Baltimore, Maryland
NOISE-CON 2004
2004 July 12-14

Handling of Barriers in ISO 9613-2

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1.0 INTRODUCTION

Sound barriers, or sound screens as they are called in ISO 9613-2[1], are one of the primary tools used in noise control engineering. The ability to accurately estimate the attenuation of a sound barrier is critical to the successful noise control design of many industrial facilities. However, far too often noise control engineers ignore the details buried within the barrier attenuation algorithms and rely on computer methods to handle critical calculations. One of the more popular algorithms for barrier insertion loss is that defined by the ISO 9613-2 standard.

The ISO 9613-2 screening attenuation equations and rules are cast as a simple method for determining the effectiveness of a sound barrier in the presence of a ground plane. The method is conducive for computer predictions made on personal computers with limited computational resources. It is often used in spreadsheet analysis or in dedicated environmental sound modeling software. Currently, the algorithm is widely used in environmental noise modeling software.

Issues associated with the perceived accuracy of the ISO 9613-2 screening algorithm can be broken down into 3 categories:

1.) misinterpretations by ISO 9613-2 users of the formulas/rules that can lead to erroneous results or discontinuity of the results,
2.) ISO 9613-2's omissions in regard to rules for handling special cases,
3.) physical phenomena that ISO 9613-2 does not account for.

This paper provides a critical assessment of the adequacy of the ISO 9613-2 barrier attenuation algorithm and identifies many misconceptions of its use and deficiencies of the algorithm.

2.0 THE ISO 9163-2 SCREENING ALGORITHMS

The ISO 9613-2 screening algorithm is a portion of ISO 9613-2's overall attenuation term, *A*, as shown below:

$$A = A_{div} + A_{atm} + A_{ground} + \mathbf{A_{screen}} + A_{misc} \quad (1)$$

where

A_{div} attenuation due to geometrical divergence
A_{atm} attenuation due to atmospheric absorption
A_{ground} attenuation due to the ground effect
$\mathbf{A_{screen}}$ ***attenuation due to screening***
A_{misc} attenuation due to miscellaneous effects (industrial sites, foliage, housing, etc.)

The term "*A*" is part of ISO 9613-2's basic equation used for calculating the sound pressure level, Lp, at a field point, such that:

$$Lp = Lw_{point} + D - A \qquad (2)$$

where

Lw_{point}	point source sound power level, in dB re 1 picowatt
D	directivity indices, in dB
A	sum of various attenuation effects defined above

The screening algorithm's primarily function is to estimate attenuation over the top edge of the vertical sound barrier. However, it also allows estimates around the vertical edges of barriers. Screening can be calculated for single or multiple screens or single screens with finite thickness. For single screens, ISO 9613-2 suggests limiting the maximum attenuation calculated to 20 dB while for multiple screens it suggests 25 dB.

The screening attenuation, D_z, is calculated from the following equations:

$$D_z = 10 \log_{10} (3 + (C_2 / \lambda)\, C_3\ z\ K_{met}) , \text{ in dB} \qquad (3)$$

where

λ	wavelength of the octave band center frequency	
C_2	= 20 for cases where ground plane reflections are included	
	or	
C_2	= 40 in special cases when ground is modeled with image sources	
C_3	$= (1 + (5\lambda/e)^2) / (1/3 + (5\lambda/e)^2)$ for multiple or finite thickness screens	(4)
or		
C_3	= 1 for single screens	
e	distance between the screens in the direction of the source and receiver	

K_{met} is the correction factor for meteorological influences, defined as

K_{met}	$= \exp(-(1/2000)\, ((d_{ss} \cdot d_{sr} \cdot d) / 2z)^{1/2})$ for $z > 0$	(5)
or		
K_{met}	= 1 for other values of z or lateral diffraction	

d_{ss}	perpendicular distance from source to plane of screen (see Figure 1)
d_{sr}	perpendicular distance from plane of screen to receiver
a	distance parallel to the screen measured between the source and receiver
d	direct distance from source to receiver

$$z = [(d_{ss} + d_{sr} + e)^2 + a^2]^{1/2} - d \quad = (\text{diffracted} - \text{direct path length}) \qquad (6)$$

The value of z is given a negative value if the source can be seen by the observer.

