some of the inherent interference problems associated with working with pure tones while keeping a narrow range of frequencies. To maintain a reproducible sound field, the voltage to the loudspeaker was held constant at 1 volt rms for the pure tones and 0.44 volt rms for the one-tenth band pink noise. The sound and vibration analyzer filters were tuned to the same frequency to avoid measurement error due to dial tracking differences of the two analyzers.

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[5]Maekawa, Z. Noise Reduction by Screens. Applied Acoustics, v. 1, 1968, pp. 157-173.

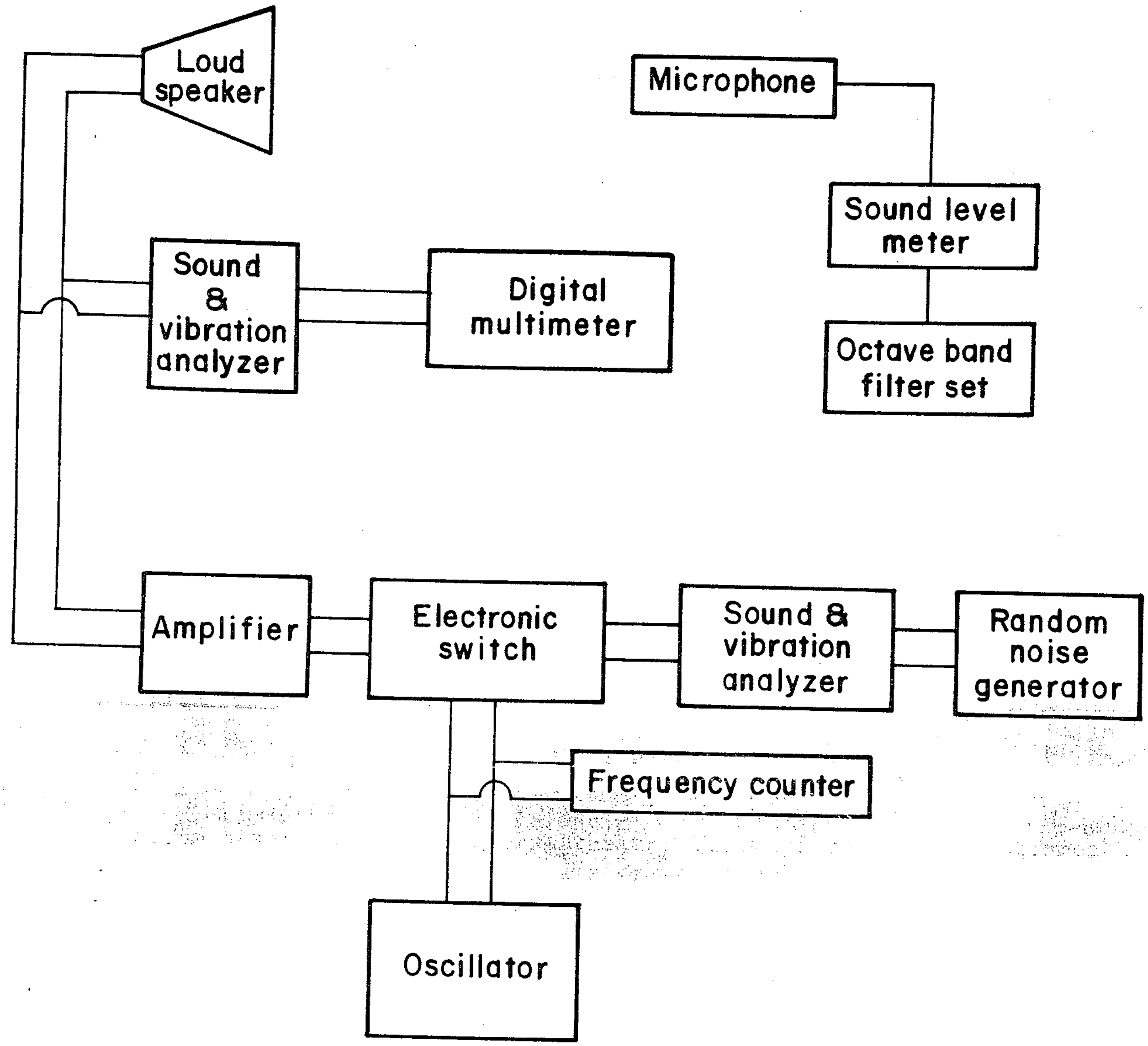

FIGURE 5. - Schematic of instrumentation.

After this was accomplished, the barrier was placed in the anechoic chamber and the above procedure repeated. By comparing the sound pressure levels at the reference position, the attenuation of the barrier was determined.

The resonator system was then attached to the barrier and a discrete frequency sweep conducted, utilizing the same frequencies and voltages for the pure tones and one-tenth octave band pink noise as before. The microphone was positioned at the reference position. This was accomplished to ascertain the insertion loss of the barrier equipped with the resonator system; and these results were compared to the barrier alone to ascertain if the resonator system afforded any additional insertion loss.

