A2555 BASS PRINCIPLES

By Richard Clark

We recently tested a loudspeaker for a manufacturer and ended up with a great opportunity to discuss the basic principles of low frequency response in a car. An understanding of how a low frequency speaker is affected when it is placed in the car can be very helpful in the design of better low frequency systems. A lot has been written about the effect the listening space has on the response of a loudspeaker but little has been published on how this applies to a car. Sometimes the information concerning loudspeakers and a home listening room can be misleading when the information is applied to car audio installations. To clear up some of these problems, let's begin with a subject that we touched upon earlier -- the subject of loudspeaker directivity.

Boundaries and Directivity

A review of the basic directivity behavior of a loudspeaker tells us that if we start with a loudspeaker in a box suspended in air (Figure 1) at wavelengths that are large (relative to the box size) the dispersion pattern of the speaker will be basically omni directional. Since we are only interested in the behavior of woofers, we are going to limit our consideration to low frequencies -- after all that is what woofers are for.

If we take that same woofer and enclosure and mount it flush in a large wall (Figure 2), the SPL will increase. The increase in SPL is because the total energy that was once radiating into a complete sphere has now been concentrated into half the space. At higher frequencies (where the wavelengths are short relative to the size of the speaker) this will result in an SPL increase of 3 dB -- a doubling of power. However, at lower frequencies this increase can be as much as 6 dB provided the dimensions of the boundary are large relative to the wavelength.

This large boundary causes a doubling of pressure (not power). This doubling of pressure at the long, in phase wavelengths is what gives us an increase of 6 dB. If another boundary is added (Figure 3), we will see an additional increase of 3 dB. Once again, however, if the boundary is sufficiently large, we can see as much as 6 dB. This would bring the total SPL increase to 12 dB.

Now adding yet another boundary (we're up to three now, see Figure 4) can add another 3 to 6 dB over our existing value. This is analogous to putting a speaker in the corner of a room. Anyone who has ever experimented with loudspeaker placement in a room quickly learns about the 9 to 18 dB of "free" bass that can result from corner placement.

What About Cars?

There are not many technical books published on the subject of bass in cars. We know that most car audio enthusiasts are eager for technical information on this subject. Often they turn to the best sources available for information - home and pro-audio books and articles. Sometimes this type of information can be used in car audio and sometimes it can't.

One of these "can't" times occur with the subject of corner or boundary loading of woofers. Although everything we have discussed so far is totally applicable in a home environment, it is not so in a car. This has led quite a number of people to a mistaken understanding of woofer behavior in a car. To understand this difference, consider the dimensions of a typical home listening room. In order for us to have wave behavior in an environment, there must be a space large enough to support the wave. There must also be a medium for that wave to travel in -- in this case air.

Whenever the longest dimension of a space is smaller than a complete wavelength, placing a loudspeaker in that environment and causing it to move at that rate will result in nothing more than an alternating pressure change in that space. The propagation is such that the pressure is equalized in the entire environment by the displacement change in the transducer. Only when the velocity of the speaker movement is increased to a point where the rate of change is faster than the propagation through the environment can we have a wave.

Pressure Zones With No Waves

It is easy to see that the dimensions of the space determine the actual frequency where this occurs. This phenomenon is fully in effect when the longest dimension of the space is equal to 1/2 wavelength. Below this frequency the entire space is a pressure zone. The pressure in this zone is no different than the pressure in any other vessel resulting from a displacement change. This means it will be the same everywhere in the space. The pressure distribution would be no different than that in a balloon -- equal at all points.

What does this mean to our speaker?

1) Unless we can factor the car into our calculations, our computer frequency response simulations are going to be totally wrong.
2) At the wavelengths we are interested in, there are no corners in cars, only a large pressure zone. Compared to the wavelengths produced, below 100 Hz the boundaries are just too confining for it to be any other way.
3) The response of the speaker is not going to be different (at low frequencies) due to different placements.
4) If we are inside this listening space, then we will not be able to localize the source of the pressure because there will be essentially no pressure differential (excluding harmonics) between our two ears.

What Does This Mean?

To see the result of these four facts, let's examine some measurements. A small-ported box (0.28 cubic feet) loudspeaker measured outside of a car can be seen in Figure 5. Notice that the response is similar to what we would expect from a simple ported enclosure. The speaker was low-pass filtered at 120 Hz. The actual computer simulation of this speaker was run on TermPro and the simulation bears close resemblance to the actual measured response as shown in Figure 6. The 120 Hz low-pass filter was not part of this simulation. Notice that the response of both graphs starts to roll off rapidly below 80 Hz.