Mathematically, the screening term, A_{screen}, is defined as follows:

$$A_{screen} = D_z - A_{ground} > 0, \text{ for top edge attenuation due to the screen} \qquad (7)$$

$$A_{screen} = D_z > 0, \text{ for side edge attenuation due to the screen} \qquad (8)$$

The A_{ground} term will then cancel when it is added to the attenuation provided in equation 1.

Unfortunately, the behavior of the screening attenuation calculated by the equations above is not intuitively obvious. Some confusion exists on how to handle the interaction between the term C_2 and the ground attenuation term, A_{ground}. Also, the vagueness of the meteorological term, K_{met}, leaves the user questioning its appropriateness and purpose.

While the formulation of the ISO 9613-2 screening algorithm appears to be complex, most users are familiar with the formulation from the Anderson and Kurze[2] Outdoor Sound Propagation Chapter in Beranek and Vér's, *Noise and Vibration Control Engineering*. The formulation, however, provides sound attenuation similar to that defined by a much simpler and more readily recognizable version of the Kurze[3,4] formulation:

$D_z = 20\text{Log}_{10}[\Omega /(\tanh \Omega)] + 5 \text{ dB}$ (9)

where

$\Omega = (2\pi N)^{1/2}$ (10)

N = Fresnel number

The above formulations are Kurze[4] curve fits to Maekawa's data. The difference between the above formulation and ISO 9613-2 is that equation 9 above does not account for ground or meteorological effects.

To demonstrate the similarities of the two formulations, a comparison was made of the ISO 9613-2 formulation and the formulation of equation 9. Figure 2 shows a comparison of the attenuation estimated by the two formulations when the barrier is located 10 meters horizontally from both the source and receiver with both source and receiver 1 meter below the top of the screen (in the shadow zone). For this comparison, the ground term C_2 is set to 40 for consistency with formulation of equation 9 indicating no reflecting plane exists below the sound source, receiver or sound screen. It can be seen that two formulations provide nearly identical results.

Figure 3 shows the same comparison provided in Figure 2 except with the ISO9613-2 term C_2 set equal to 20. The inclusion of the "ground" is accomplished by introducing hemispherical versus spherical spreading C_2 = 20 versus C_2 = 40.

Figures 4 and 5 show comparisons of the attenuation estimated by the two formulations when the barrier is located 50 meters (Figure 4) and 100 meters (Figure 5) horizontally from both the source and receiver with both source and receiver 1 meter below the top of the screen. The meteorological term, K_{met}, comes into play at these larger distances and has the effect of reducing the calculated screen attenuation to a maximum of 4.8 dB.

3.0 COMMON MISINTERPRETATIONS OF THE ALGORITHMS

The ISO 9613-2 barrier algorithm is based on a series of equations and rules. For the screening algorithm to work as intended, the "rules" cast within the formulation must be followed as diligently as the equations themselves. Quite often, however, the relatively simple equations are followed but the rules are ignored. This often leads users to believe deficiencies exist in the algorithm. To minimize the length of the discussion, the author will address only the most common misinterpretations based on numerous discussions with colleagues.

Common Misinterpretation 1 – The combination of the ground attenuation and the screening attenuation can lead to large, unrealistic attenuations.

Many have interpreted the ***combination*** of the screen attenuation and ground attenuation to allow for unrealistically large attenuations. From equation 1, the ground and screen effects appear to be additive. In reality, ISO 9613-2's handling of attenuation due to screening and ground effects is not additive. It can be simply viewed as the screening term contains the ground attenuation. The two A_{ground} terms then cancel when combined in equations 1 and 7.