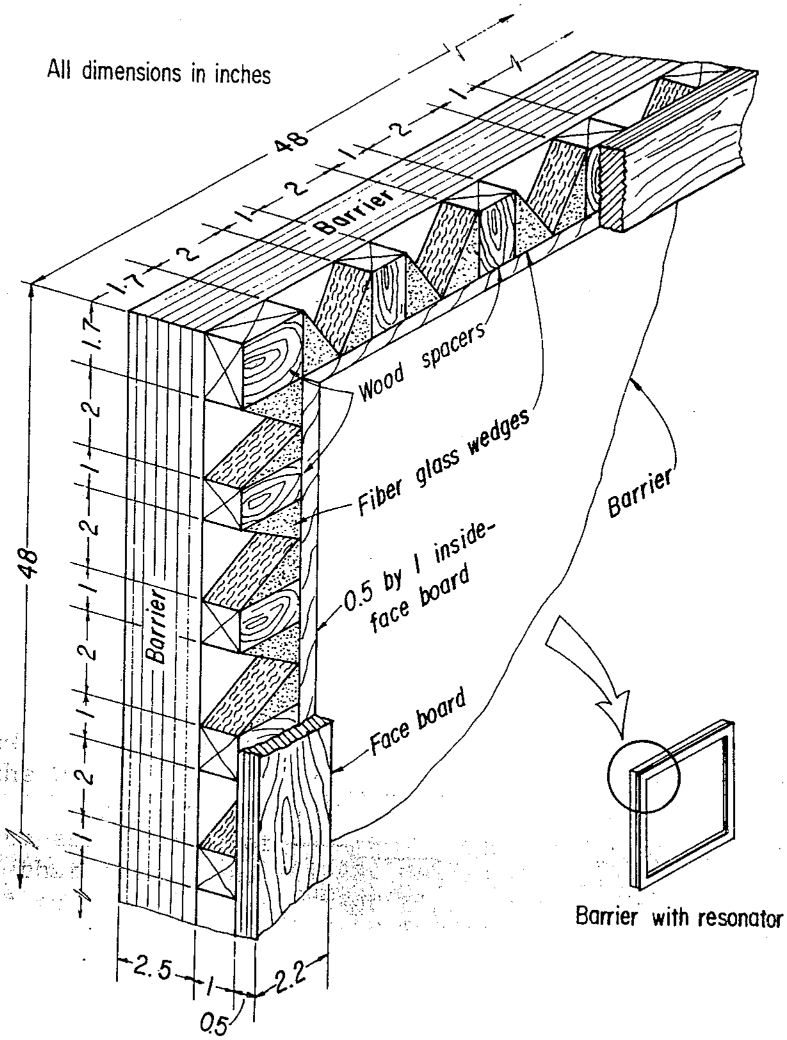

FIGURE 6. - Sectional enlargement of barrier with resonator containing fiberglass wedges.

All measurements in each step were repreated twice to assure precision.

The edge was modified by adding fiberglass wedges to the resonator cavities. The density of the fiberglass was 9 lb/ft^3. The fiberglass was sliced into triangles and two triangles were placed in the resonator cavity leaving a hole in the middle (fig. 6). The purpose of the fiberglass wedges was to produce a uniform acoustic impedance change in the resonator (acoustic impedance is the ratio of the sound pressure, force per unit area, on the surface by the flux: volume velocity or linear velocity multiplied by the area, through the surface). Also, the fiberglass wedges were intended to absorb some of the sound that propagated into the resonator.

The sound field was measured as described above for the quarter wavelength resonator system at both the reference position and the 44 microphone positions. Data were collected for pure tones and one-tenth octave band pink noise centered at the pure tone frequencies. As before, the voltage to the loudspeaker remained at 1 volt rms for the pure tones and 0.44 volt rms for the one-tenth octave band pink noise. The results were compared to those obtained using the untreated barrier.

RESULTS

The discussion will be confined to the results of one-tenth octave band pink noise. The pure tone data were consistent with the one-tenth octave band pink noise data; however, the pure tone data exhibited great fluctuations. These fluctuations were partially due to inherent problems dealing with pure tones. For pure tones, the positioning of the microphone became very critical especially at higher frequencies.

The insertion loss of the barrier at the reference position versus frequency for one-tenth octave band pink noise is illustrated in figure 7. Referring to figure 7, it seems that the barrier did not attenuate sound in the shadow region until the frequency approached 500 Hz. This finding is consistent with theory since a barrier will not attenuate sound unless the barrier is much larger than the sound wavelength. From 500 Hz upward the insertion loss increased until 1,300 Hz was reached, after which the insertion loss began to decrease. The reason the insertion loss declined at 1,600 Hz appears to be that the barrier was resonant at 1,600 Hz. Other resonance frequencies were 200, 600, 1,100 and 3,100 Hz. The calculated critical frequency, using the equation given in Chapter II of Beranek's Noise and Vibration Control, was 270 Hz. These resonances were indicated by acceleration measurements obtained on the barrier itself. The reduction in insertion loss in the region around 2,000 Hz was not explained. From 2,000 Hz upward, the insertion loss generally increased except for a dip that occurred near 4,000 Hz.

It is interesting to note that the two dips were approximately one octave apart. The insertion loss generally increased with increasing frequency. This observation is consistent with theory, since barriers attenuate high frequency sound better than low frequency sound.

