Audio Noise Masking Countermeasures and Voice Spectrum Analysis

Abstract

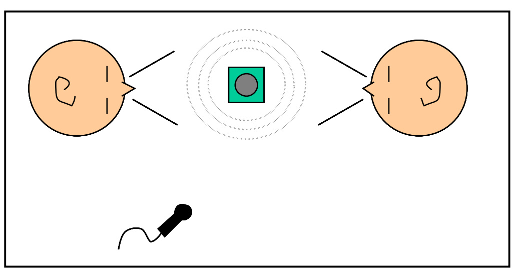
Using audio noise to mask confidential conversation and to provide a countermeasure to eavesdropping is a useful technique that has been utilized for many years; however, it is a basic technology that is often misunderstood and improperly implemented. This article is intended to provide a good understanding of the effects of voice band noise masking, and some guidance about proper implementation.

Background

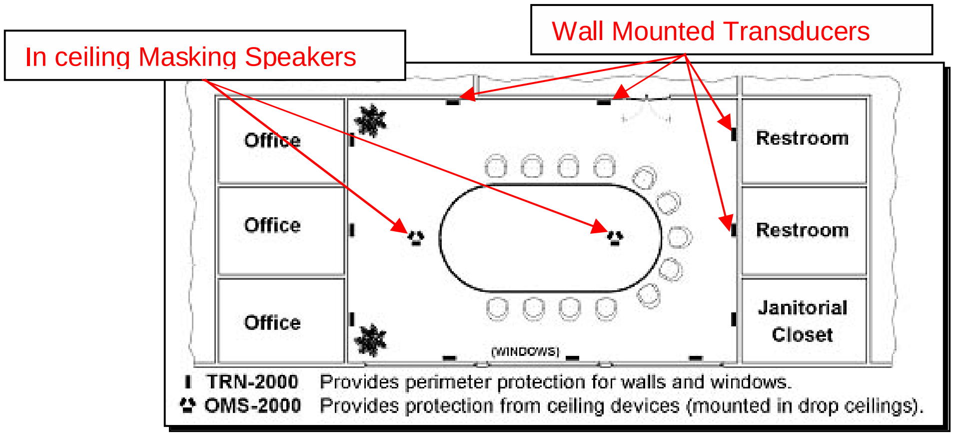
Perimeter Masking Techniques

The first important point to understanding noise masking is the simple principle that if two people can hear each other talk and there is a microphone in close proximity of the people, then the microphone can "hear" the conversation as well. Thus, Noise Masking countermeasure techniques should only be considered a perimeter function.

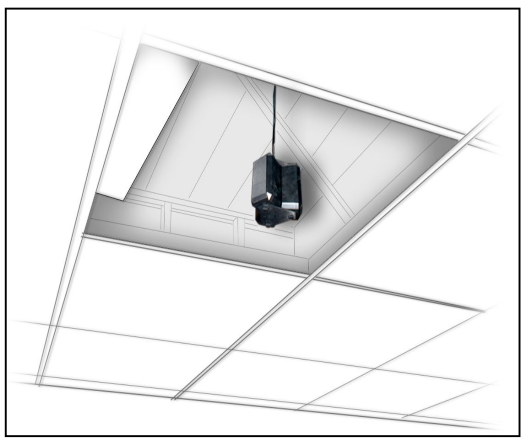
Furthermore, if two people are talking and a single noise-generating device is placed between them, it does not work well to mask the conversation. The main reason is the location of the noise-generating source. If the two people can talk above the noise and hear each other, then so will a covert microphone.