Some confusion exists as to how the situation is handled when the screens attenuation, D_z, is less than the ground attenuation. The assumption in equation 7, although not specifically addressed by ISO 9613-2, is that if $A_{screen} \leq 0$, *then* A_{screen} is then set equal to 0. If this is the case, the ground attenuation, A_{ground}, must be larger than the screen's attenuation. Effectively, the logic says use the larger of either the barrier's attenuation or the ground attenuation alone - but not both.

Common Misinterpretation 2 – A discontinuity exists when the observer's line of sight to the sound source is just broken by the screen.

Another common misconception is that when the line of sight between the sound source and observer are just broken, the attenuation from the screen jumps from 0 dB (sound source in line of sight) to 4.8 dB (sound source line of sight just broken). However, if the rules defined by the ISO 9613-2 are carefully followed, the perceived discontinuity will not exist. If the screen blocks the line of sight, the observer is in the shadow zone of the screen, while if the source can be seen from the observer, the observer is in the transition zone or bright zone of the screen. ISO 9613-2 accounts for the source being visible to the observer by requiring that the diffraction distance, z, be set equal to negative z "if the line of sight between the source and receiver passes over the top edge of the barrier". When applied to equation 3, this rule provides a smooth and continuous transition from 0 dB to the maximum attenuation allowed by the algorithm. Figure 6 provides the estimated attenuation from the presence of a sound screen when both the observer and sound source are 1 meter ***above*** the top of the screen. It can be seen that at shorter wavelengths (higher frequencies) and corresponding larger negative values of the Fresnel number, the algorithm provides the result we expect - less attenuation.

4.0 HANDLING EQUATIONS WHEN "RULES" FOR SPECIAL CONDITIONS DO NOT EXIST

When the rules and equations of ISO 9613-2 are followed, the calculations from the algorithm appear to provide reasonable results when used to compute the attenuation of barriers at relatively close distances. For large distances and high barriers ISO 9613-2 warns that the insertion loss calculated has not been sufficiently confirmed by measurements.

It should be added that very short barriers may also cause erroneous results. While the method provides criteria for the horizontal dimension of the barrier such that the horizontal dimension of the object normal to the line created by the source to receiver must be greater than a wavelength before the object can be considered a screen, it does not specify a requirement for the vertical dimension of the object. A very short object, such as a 1 meter tall divider wall along a roadway, can provide several decibels of attenuation at low frequencies – even when the receiver has a clear line of sight to the sound source. A simple solution can be correcting the term, D_z, by multiplying it by the ratio of the barrier height to the wavelength when the barrier height is less than the wavelength of interest. While this appears to be a simple and straight forward solution when objects are modeled as sound screens, it is difficult to implement in automated computer analysis that model ground elevation differences as sound screens. In the case of ground acting as a sound screen, it is impossible to determine the barrier's vertical dimension.

5.0 PHYSICAL PHENOMENA NOT ACCOUNT FOR IN ISO 9613-2

Two weaknesses of the ISO 9613-2 screening algorithm relate to how the propagation of sound around a barrier truly interacts with the ground and the effects of wind/atmosphere on the barrier's ability to attenuate sound.

Lam[5] has shown the necessity of computing each path around the barrier and its corresponding reflection with the ground plane. Lam concludes that energy summation methods work well with large barriers and high frequencies where "closely packed interference patterns tend to average out and leave insertions loss values closer to energy summation". Lam shows, however, that energy summation consistently over predicts the insertion loss of the lower frequency octave bands with maximum errors of around 9 dB. Over prediction of barrier insertion loss can lead to designs that exceed noise goals. It should be noted, however, that accurate prediction of the insertion loss of the barrier would require knowledge of the sound source's narrow band frequency spectrum - which is not typically available for most modeling applications. Octave band sound power levels are most often the best available sound source descriptors. With this being the case, we must allow for the potentially large errors that may exist in our ability to estimate the barrier's low frequency attenuation.