The differential attenuation due to the resonator system for the reference position, as compared to the barrier alone, is depicted in the data in figure 8. Due to the microphone positioning, the amount of additional attenuation fluctuated greatly. Microphone positioning was very critical since a small position shift to the right or left of the center line of the barrier,

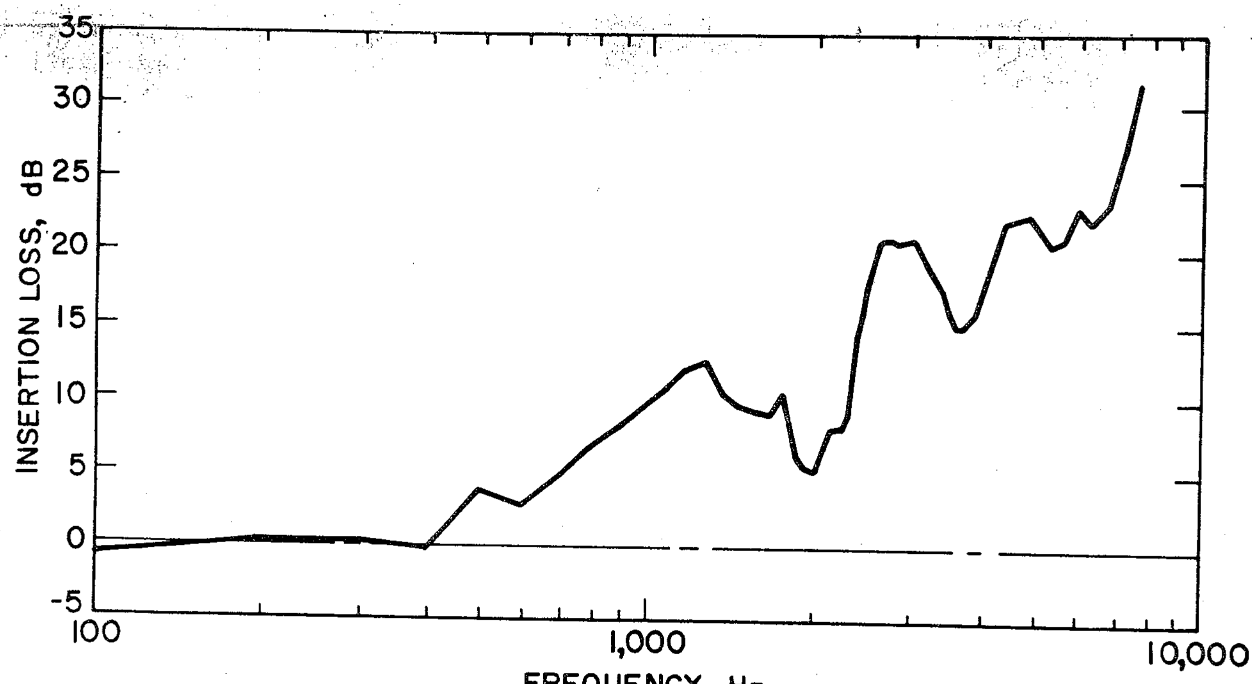

FIGURE 7. - Insertion loss versus frequency at reference position for one-tenth octave band pink noise.

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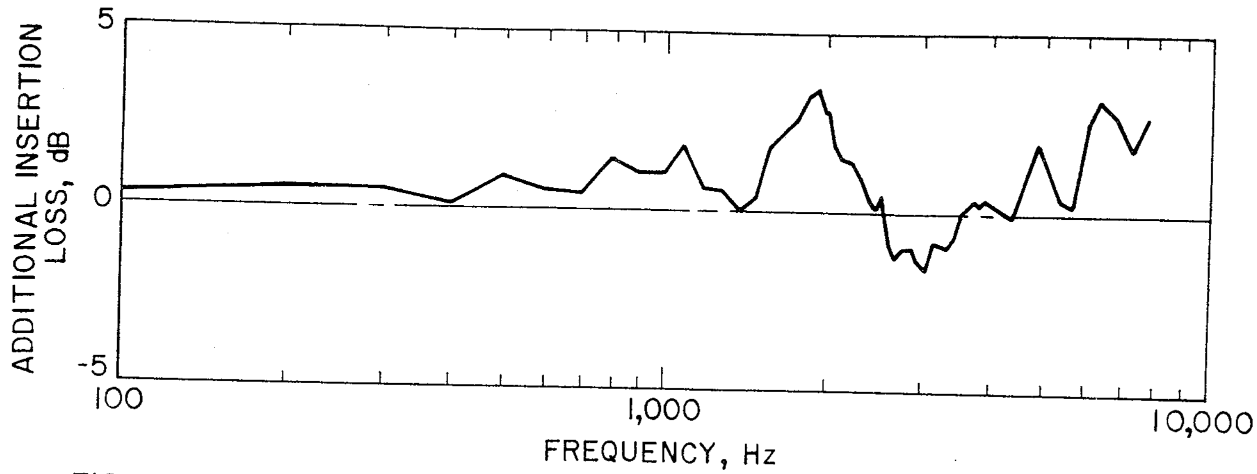

FIGURE 8. - Additional insertion loss by simple resonator system at reference position for one-tenth octave band pink noise.

or a position shift in height, produced a large deviation in the sound pressure level because the sound was focused along the center line. This phenomenon is well known and is described in studies in optics where results indicate a bright spot in the center of the shadow region for an isotropic structure that blocks the light source. As the frequency increased, the more critical the microphone position became. Because wavelength decreases with increasing frequency, the bright spot may miss the most sensitive area of the microphone diaphragm, thus resulting in a lower sound pressure level.