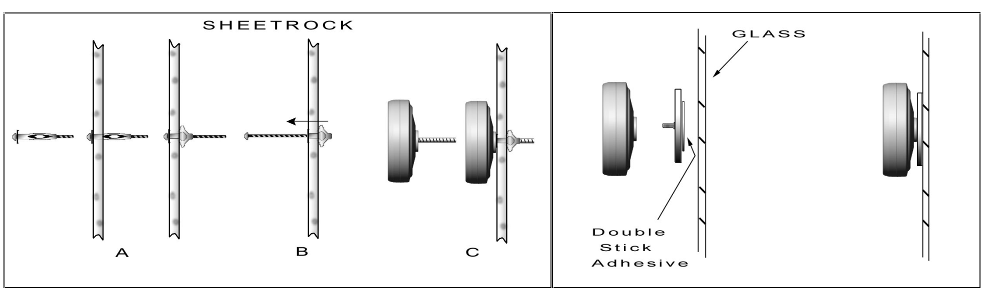
The proper method to setting up a noise masking system is to design a noise-masking perimeter so that listening devices at the edge or outside of the perimeter will have difficulty acquiring intelligible audio. The diagram below illustrates this concept in a conference room. This conference room design has noise masking transducers placed along the walls, along the glass, and noise masking speakers within the ceiling spaces. This provides an effective noise shield around the perimeter of the conference room. If the masking noise level is properly adjusted and a listening device is placed within walls or in the ceiling, then the listening device will pick-up mostly noise and potential loss of information is greatly reduced. However, if a listening device is brought into the room near the conversation area, then the perimeter noise masking system can be defeated. The pictures below provide a conceptual conference room layout and some design sketches describing an effective noise countermeasure.



Basic Design Layout



Installation of Omni-Masking Speaker (OMS) in Ceiling Plenum

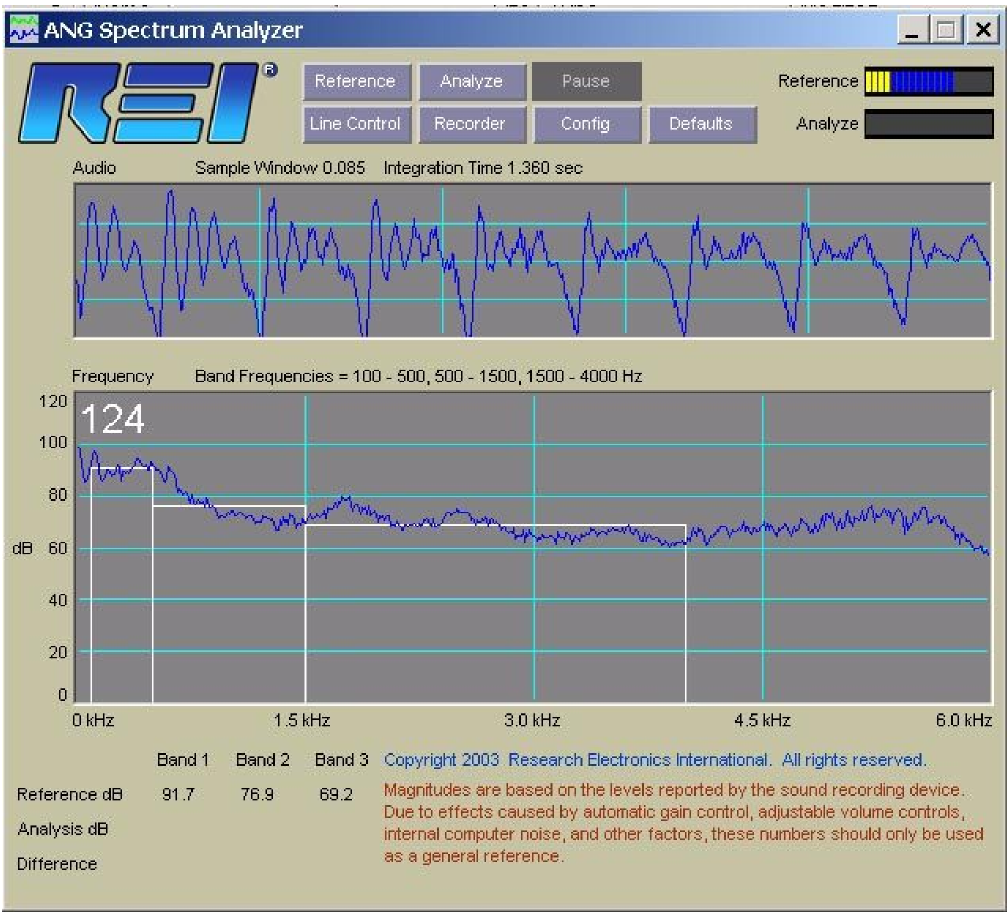


Installation of Noise Masking Transducers (TRN) on Walls and Glass

Voice band Energy Frequency Spectrum

An important consideration about noise masking is to understand the energy frequency spectrum in the human voice. This section provides some of the basic frequency considerations for noise masking system design.