Figure 7 shows the result of placing this speaker inside a sealed car. Notice the tremendous increase in low frequency response below 80 Hz when compared to the computer simulation and the out of car response. This response increase is a result of two factors. Pressure loading from the car concentrates the energy from the speaker into a small-enclosed space. The increase is even higher than what we would expect from corner loading. Second, this higher pressure causes an increase in radiation resistance that actually makes the speaker more efficient. This effect is not that great so we will not concentrate greatly on it.

What happens if we move the speaker to other locations? For the next few measurements we kept the microphone in the same location and moved only the speaker. Notice that only minor variations resulted from moving the speaker. There are some small differences, which are generally at higher frequencies (above 60 Hz) where some modal behavior starts to occur as the wavelengths become shorter.

How audible would these differences be? It can be seen that the peaks and dips that occur between 60 and 120 Hz are all about 1/3 or less of an octave wide. For example, on some measurements there is a dip between 60 and 80 Hz, on others there is a peak between 50 and 60 Hz. One-third octave represents a critical bandwidth. This means that when we listen to the overall response, our brain will integrate the total energy into a curve that contains the points that represent the average energy in each 1/3 octave. So eight data points (20, 25, 31, 40, 50, 63, 80, 100, and 125 Hz) would be used and a line that best fit these points would represent the way we hear the response. This curve is known to mathematicians as a "least squares fit" (LSF). An approximate LSF curve has been drawn as a dotted line through the curves in Figures 14 and 15. Notice that the overall LSF curves do not vary from each other by more than 2 dB. By looking at the LSF represented by all of the previous measurements it can be seen that the low frequency response (below 80 Hz) in a car is not going to vary with box location more than a minor amount. This does not mean that different locations will not produce higher or lower subjective boom between 80 and 200 Hz. This is the range where modal variations begin to occur because the wavelengths start to become small relative to the car size. The varying pressure modes are independent of speaker location and are determined by the size and shape of the interior. If the speaker is located where it radiates into a high-pressure mode, it will be more efficient than if it is placed in a low-pressure mode. Normally, we don't care about woofer response above 80 Hz, and are not concerned with this phenomenon.

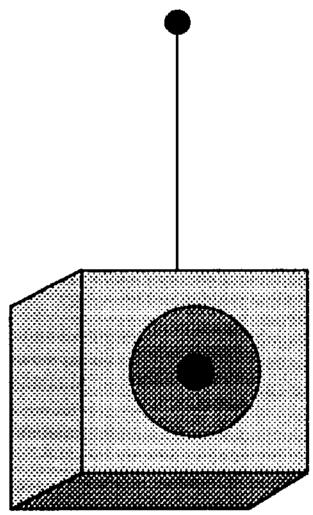


Figure 1: An enclosed speaker radiating into free space

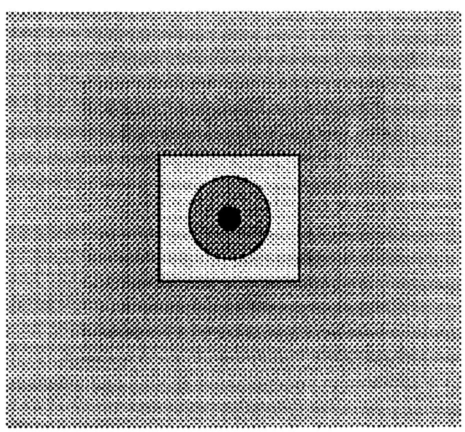


Figure 2: Speaker radiating into half-space (+6 dB)

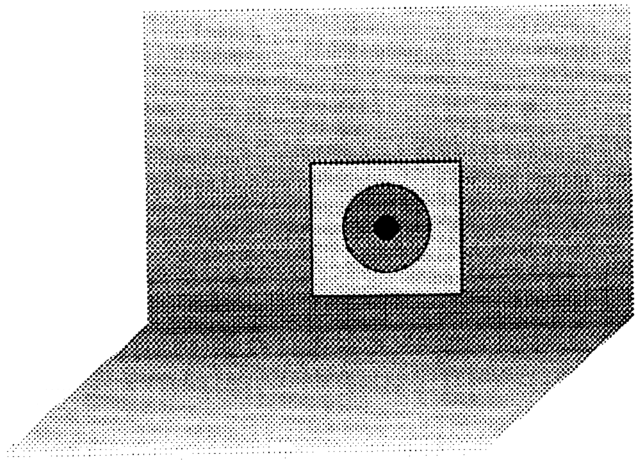


Figure 3: Speaker radiating into quarter space (+12 dB)