The resonator did not provide any additional insertion loss until a frequency of about 800 Hz was reached. The first peak of additional insertion loss occurred at 1,100 Hz. The insertion loss then gradually declined to zero at 1,400 Hz. A second peak of additional insertion loss occurred at 1,950 Hz; and this frequency was where the maximum additional insertion loss was obtained. The additional insertion loss increased until 3,100 Hz was reached, where the resonator actually increased the sound pressure level in the shadow zone. From this valley the additional insertion loss generally increased with increasing frequency. The resonator was actually designed to give the maximum additional insertion loss at 2,000 Hz. A quarter wavelength at 2,000 Hz is 1.7 inches long. Wavelength equals speed of sound divided by frequency. This distance was also the design center length of the resonator. No equivalent resonator length was calculated because the resonator did not satisfy the requirements of Rayleigh's correction factor for length. Rayleigh's correction factor for length requires $ka \ll 1$, where $k = \frac{2\pi}{\lambda}$ and a equals the equivalent resonator neck radius. Rawlins stated that pressure fluctuations approach zero for an acoustically soft edge condition. The pressure fluctuations at the neck of a quarter wavelength resonator also approach zero. Therefore, the resonator should be most effective in increasing insertion loss in the frequency region near 2,000 Hz.

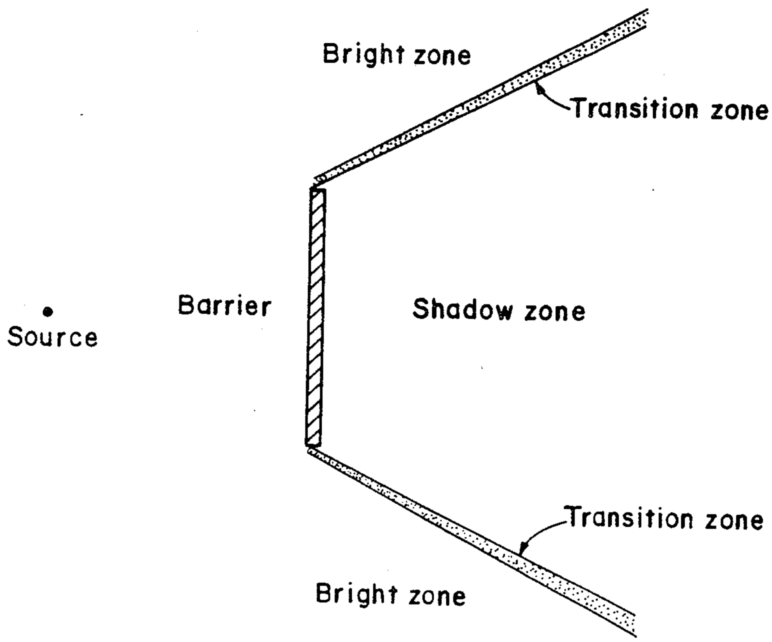

FIGURE 9. - Relationship between bright, transition and shadow zones.

The resonator system provided a maximum of additional insertion loss of 3.4 dB at 1,950 Hz. This amounted to approximately a halving of the sound intensity at the receiver position. However, at 3,100 Hz the resonator system provided a 1.6 dB gain in sound pressure level at the receiver position. Thus, the resonator system provided additional insertion loss over only a narrow range of frequencies.

Table 1 shows how the barrier equipped with the resonator influences the sound field for one-tenth octave band pink noise. The shadow, transition and bright zones are defined by Fresnel numbers.[6] The shadow zone is defined to have a Fresnel number greater than zero. In the transition zone the Fresnel number lies between zero and -0.2 and in the bright zone the Fresnel number is less than -0.2. Figure 9 shows the relationship between zones. The greatest additional insertion loss occurred at 2,000 Hz for the shadow and transition zones. (This is consistent with the predicted theory.) The greatest increase in sound pressure level occurred in the bright zone at 2,000 Hz. The greatest additional insertion loss in the bright zone occurred at 3,000 Hz even though the magnitude of the insertion loss decreased dramatically. At 3,000 Hz, the resonator provided additional insertion loss in all three zones.

TABLE 1. - Additional barrier insertion loss due to resonator system (one-tenth octave band pink noise data)

Center frequency	Zone					
	Shadow	No. of position	Transition	No. of position	Bright	No. of position
1,000 Hz	0.6 dB	26	0.8 dB	13	-0.1 dB	5
2,000 Hz	2.0 dB	26	1.8 dB	14	-0.5 dB	4
3,000 Hz	0.6 dB	26	0.8 dB	15	0.2 dB	3

[6]Fresnel number equals two times the path length difference between a sound ray diffracted over the edge of a barrier and the direct ray from the source to the receiver when the barrier is absent divided by the wavelength. The path length difference is positive in the shadow zone and negative in the other zones.

In figure 10 a graph was constructed to illustrate where, in the shadow zone along the center line to the barrier, the resonator system produced the most additional insertion loss. The maximum additional insertion loss occurred at the barrier for both the 1,000 and 3,000 Hz bands and at 2 feet from the barrier for the 2,000 Hz band. The amount of additional insertion loss remained virtually unchanged at 2,000 Hz as distance from the barrier increased to the maximum distance of 9 feet. The additional insertion loss of the one-tenth octave band pink noise centered at 2,000 Hz exceeded the additional insertion loss of the other one-tenth octave band pink noise signals for the measured distances except for the 3,000 Hz signal at the barrier itself. For one-tenth octave band pink noise centered at 1,000 and 3,000 Hz, the curves of additional insertion loss were practically equal with the 3,000 Hz curve showing more fluctuation.

In figure 11, the additional insertion loss of the barrier equipped with the resonator system containing the fiberglass wedges at the reference position, is compared to the barrier alone. Not until 1,400 Hz was approached does the additional insertion loss occur and it reached a peak at 1,950 Hz. The additional insertion loss generally declined with increasing frequency up to 3,100 Hz. At 3,100 Hz the sound pressure level in the shadow zone was actually increased. Peaks in additional insertion loss occurred at 3,500 Hz and 5,000 Hz and dips occurred at 4,500 Hz and 6,500 Hz. The dip at 6,500 Hz was very severe. The sound pressure level at this dip increased by 2.5 dB as compared to the sound pressure level when no resonators were attached to the barrier. This was almost a doubling of power. At 5,000 Hz, the additional insertion loss reached a maximum of 4.4 dB.