The picture below is the frequency spectrum of the authors voice saying "Testing 1, 2, 3" in a normal speaking voice.



It is important to observe the following points about the above graphs.

- Most of the energy exists at lower audio frequencies.
- There are a few obvious dominant frequencies in the lower frequency range, and the energy in frequencies above 500Hz is not as well defined as the energy in the lower frequencies.
- The top graph shows the time domain and indicates some very periodic activity. But it is very hard to predict what portion of the speech is visible in the short 0.085 second sample window displayed.

There are two important characteristics to consider when understanding Noise masking.

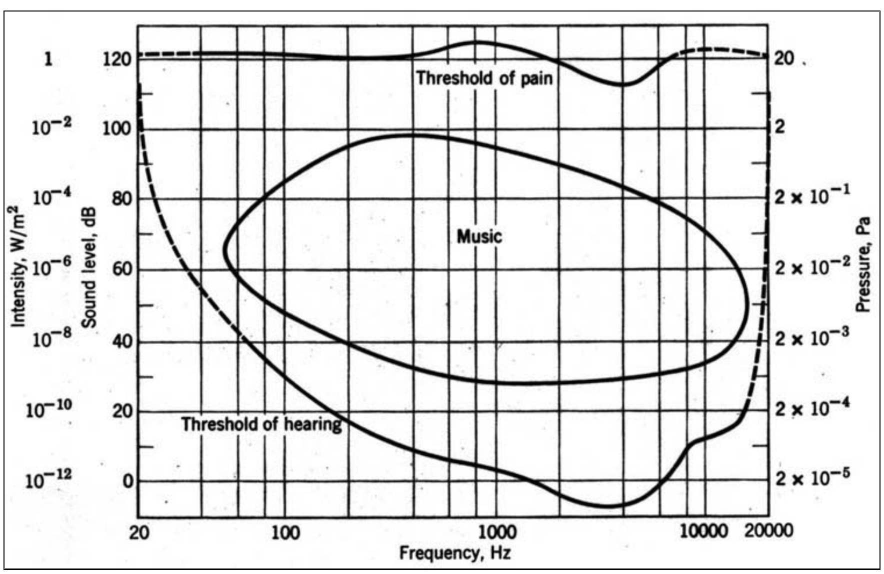
1. Most of the voice energy from an individuals voice occurs at the primary vocal frequency. This can be easily seen in the previous graphic as indicated by the spike at 124Hz in the above graph. Furthermore, this resonant energy is generally created by the speaking of the vowel sounds such as “a,e,i,o, and u”. However, while vowel sounds contain a large amount of the voice energy, these resonant sounds do not provide a lot of the energy associated with the intelligibility of the spoken word.
2. The sounds in the spoken word that affect intelligibility are more dominated by consonant sounds such as “T,K,P,D,B etc….”, and consonant sounds occur at higher frequencies. Therefore, the intelligibility of the spoken word is contained in the energy associated with higher frequency consonant sounds.

Let’s consider some basic audio frequency characteristics:

	Minimal Frequency	Maximum Frequency
Hi Fidelity Music Audio	20 Hz	15 kHz
Normal Hearing	~50 Hz	~13 kHz
Telephone Audio	300 Hz	3 kHz

In the above table, it is important to note that while much of the voice band energy exist below 300Hz, the telephone system basically ignores this energy. This works because most of the sound that affects the intelligibility of audio exists between 300 Hz and 3kHz. Furthermore, this is the accepted frequency band for most voice-band communications.

One last point is that human hearing responds in a logarithmic manner. In other words, humans hear better at higher frequencies (~1500Hz to ~6000Hz) as indicated below by the “Threshold of Hearing” curve.



Average Sound Intensities for Human Hearing
(Courtesy of Bell Telephone Laboratories)

Finally, while much of the voice band energy exists below 300Hz, the frequency range that should be masked with the greatest emphasis is above 300Hz to about 3 or 4 KHz. This conclusion is based on the normal range of voice band energy that affects the intelligibility of conversation and the human hears ability to hear at those frequency ranges.