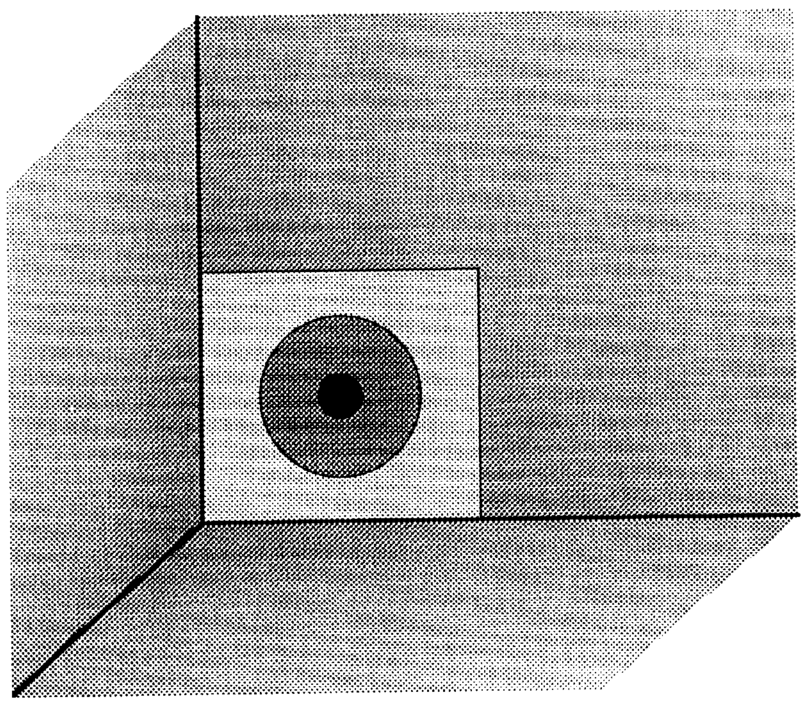


Figure 4: Speaker radiating into eighth space (+18 dB)