The effect of wind on a barrier's attenuation is also a notable affect not explicitly addressed by the ISO 9613-2 algorithm. Testing performed by DeJong and Stusnick[6] has shown wind to have substantial effects on the sound barrier's performance. Their model data shows approximately a 5 dB decrease in the barrier's attenuation under downwind conditions of 5 meters per second. This corresponds to the upper limit on wind speed allowed by the ISO 9613-2 standard. The wind appears to influence high frequencies more so than low frequencies. Salomons[7] and Rasmussen[8] have provided theory and data on downwind and upwind effects. In general, higher velocity wind and longer distances exacerbate the effect. Since more attenuation is observed in upwind conditions than that predicted by the "no wind" model, the upwind case has no impact on the assessment of ISO 9613-2. Certainly, the meteorological term, K_{met}, has a substantial impact in reducing the estimated barrier's effective attenuation at large distances. It is questionable, however, that the ISO 9613-2 algorithm adequately accounts for the decrease in barrier performance within the wind parameters stated.

7. SUMMARY

This paper presented the basic ISO 9613-2 sound screening algorithms. It has addressed several areas where users must use caution to avoid undesirable modeling outcomes.

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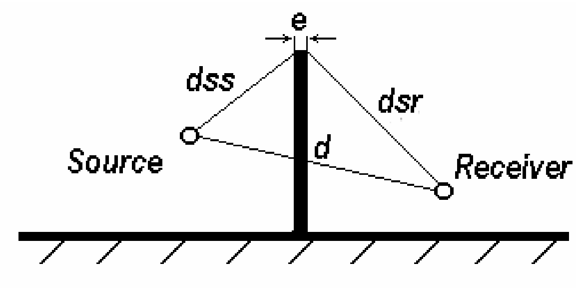
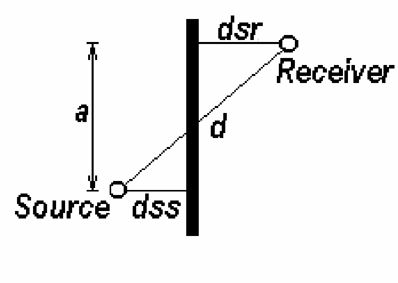