Comparing information presented in figures 8 and 11, the additional insertion loss for the simple resonator system did not begin until around

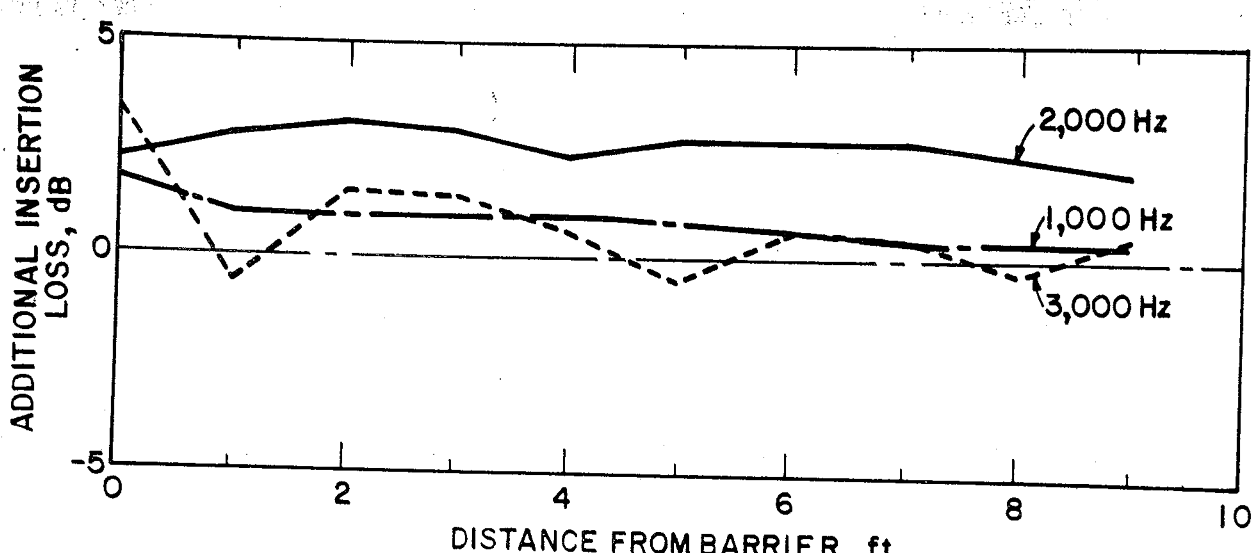

FIGURE 10. - Additional insertion loss by resonator system versus distance for one-tenth octave band pink noise.

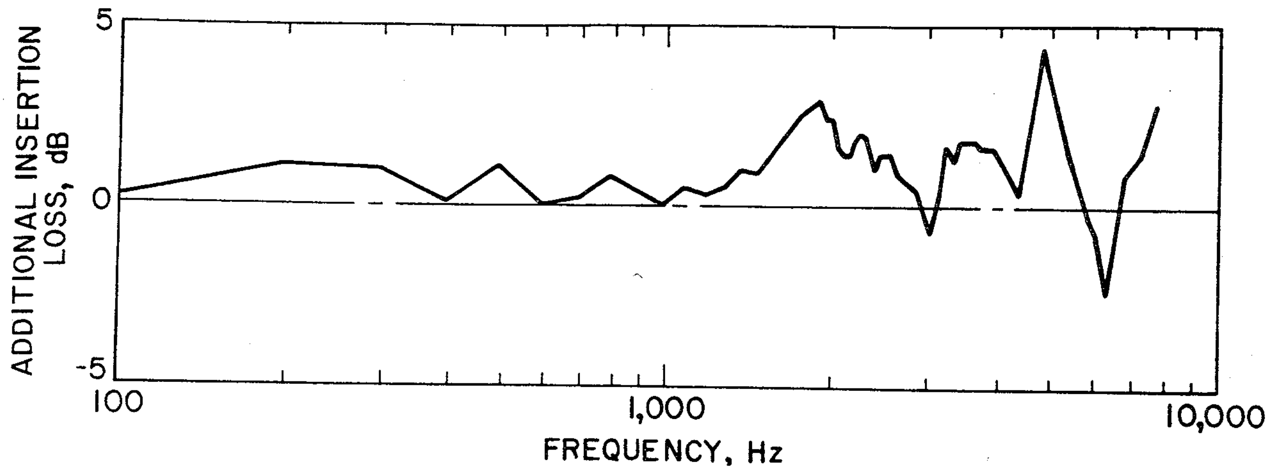

FIGURE 11. - Additional insertion loss by resonator system containing fiberglass wedges at reference position for one-tenth octave band pink noise.

800 Hz, while for the resonator system containing the fiberglass wedges, the additional insertion loss did not begin until around 1,400 Hz. The additional insertion loss at 1,950 Hz, which was essentially the design center frequency of the resonators, was 2.9 dB for the resonator system with fiberglass wedges and was 3.4 dB for the simple resonator system.

Furthermore, the addition of the fiberglass wedges improved the insertion loss and narrowed the dip that occurs around 3,100 Hz. It is noted from an inspection of figures 8 and 11 that the width of the dip at 3,100 Hz was reduced from 1,000 to 200 Hz. The increase in sound pressure was reduced from 1.6 to 0.7 dB.