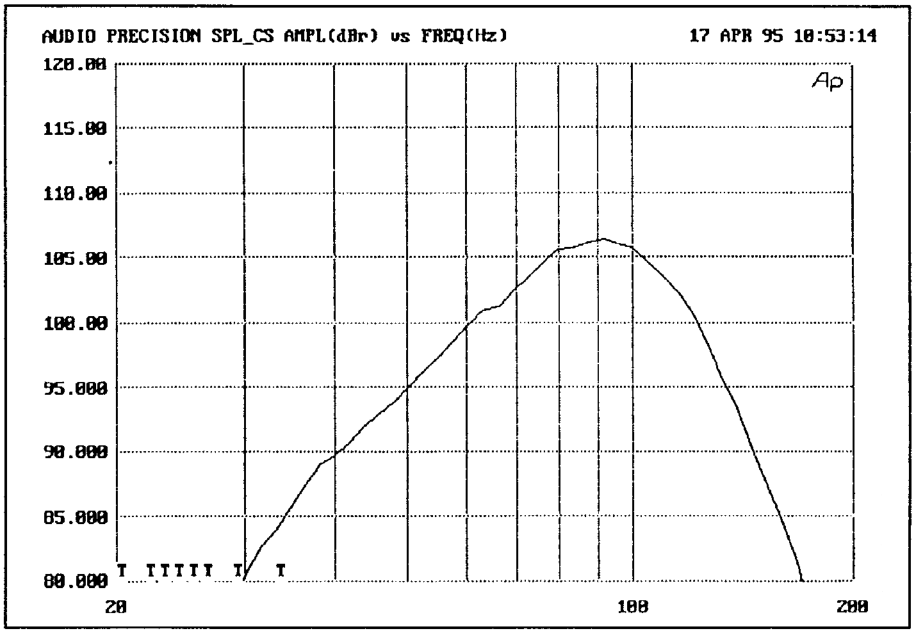


Figure 5: Small ported box measured outside of a car

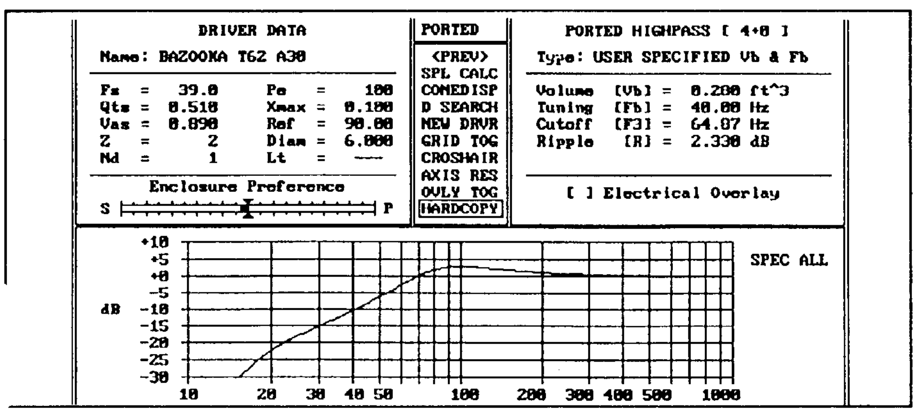


Figure 6: Computer simulation of loudspeaker measured in Figure 5