White Noise and Pink Noise

There are systems that advertise White Noise and some that advertise Pink Noise; this section will address the difference. Another good reference article concerning White and Pink Noise can be found at:
http://www.ivie.com/pages/white_vs_masking_noise.html.
White Noise is audio noise that has equal energy per frequency. In other words, the energy frequency spectrum is basically flat. Note, since Human hearing responds in a logarithmic manner as seen in the previous graph, White noise sounds to a human as if the high frequencies are loudest. Furthermore, a common term used to describe the High Frequencies sounding louder is to say that the audio sounds "Brighter".
Pink Noise is audio noise that has equal energy per frequency octave. In other words the noise energy level decreases as frequency increases, or for example, there is the same amount of energy in each of the following frequency bands:

100 to 200 Hz
200 to 400 Hz
400 to 800 Hz
800 to 1600 Hz

Pink Noise has a frequency roll-off similar to the human hearing capability and therefore sounds less bright and richer at the lower frequencies when compared to White Noise.

The common question is this: What is the best type of noise to use as an eavesdropping countermeasure? Because Pink Noise sounds richer to the human ears, it is often used for noise masking applications in large office spaces where the goal is to create a noise level that does not necessarily to block the intelligibility of audio in an adjacent office, but the goal is to create a pleasant noise level such that the adjacent office conversations and general offices noises (keyboards, printers, foot steps, water fountain, typewriters, coffeepot, etc…) will not disturb the train of thought for everyone around. In this type of application, the goal is generally to provide a wide area diffuse sound field of masking noise.

However, if the goal is to provide an eavesdropping countermeasure, the goal is to focus on defeating intelligibility of the spoken word in the surrounding perimeter rather than simply creating a pleasant sound environment. This goal generally takes more power and sound energy in the perimeter of the protected space. Therefore, a White Noise system is more generally appropriate because energy is evenly distributed and the higher frequency components (and thus the intelligibility) of the spoken word are more greatly impacted by the energy level in a white noise system versus a pink noise system. Or an alternate approach is a

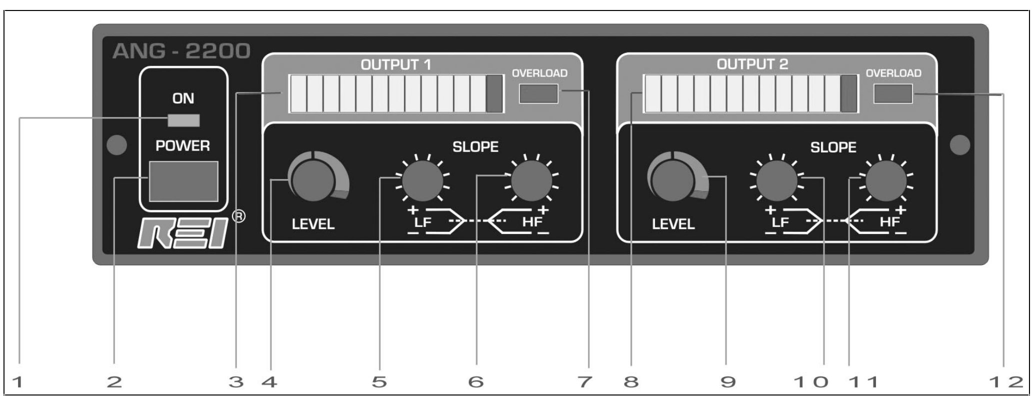
Noise Masking system in which the noise frequency spectrum is customized for the application at hand. The REI ANG system provides this capability.

Applying Noise to Perimeter Structure

As previously described, Noise Masking for Eavesdropping Countermeasures requires that the noise be injected into the surrounding structure. This can be done using transducers and speakers as previously described. But, one major problem is that regardless of the frequency response of the electronically generated noise (whether it's White or Pink), the structure in which the noise is injected will also have a major impact on the noise frequency spectrum. For example, glass is a very stiff or brittle material, which responds well to higher frequency signal while wood paneling is very flexible, and will respond much better to lower frequency noise. Therefore, regardless of the noise spectrum that is electronically generated, the noise spectrum that exists in the perimeter structure will be influenced by the physical nature of the structure. For this reason, REI has developed a noise masking system that is adaptable to various types of Structures, and REI has developed a testing procedure and software to adjust the proper noise level and frequency spectrum to the specific application.

REI ANG-2200 Noise Masking System

This section provides a very brief description of the system in general terms. For more specific detail visit the REI web-site at www.reiusa.net.
The REI ANG-2200 system provides two output channels so that levels may be adjusted for different masking structures (for example: glass windows and gypsum walls). Furthermore, the ANG system provides frequency slope control so that each channel may be independently adjusted to accommodate variation in the structural frequency response.