The addition of the fiberglass wedges increased the insertion loss at 5,000 Hz by 2.4 dB. However, the wedges changed an insertion loss peak at 6,500 Hz into a dip where the sound pressure level was increased by 2.4 dB.

Table 2 shows how the barrier equipped with a resonator system containing fiberglass wedges influenced the sound field. All three one-tenth octave band pink noises had additional insertion loss in the shadow zone with 3,000 Hz exhibiting the greatest amount of additional insertion loss and 1,000 Hz the least. Also, all three had additional insertion loss in the transition zone and only the 1,000 Hz noise exhibited amplification in the bright zone. The greatest additional insertion loss in the transition zone occurred at 2,000 Hz and in the bright zone at 3,000 Hz. The pattern of additional insertion loss exhibited by the fiberglass treated resonators differed from the pattern displayed by the untreated resonators when the signal was one-tenth octave band pink noise. The simple resonator system had the greatest additional insertion loss at 2,000 Hz for both the shadow and transition zones; while for the resonator system containing the fiberglass wedges, the greatest insertion loss occurred at 3,000 Hz in the shadow zone and at 2,000 Hz in the transition zone. In the bright zone for both cases, the greatest additional insertion loss occurred at 3,000 Hz.

TABLE 2. - Additional barrier insertion loss by the resonator system containing fiberglass wedges (one-tenth octave band pink noise data)

Center frequency	Zone					
	Shadow	No. of position	Transition	No. of position	Bright	No. of position
1,000 Hz	0.7 dB	26	1.6 dB	13	-0.5 dB	5
2,000 Hz	2.2 dB	26	2.3 dB	14	0.1 dB	4
3,000 Hz	2.4 dB	26	0.9 dB	15	0.7 dB	3

When fiberglass wedges were installed, the most dramatic increase of additional insertion loss, for one-tenth octave band pink noise signals, occurred at 3,000 Hz in the shadow zone. The increase was from 0.6 dB to 2.4 dB. At 3,000 Hz in the transition zone, additional insertion loss remained virtually unchanged: 0.8 dB for the simple resonator system compared to 0.9 dB for the resonator system containing the fiberglass wedges. For the one-tenth octave bank pink noise centered at 3,000 Hz, the additional insertion loss in the bright zone rose from 0.2 dB to 0.7 dB when the fiberglass wedges were added to the resonator system. At 2,000 Hz all three zones experienced an increase of additional insertion loss: 1.0 dB to 2.2 dB in the shadow zone; 1.8 dB to 2.3 dB in the transition zone; and -0.5 dB to 0.1 dB in the bright zone when fiberglass wedges were added to the resonator. A comparison of the resonator system containing fiberglass wedges to the resonator system alone indicated virtually no change in the additional insertion loss at 1,000 Hz in the shadow zone (0.7 dB to 0.6 dB). However, the addition of the fiberglass wedges to the resonator system increased the additional insertion loss in the transition zone from 0.8 dB to 1.6 dB and in the bright zone from -1.0 dB to -0.5 dB. The addition of fiberglass wedges to the resonators generally improved the insertion loss of the barrier.

In figure 12 a graph was constructed to illustrate where, in the shadow zone along the center line to the barrier, the resonator system equipped with fiberglass wedges produced the greatest additional insertion loss. The maximum additional insertion loss occurred at 1 foot from the barrier for both the 1,000 and 2,000 Hz signals and at 2 feet for the 3,000 Hz signal. There appears to be a relationship between distance and additional insertion loss. The maximum additional insertion loss occurred near the barrier and decreased with increasing distance from the barrier. This result must be viewed with caution since the additional insertion loss fluctuated greatly. The additional insertion loss of the one-tenth octave band pink noise centered at 3,000 Hz exceeded the additional insertion loss of the other one-tenth octave band pink noise signals for the measured distances except for the 2,000 Hz signals at 3, 6 and 9 feet and the 1,000 Hz signal at 3 feet. The additional insertion loss of the one-tenth octave band pink noise centered at 2,000 Hz exceeded the additional insertion loss of the 1,000 Hz signal at all measured distances. The above results were not consistent with the results from the simple resonator system. In the simple resonator system, the additional insertion loss of the one-tenth octave band pink noise centered at 2,000 Hz was increased the most while, with the resonator system containing the fiberglass wedges, the 3,000 Hz signal exhibited the greatest increase in additional