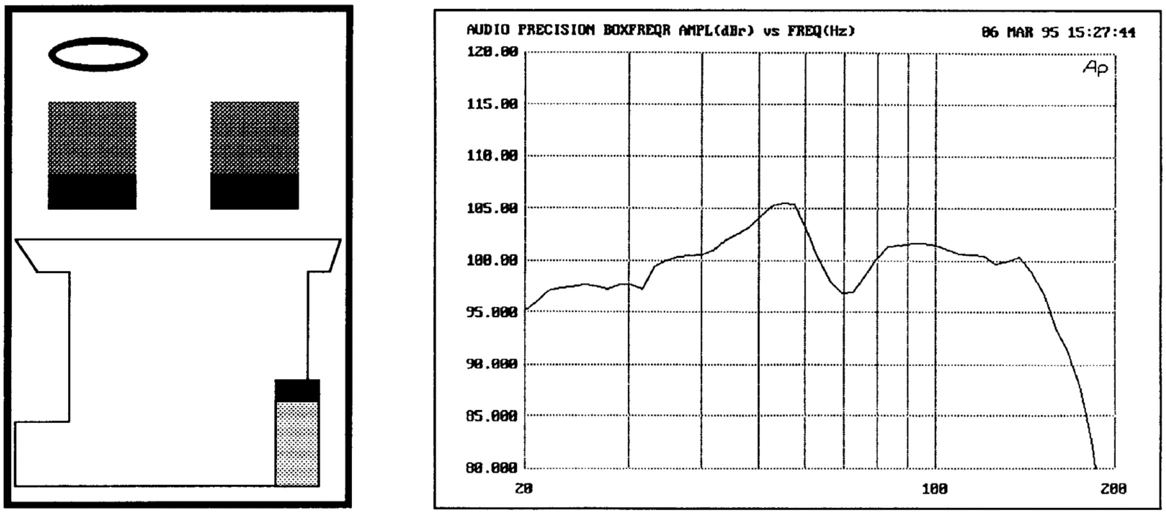


Figure 7

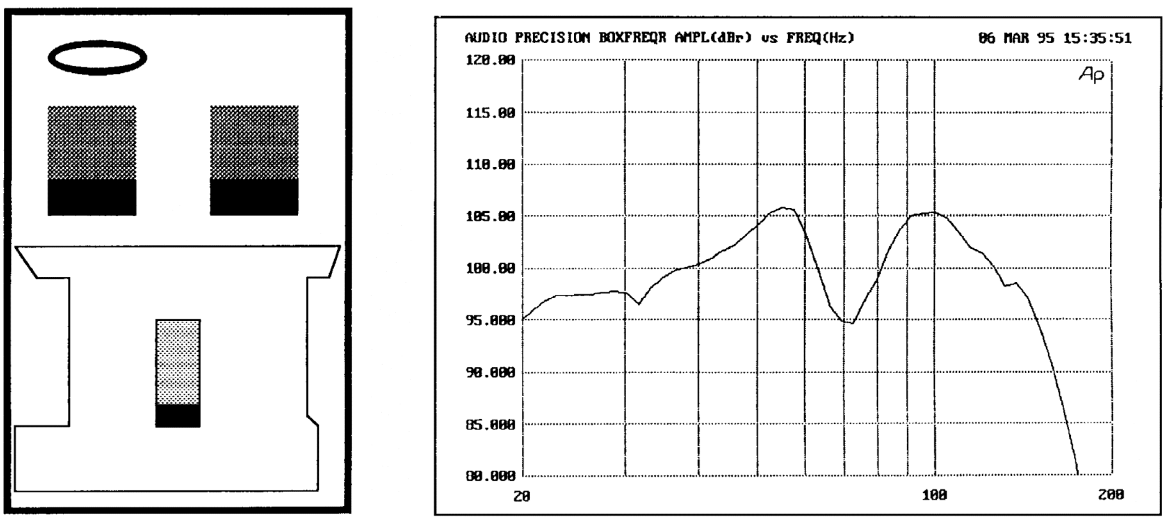


Figure 8

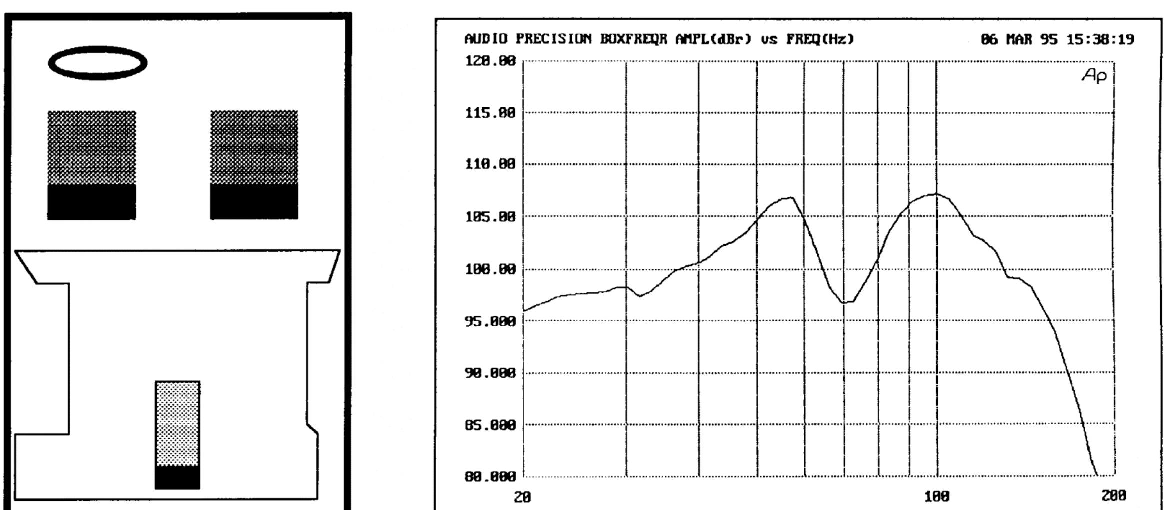


Figure 9