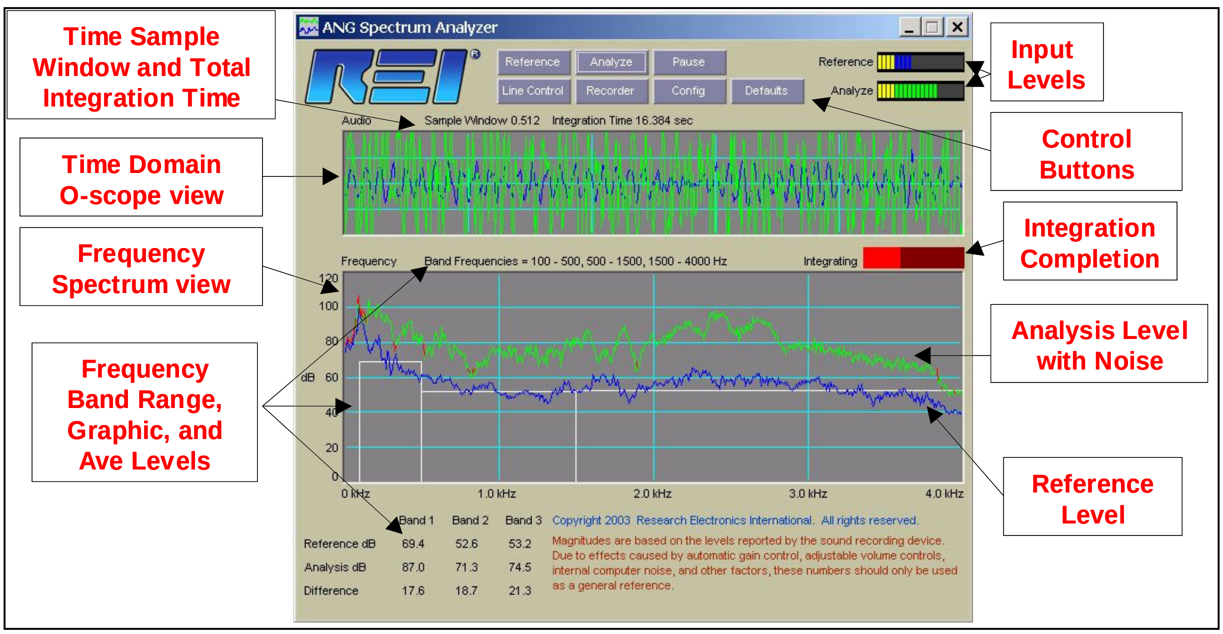
1. On Indicator
2. Power Switch
3. Level Indicator – Output 1
4. Level Control – Output 1
5. Low Frequency Control – Output 1
6. High Frequency Control – Output 1
7. Overload Indicator – Output 1
8. Level Indicator – Output 2
9. Level Control – Output 2
10. Low Frequency Control – Output 2
11. High Frequency Control – Out put 2
12. Overload Indicator – Output 2

For detailed information about designing and installing the ANG-2200 system, consult the ANG-2200 manual. This can be downloaded directly from the REI web-site if necessary.
The main approach to adjusting the level and frequency response is described in the following section.

REI Audio Spectrum Analysis Software

The purpose of the Audio Spectrum Analysis (ASA) software is to provide the capability to measure the audio being absorbed by environmental structures and then analyze and adjust the noise masking levels for an effective countermeasure. The first step is to make a reference measurement to get a baseline of the amount of noise being absorbed into the structure. Then after taking this basic measurement, the next step is to inject masking noise into the structure and use the software to measure and adjust the level for effective masking. In this manner, the ASA software provides a useful tool for customizing the ANG-2200 settings for different environments and different building materials.

Here is a basic overview of the main display Screen.



The graph at the top of the display is a time domain graph or basically an Oscilloscope view of the audio. This graph shows displays the most recent sampled time window. The graph at the bottom of the display shows the frequency spectrum. The Frequency Spectrum is generated by integrating (basically averaging) the frequency spectrum from multiple sampled windows of time. In the middle, right side of the screen there is a bargraph that is labeled “Integrating”. This bargraph indicates when the total number of sample windows has been taken to produce the integrated spectrum display. It should be noted that even after the integration is complete, the software will continue to make measurements and continuously integrate new sampled time windows. The total integration time is also indicated in the menu. The sampling and integration parameters can be adjusted as described later in this document.