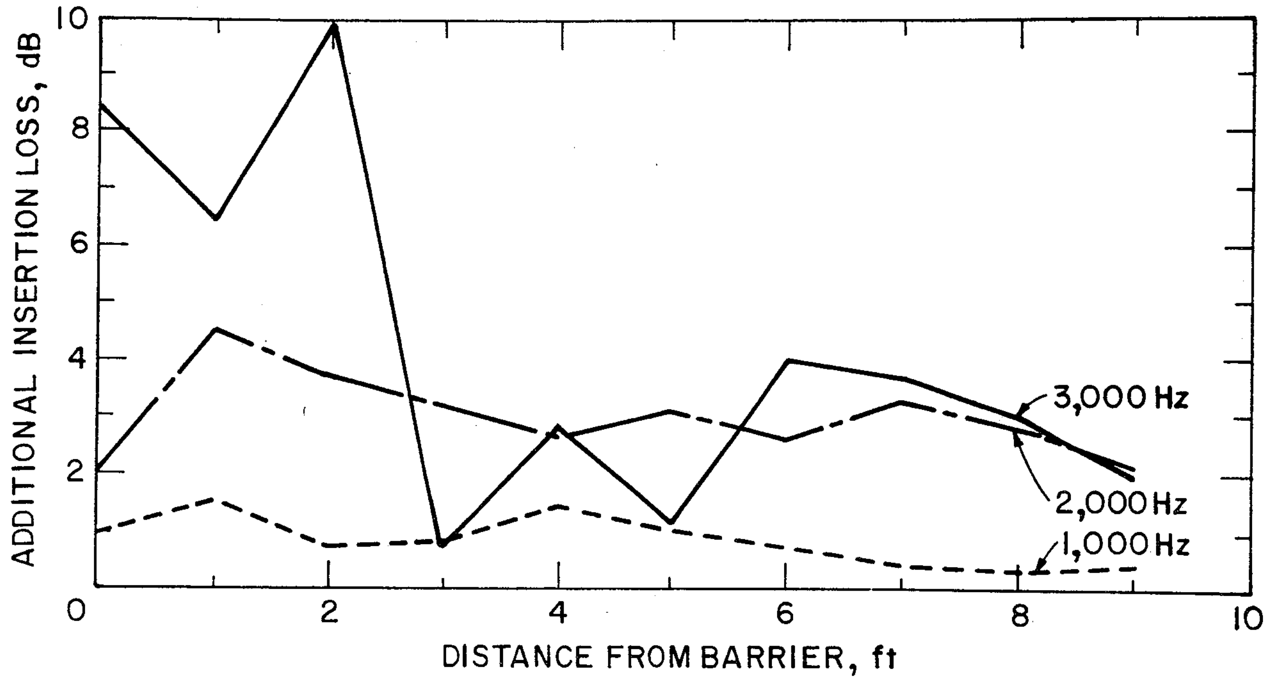

FIGURE 12. - Additional insertion loss by resonator system containing fiberglass wedges versus distance for one-tenth octave-band pink noise.

insertion loss. Both resonator systems provided less additional insertion loss as distance from the barrier increased. The additional insertion loss values for the resonator system containing fiberglass wedges fluctuated greatly.

DISCUSSION

The results of this study are comparable to those obtained by other researchers using an absorbent layer attached to a rigid barrier. Masiak[7] found little appreciable increase in barrier attenuation for Fresnel numbers under 10; however, the barrier equipped with a resonator system increased the insertion loss for the 2,000 Hz signals for Fresnel numbers under 10 and when fiberglass wedges were added, the insertion loss increased for the 2,000 and 3,000 Hz signals.

Maekawa found, according to Kurze,[8] that the addition of an absorptive layer to a barrier marginally increased the effectiveness of the barrier when the diffraction angle, ρ, was less than 45° (refer to figure 13 for a definition of diffraction angle). Unfortunately, Kurze did not report the type of signal used by Maekawa.

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[7]Masiak, J. E. Model Studies of Acoustic Barriers. Journal of the Acoustical Society of America, v. 55, 1974, p. 537(A).

[8]Kurze, U. J. Noise Reduction by Barriers. Journal of the Acoustical Society of America, v. 55, 1973, pp. 504-518.

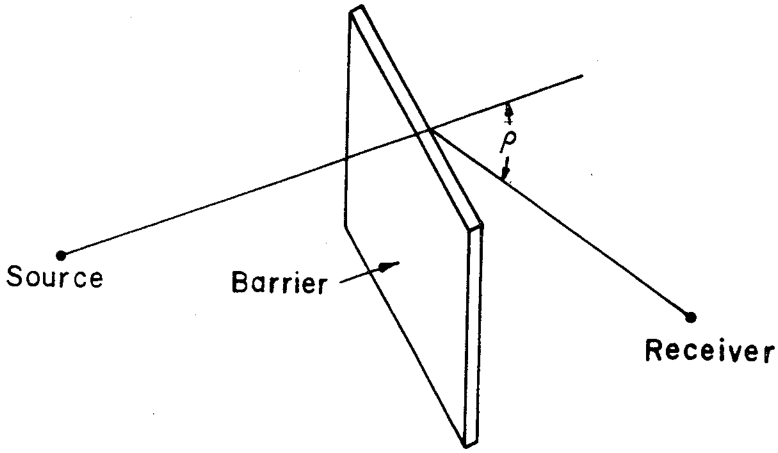

FIGURE 13. - Perspective view of a barrier where ρ is the diffraction angle.

For one-tenth octave band pink noise centered at 1,000 and 3,000 Hz, the plain resonator system provided marginal effectiveness (insertion loss increased 0.4 dB), when the diffraction angle was less than 45°. The resonator system did provide 1.8 dB additional insertion loss for the one-tenth octave band centered at 2,000 Hz. Maekawa found the attenuation improved from 5 to 8 dB when the diffraction angle was greater than 90° and the Fresnel number greater than unity. Since Kurze was not explicit in reporting Maekawa's results for the diffraction angle greater than 90° and the Fresnel number greater than unity, no valid comparisons can be drawn between the results obtained by Maekawa and the present study. In this study, however (for conditions $\rho > 90°$ and $N > 1$), as shown in table 3, the resonator system yielded 1.7 dB, 2.9 dB and 2.0 dB of additional insertion loss for the one-tenth octave band pink noise centered at 1,000, 2,000 and 3,000 Hz, respectively.