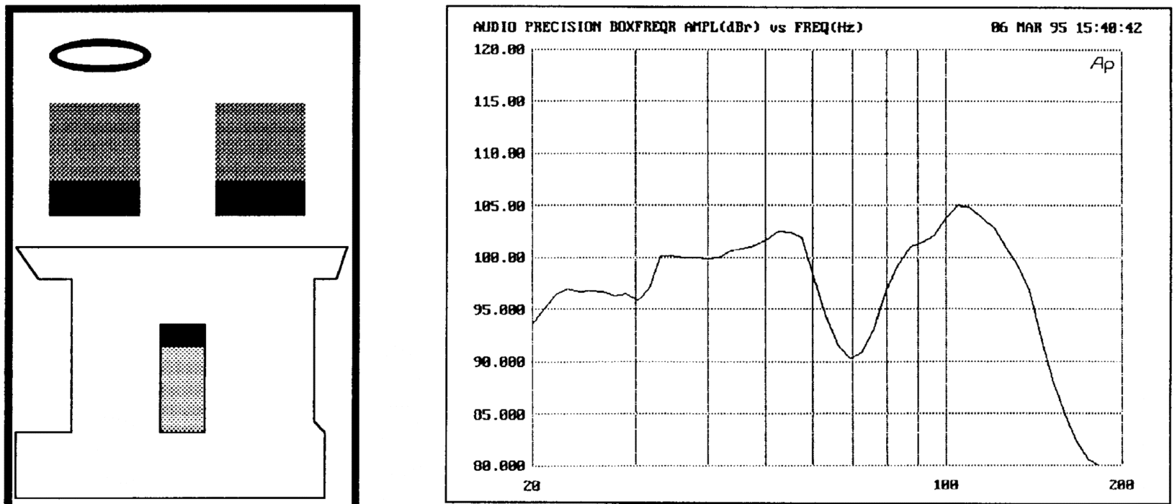


Figure 10

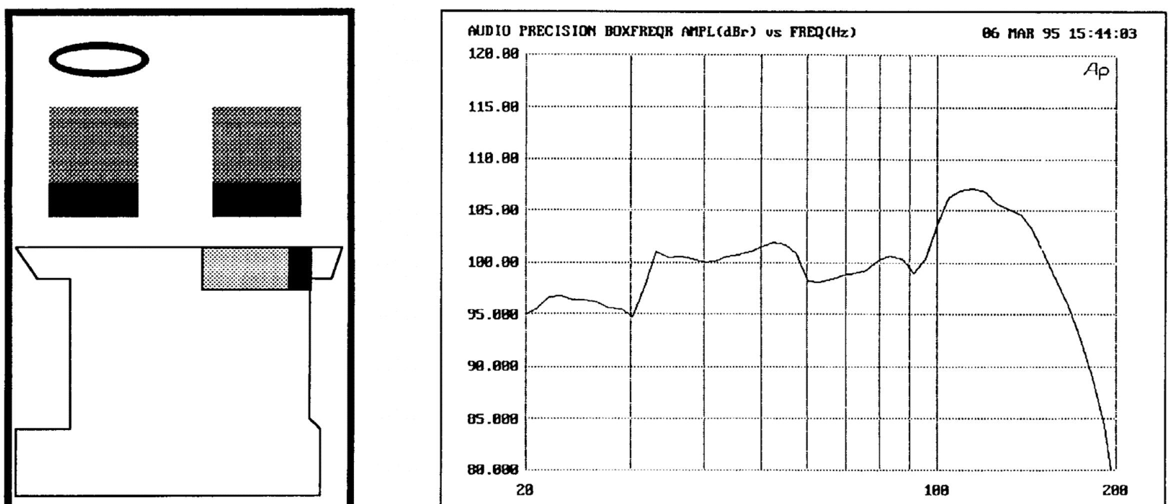


Figure 11

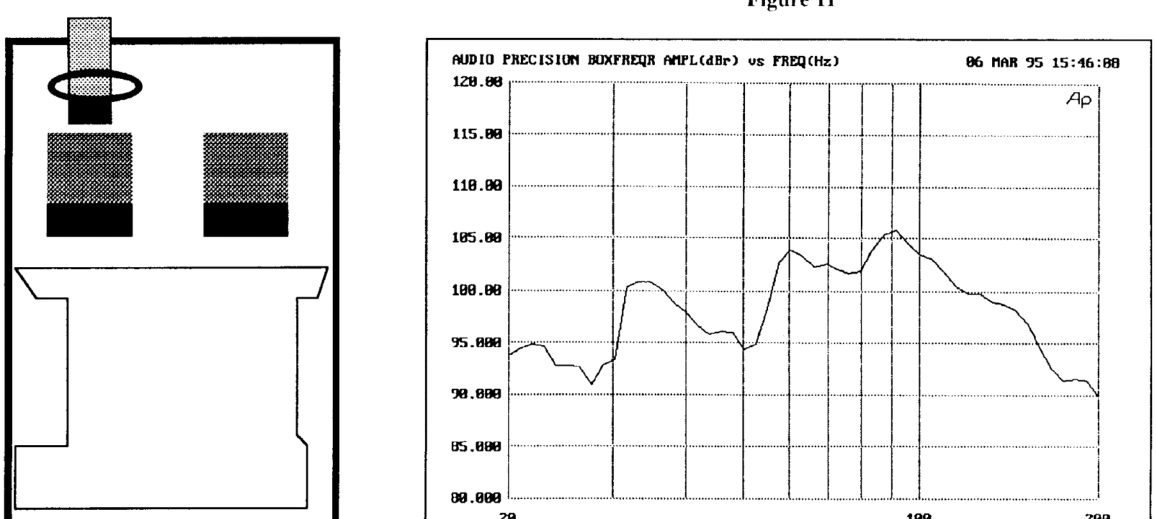
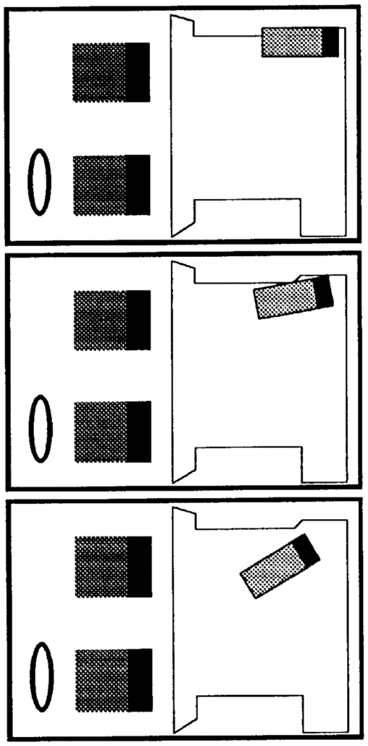