During the Reference Measure integration time, the software automatically normalizes the input data from the Acoustic Leakage Probe (contact Microphone). This normalization is performed mainly for graphing purposes. It is important to note that the absolute magnitudes shown in the display are not accurate in an absolute sense. The magnitudes displayed are based on the data reported by the sound recording device in the computer (the sound card). Due to the affects of differing sound cards, automatic gain control settings, volume control settings, internal computer noise; and other factors; the ASA software should not be used for making accurate sound level measurements, however, the software provides an excellent tool for measuring relative sound levels associated with measuring audio leakage in a structure with and without injected noise masking.

Furthermore, the software breaks the spectrum into 3 frequency bands. These bands are somewhat arbitrary, but are provided to show a basic average level of masking over a desired frequency band.

The process of measuring masking levels is further described below.

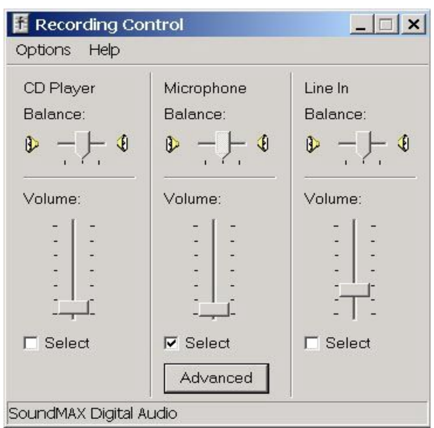
Making a Reference Measurement

The following steps should be taken to measure the Reference Audio level.

- Plug the Acoustic Leakage Probe into the proper 3.5mm jack on the computer, and place the Acoustic Leakage Probe on the desired surface to be tested. This should be done using either the suction cups or push pins provided with the Probe. It is very important to be careful with the placement of the contact microphone, and the pressure of the microphone on the surface. If the microphone is held in place by hand, the measure has error and noise is introduced due to the movement of the hand. *(Note: the ASA software can also accept audio from an external source. For example, the REI Counter Measures Amplifier (CMA) can be used as a source. In this case, the CMA contact microphone is plugged into the CMA and the CMA line-out is plugged into the computer Line In. This configuration provides a little better performance because of the quality in the CMA amplifier circuits and the CMA voice band filter.)*
- Start the ASA software, and Click on the button labeled “Line Control”. This button opens the normal windows control window to ensure that the proper input is selected. If the probe is plugged directly into the computer then the proper input is Microphone. (Note: if an alternate audio source is used such as the CMA as previously described, then the Line-Input should be selected.) Note: The input volume level should be set relatively low; this volume level may need to be adjusted again later.

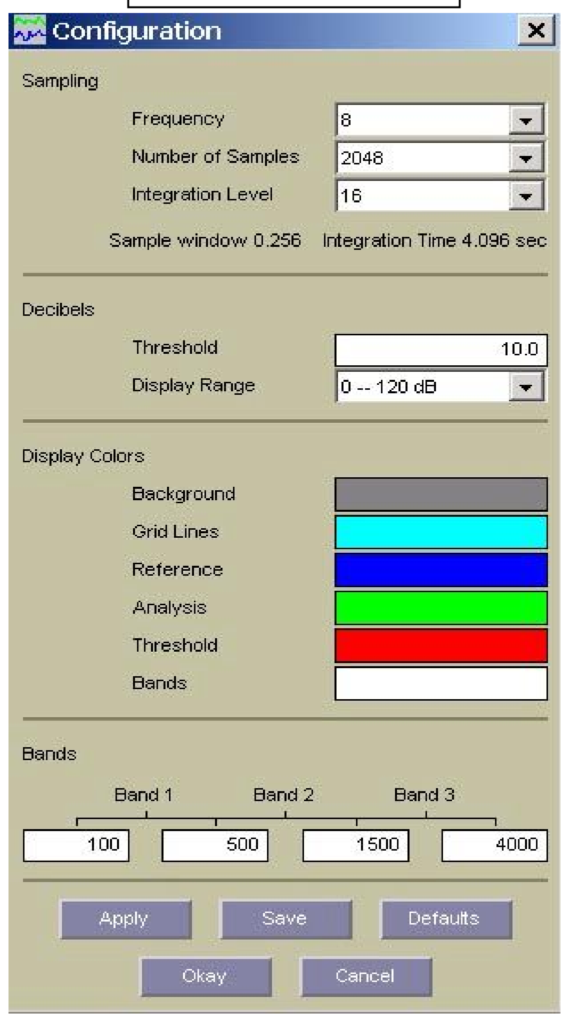
- Close the line control window or simply click on the main ASA menu and click on the button labeled “Reference”. This button turns on the audio spectrum analysis function and immediately begins displaying results from the probe. To ensure that the probe is working properly, make a known noise by clapping, whistling, singing, etc.. and visually check that the software is responding in an expected manner. Note: The reference measurement can be re-started at any time or the display can be paused by pressing the “Reference” or “Pause” button. It may be necessary to review the Sampling Parameters and other configuration parameters.
- To review and adjust these parameters, Press the “Config” Button. Note: the “Threshold” number indicates the desired level of masking. The example above indicates a 10dB masking level is desired. The software uses this number to graphical indicate the areas of the frequency spectrum where the desired masking level is achieved. There are several other parameters that can be adjusted using this menu. These settings can be saved for future analysis.
- To make sample recordings of measured audio, Click the “Recorder” button to open the default Windows audio recorder. This menu provides the capability to record WAV file examples of both the before and after (Reference vs Analysis) noise audio.