TABLE 3. - Insertion loss of resonator systems for different diffraction angles

	Diffraction angle	One-tenth octave band pink noise center frequency		
		1,000	2,000	3,000
Simple resonator........................	$\rho < 45°$	0.4	1.8	0.4
	$\rho > 90°$ $N > 1$	1.7	2.9	2.0
Resonator systems equipped with fiberglass wedges................................	$\rho < 45°$	0.5	2.1	1.5
	$\rho > 90°$ $N > 1$	1.2	2.6	4.1

For the resonator system containing fiberglass wedges, when the diffraction angle was less than 45°, additional insertion loss of 0.5 dB, 2.1 dB and 1.5 dB occurred at the one-tenth octave band pink noise centered at 1,000, 2,000 and 3,000 Hz, respectively. Thus, the additional insertion loss increased for the 3,000 Hz signals. In the case when the diffraction angle was greater than 90° and the Fresnel number exceeded unity, additional insertion loss amounted to 1.2 dB, 2.6 dB and 4.1 dB for the one-tenth octave band pink noise centered at 1,000, 2,000 and 3,000 Hz, respectively. Thus, in both zones ($\rho < 45°$, $\rho > 90°$, and $N > 1$), the addition of fiberglass wedges to the resonators improved the insertion loss.

Fleischer, according to Kurze,[9] found from field measurements that an absorption layer increased barrier attenuation a maximum of 5 dB and averaged as low as 1.6 dB. For one-tenth octave band pink noise centered at 1,000, 2,000 and 3,000 Hz, the resonator system averaged 0.7 dB, 2.0 dB and 0.6 dB, respectively. Therefore, the resonator system again appeared to perform better for the 2,000 Hz signal and worse for the 1,000 and 3,000 Hz signals. The addition of fiberglass wedges to the resonator system produced additional insertion loss of 0.7 dB, 2.2 dB and 2.4 dB for noise centered at 1,000, 2,000 and 3,000 Hz, respectively. Thus, the resonators containing fiberglass wedges appeared to perform better than an absorptive layer for one-tenth octave band pink noise centered at 2,000 and 3,000 Hz. These comparisons must be viewed with caution since the type of signal used by Fleischer was not reported by Kurze.

No valid comparisons can be made between this study and the field studies of Butler[10] and Jonasson.[11] In the subject experiment, a point source was approximated; Jonasson approximated a line source. Butler found 5 dB of additional attenuation "deep in the shadow zone," but he failed to define what he meant by "deep in the shadow zone."

Rawlins' calculations showed that an acoustically soft edge condition will increase barrier attenuation up to 30 dB and an absorptive condition up to 6 dB. Jonasson calculated that an acoustically soft edge condition will increase barrier attenuation up to 24 dB and an absorptive edge condition up to 6 dB. In this study, when the additional insertion losses at any point were averaged, the additional insertion loss at any point was less than 5 dB.

The resonator system's data compared more favorably with an absorptive condition than an acoustically soft condition.

The sound pressure level measurements made at discrete frequencies for one-tenth octave band pink noise had replications that were within 0.5 dB for 67 percent of the observations and within 1.0 dB for 86 percent of the observations. The replication of the sound pressure level measurements for one-tenth octave band pink noise at the microphone positions was within 0.5 dB for 64 percent of the observations and within 1.0 dB for 86 percent of the observations. Thus, the observed trends in insertion loss appear to be valid.

CONCLUSION

The central purpose of this study was to evaluate the effect upon insertion loss of two barrier edge conditions. The barrier edge conditions consisted of two types of resonators. One resonator system was composed of a set of simple quarter wavelength cavities mounted completely around the edge of the barrier. The other edge condition utilized the same system except fiberglass wedges were inserted into the cavities.

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[9] Work cited in footnote 8.

[10] Butler, G. F. A Note on Improving the Attenuation Given by a Noise Barrier. Journal of Sound and Vibration, v. 32, 1976, pp. 367-369.

[11] Jonasson, H. G. Sound Reduction by Barriers on the Ground. Journal of Sound and Vibration, v. 22, 1972, pp. 113-126.

Both resonator systems improved the barrier insertion loss as compared to the barrier alone. This was true for both pure tones and one-tenth octave sources used in this study. The improvements in insertion loss were restricted to narrow frequency regions. The addition of fiberglass wedges to the cavities broadened the frequency region over which the insertion loss was improved. Each resonator system provided additional insertion loss of two to four decibels.

The following is a hypothetical example on how the barrier equipped with a resonator system would decrease a miner's noise exposure. In this example, the fan will have a pure tone component at 2,000 Hz; however, in reality the pure tone component would be closer to 630 Hz. Table 4 shows the A weight sound level to which a miner working near the fan would be exposed. The noise reduction was calculated based upon a fan noise spectrum and insertion losses taken from figures 7, 8 and 11. One can see that the quarter wavelength resonator improved the noise reduction by 1.7 dBA and that the resonator containing fiberglass wedges improved the noise reduction by 1.6 dBA. Thus, the operator in this example would be in compliance with MSHA noise regulations using a barrier with either resonator system but not in compliance with a simple barrier.

TABLE 4. - Sound pressure levels at the miner's position

No barrier	Barrier	Barrier with resonators	Barrier with resonators containing fiberglass wedges
98.0 dBA	91.4 dBA	89.7 dBA	89.8 dBA

Noise sources that have low frequency pure tones lend themselves particularly well to these noise control techniques. Low frequency noise is not attenuated well by acoustic materials while resonators can be adjusted to attenuate low frequency noise. Also, the resonator systems with or without fiberglass wedges are more rugged and thus more suitable for the rigorous mining environment. Ventilation fans, power transformers and vacuum pumps are examples of mining noise sources.

The results of this study indicated that the effective height of the barrier was increased, but by comparison to data in the literature, the resonator system does not conform to an acoustically soft condition.

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