Figure 12



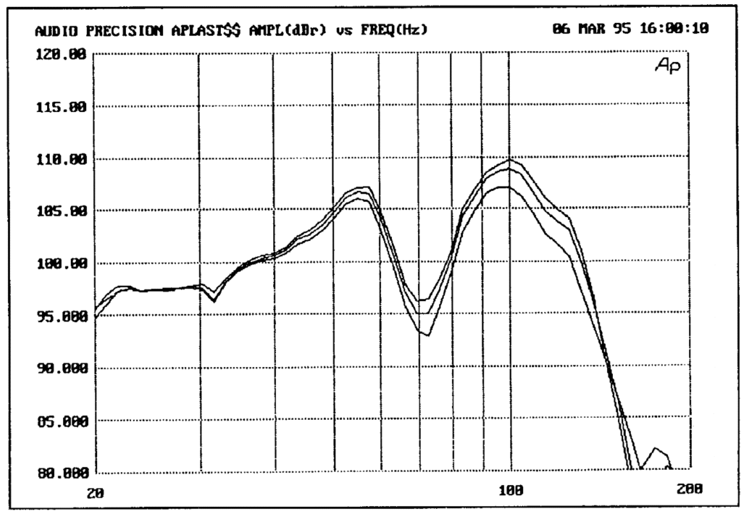


Figure 13

Figure 13: All three loudspeaker locations on the left are shown in the curves above.

Figures 14 and 15: The graphs below show the Least Squares Fit of two responses with the widest variation

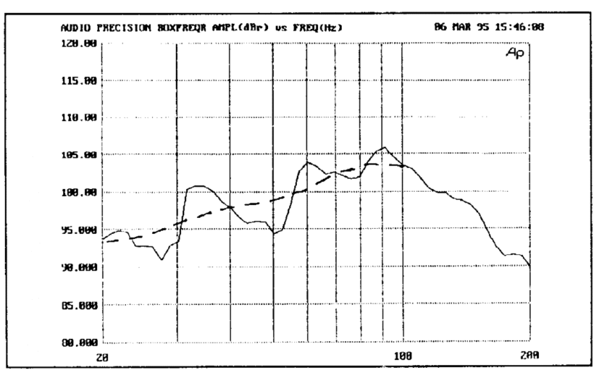


Figure 14

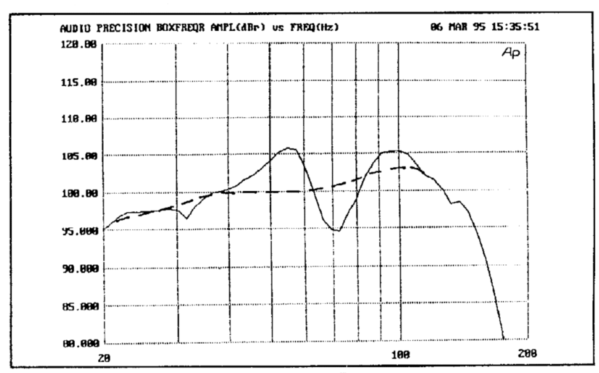


Figure 15