Line Control.

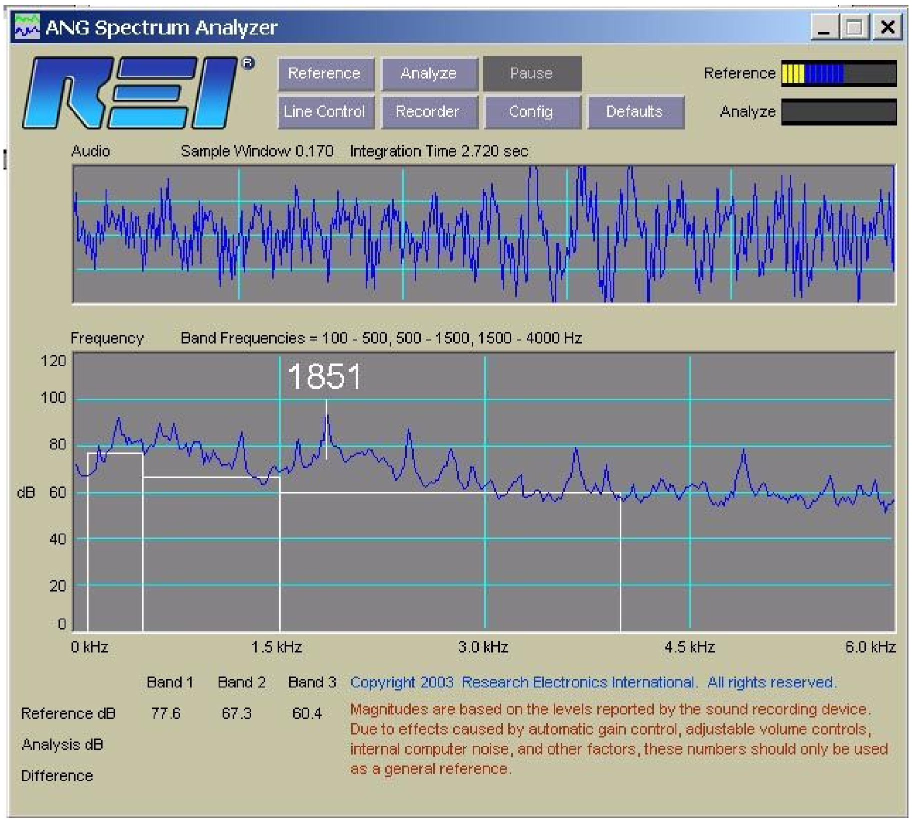


Sound Recorder

Configuration Control.