Elevation View of Sound Screen



Plan View of Sound Screen

Figure 1. Screening Geometry

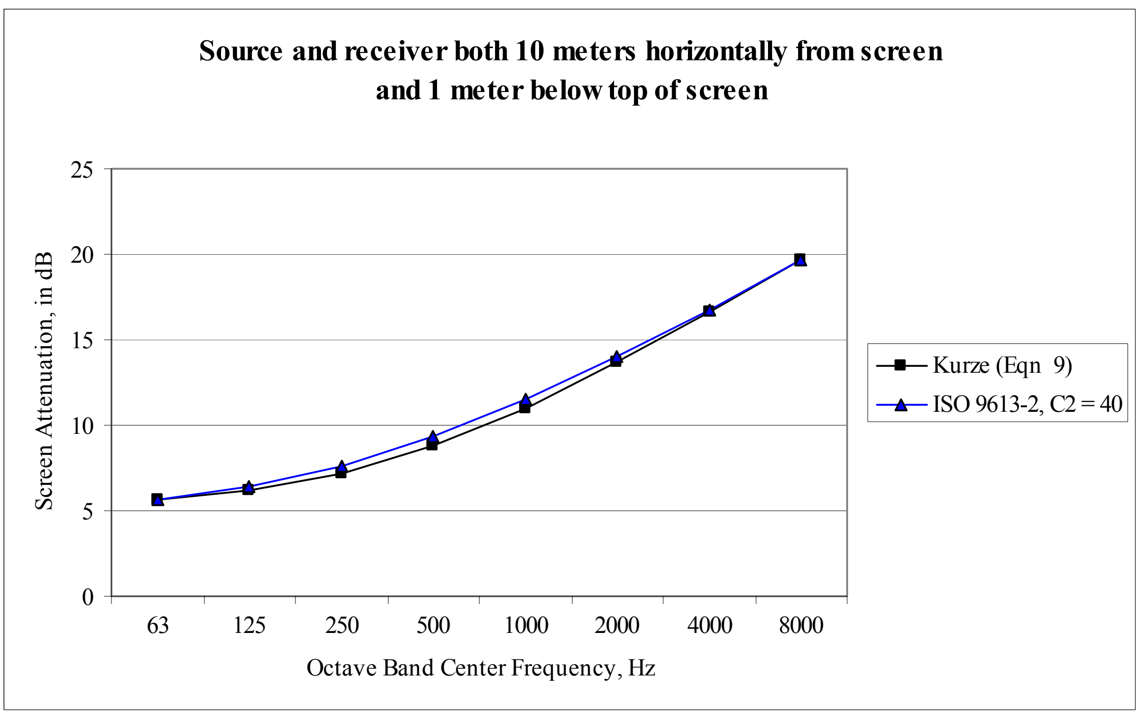


Figure 2. Comparison of ISO 9613-2 Screening Formulation and Kurze Formulation that Neglects Ground and Meteorological Effects

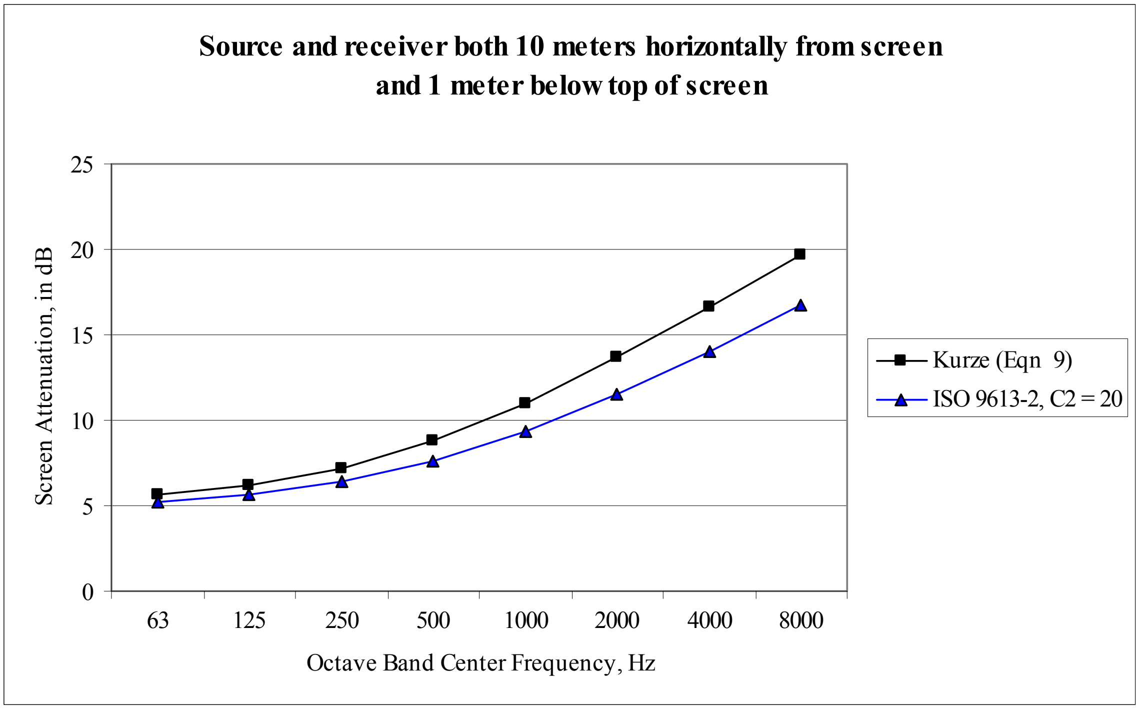


Figure 3. Effect of ISO 9613-2 Screening Ground Term C_2

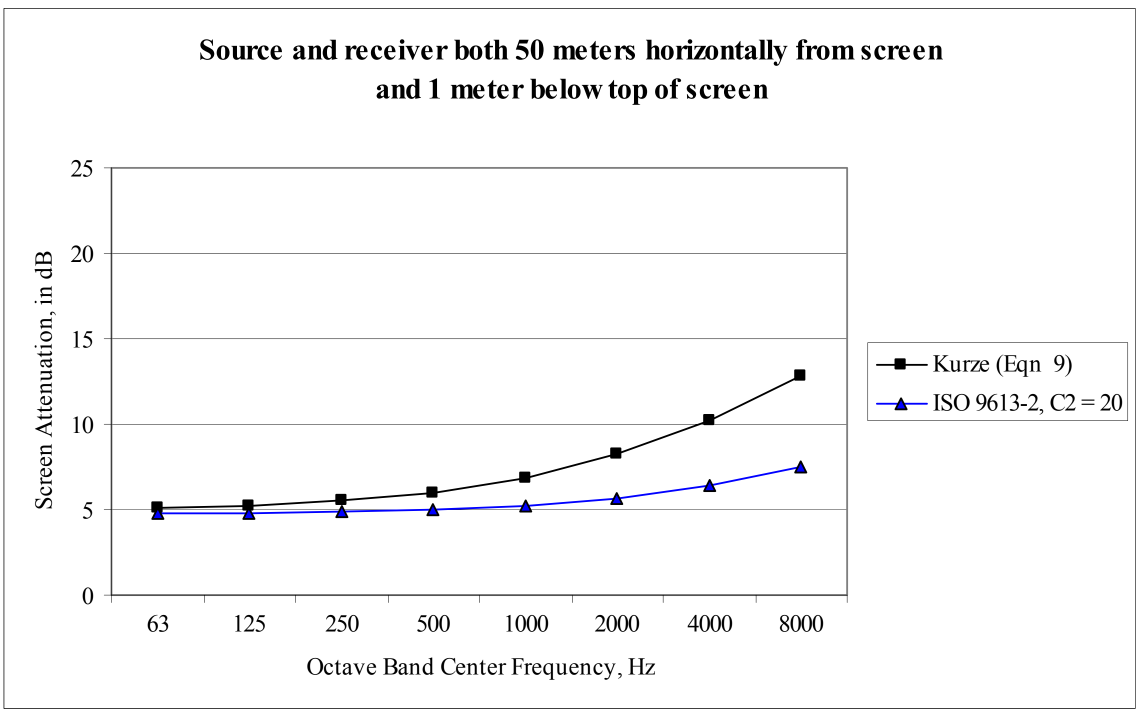


Figure 4. Effect of Meteorological Term, K_{met},at 100 Meters

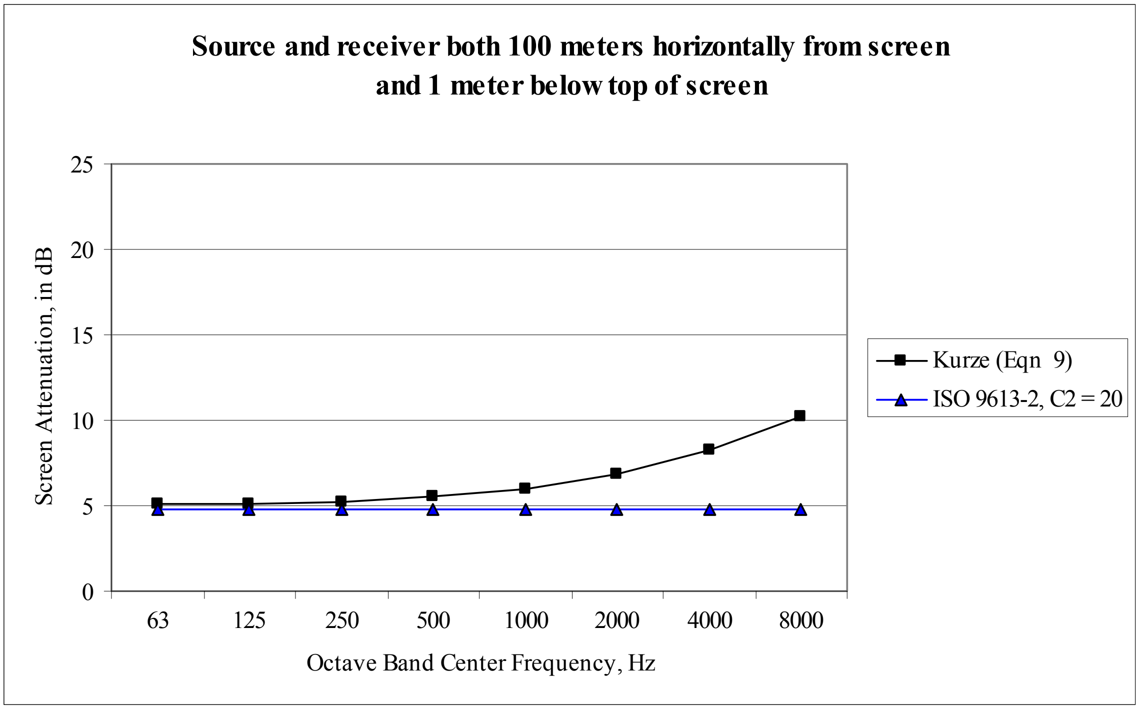


Figure 5. Effect of Meteorological Term, K_{met}, at 200 Meters