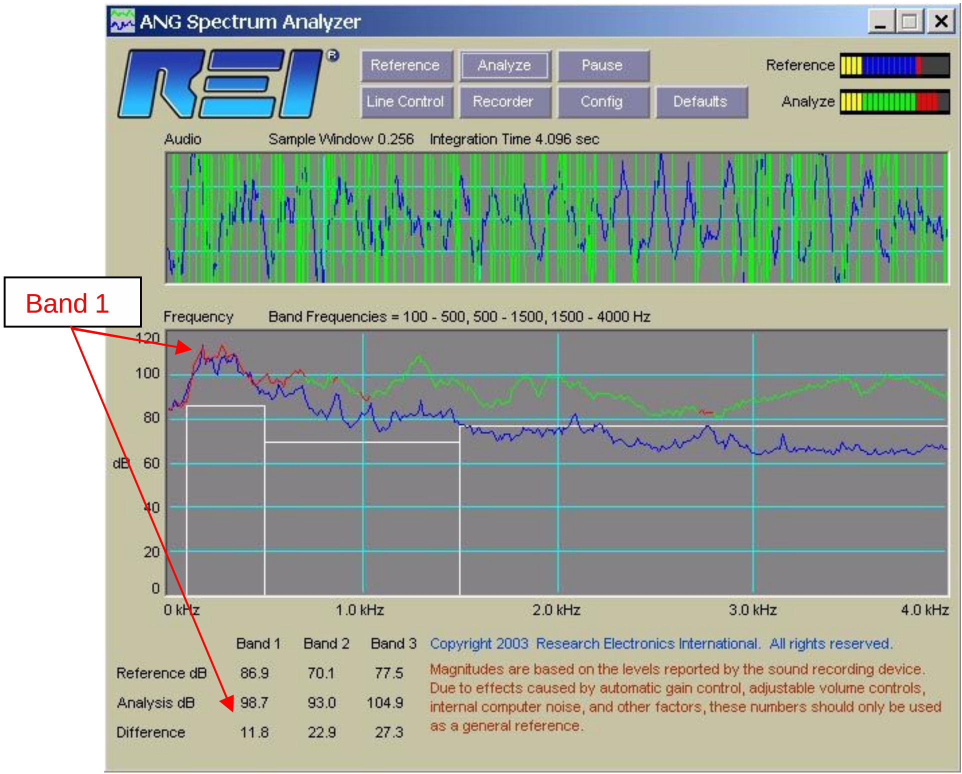
- When a satisfactory Reference measurement has been recorded, press the "Pause" button to freeze the internal settings and prepare to analyze the noise masking capability. The graphic below is a good example of a reference measurement. (Note: this example was using music as a reference source, this is indicated by the many dominant frequencies in the spectrum; human voice would not have the dominant higher frequency components displayed here.)



Analyzing and Adjusting the Noise Levels

- After the Reference measurement has been taken, the masking noise source (ANG-2200) should be activated.
- Press the Analyze button to begin the Analysis process.
- When the integration process is completed. Adjust the ANG Level control to increase or decrease the overall noise level, and use the Slope adjustment to adjust the noise to the frequency response.

Two screen shots are provided below. The first graphic shows a noise level that is very weak at the low end (Band 1) of the frequency spectrum. The second graphic shows the noise masking level after the slope of the noise frequency spectrum has been adjusted. Even in the 2nd graphic, the masking level in Band 1 appears weak in some areas, but the overall average of the noise masking level is still well above the desired level. The desired masking level of this example was set to a 20dB masking level. This 20dB masking level was accomplished using the output slope controls on the ANG.



In conclusion, the ASA software provides a useful method for setting up, testing, and calibrating a noise masking system. Furthermore, it should be noted that the concept of White Noise, Pink Noise, and blanket noise masking become very vague when considering several important facts:

- Different structural surfaces have different responses to audio. Some surfaces will respond more to high frequencies and some will respond to low frequencies, and many surfaces will have characteristic resonant frequencies.
- Many surfaces in a building will have inherent ambient noise from the building itself. This ambient noise may be due to structure born audio sources such as Traffic noise, machinery, people walking, elevators, printing machines, etc…
- When measuring noise surfaces, it is easy to introduce error. These errors may be due to many factors such as the placement of the Acoustic Leakage Probe, the method of holding the contact microphone, the inherent noise in the sound card system used to measure the noise spectrum.

The main point is that the ASA system provides an approach that is based on a differential comparison of before and after noise masking. This approach ignores the exact definition of White or Pink Noise and provides acoustic noise masking that is directly designed and calibrated for the masking application at hand.