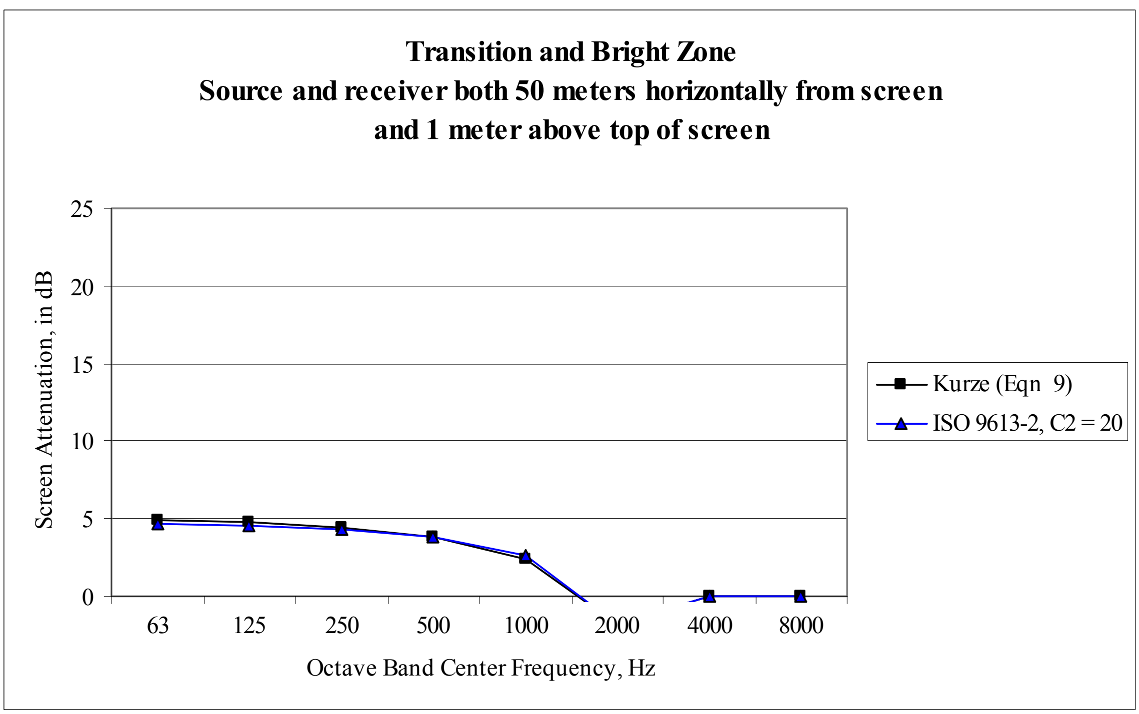


Figure 6. Modeling of Bright and Transition Zones

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The proceeding paper was authored by **Dave Parzych, Principal Acoustical Consultant and Noise Control Consultant of Power Acoustics, Inc.**

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