By Kevin Bennett, President Integral Audio
kevin.bennett@integralaudio.com

Car Audio 101: Proper Subwoofer Design

Adding a subwoofer is one of the most common car audio upgrades. It is also one of the most misunderstood, and most poorly executed. Look through any aftermarket audio catalog or website, and you get the impression that all you need to do is build or buy an enclosure, put any woofer you like in it, and call it done. If your goal is accurate sound, it will take quite a bit more than that. Proper subwoofer design must account for the listening room (the cabin of the MINI), the actual woofer enclosure, and the speaker itself. Each of these three things is a critical element of the total system. Changing any of the three elements changes the system.

The listening room—in this case the vehicle cabin—has a tremendous influence on the low frequency response of a system. The behavior of reflected sound in a room can be divided into two broad groupings—at higher frequencies it can best be described by ray theory, and at lower frequencies acts according to wave theory. The division point between the two is called the Schroeder (or transition) frequency, and is determined primarily by the size of the listening room. As the wavelength of sound begins to approach or exceed the dimensions of the room, the behavior changes (for reference, the wavelength of 1kHz sound is about 1ft, 200Hz is about 5ft, and 20Hz is about 50ft). As the wavelength begins to exceed the room dimensions the wave can no longer fully form and begins to be reflected back into the room, interacting with itself. I'm going to skip the physics and just give you the upshot, which is this: below the transition frequency, low frequencies start to get a boost that increases as frequency decreases. This is called cavity effect, also commonly known as cabin gain. The transition frequency, and the shape and slope (amount) of the cabin gain, are all determined by the size and shape of the listening room. Generally speaking, the smaller the room the higher the transition frequency and the greater the amount of cabin gain. In most vehicles the transition frequency is around 250-350Hz, and the amount of gain ranges from 3-12dB/octave. The exact shape of the cabin gain curve for a vehicle is called its transfer function. This transfer function will vary dramatically from one vehicle to the next. Take a look at *Figure 1*. The red line is the transfer function of a small hatchback, and the blue is of a sedan. Both start a general trend upwards at around 300Hz, but the total gain is much greater in the small hatchback—nearly 30dB at 20Hz. The hatchback transfer function is also much more uneven—the peak at 80Hz and the null at 60Hz are related to the specific dimensions of the vehicle. What does this mean? Well, if you want flat frequency response Vehicle A is going to require a very different subwoofer from Vehicle B. It also means that if you tried to use the subwoofer from Vehicle A in Vehicle B, the frequency response would change by the difference between the red and blue curves. So a subwoofer with good response in Vehicle A would have a 15dB hole at 60Hz in Vehicle B.

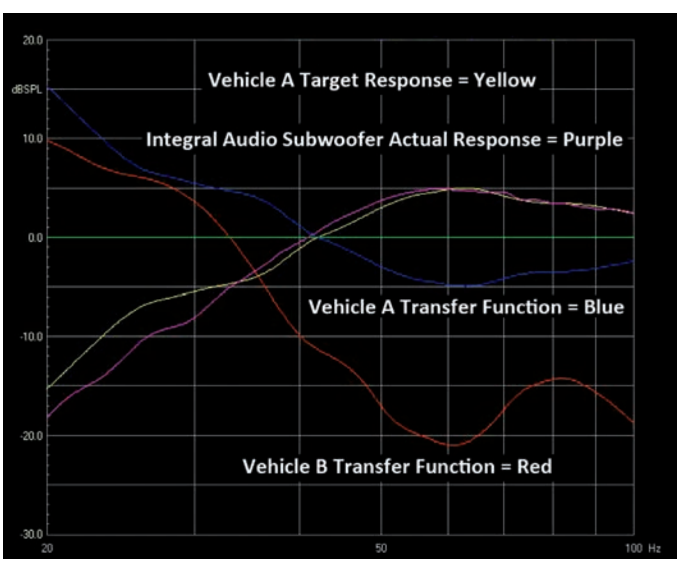

Figure 1: Transfer Function & Ideal Response

A speaker is a complex electro-mechanical device, and one model of speaker will behave completely differently from another. The physical and electrical properties of the speaker—the size and weight of the cone, the stiffness of the suspension, the strength of the magnet, the amount and placement of wire in the voice coil/gap, among other things—all determine how the speaker behaves. These properties—quantified as Thiele/Small parameters—are what determine how a particular speaker will sound in an enclosure. The enclosure is a critical part of this. Change the size of the enclosure, and you change the response of the speaker/enclosure system. This is because the amount of air in the enclosure acts as a major element of the speaker's suspension. In a smaller enclosure, the reduced amount of air compresses faster and begins to exert a restorative force pushing back on the woofer sooner, essentially becoming a more "springy" suspension. The opposite is true of a larger enclosure. Take a look at *Figure 2*. This is the modeled response of a subwoofer in an enclosure. The speaker is the same in all three examples—only the enclosure size was changed. As you can see, changes in enclosure size have a tremendous effect on the frequency response. They also have an equally significant effect on the character of the sound.

What you're probably already noticing is that the frequency responses of the speaker/enclosure systems from *Figure 2* are shaped roughly opposite that of the vehicle transfer functions from *Figure 1*. The key to getting flat low-frequency response is to create a speaker/enclosure system that has the exact inverse response of the vehicle's transfer function. Take another look at *Figure 1*. The yellow line is the calculated inverse of the blue line (Vehicle A's transfer function). This yellow line is the ideal

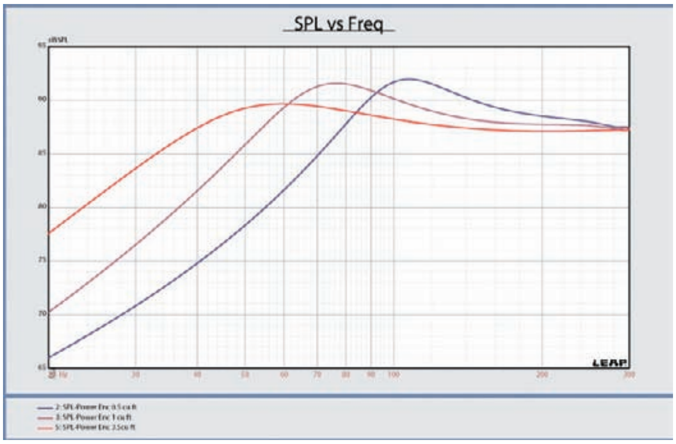

Figure 2: Frequency Response of Different Enclosure Sizes

target response for a subwoofer for Vehicle A—it is the response that, when added to the vehicle's transfer function, will yield a perfectly flat response. The purple line is the actual measured acoustic response of the subwoofer we designed for the vehicle. Look how closely the actual subwoofer response tracks the ideal response [remember that for a subwoofer we are only interested in the area below 100Hz].

Now that you know all this, how can it help you? I'll be honest here—without sophisticated measurement tools and expertise you aren't going to be able to achieve results like the above on your own. Accurately measuring the vehicle's transfer function is extremely difficult. We do it using our own proprietary method and software that we've developed. We also have the ability to change the speaker parameters, whereas, the general aftermarket is limited to off-the-shelf drivers. But if you have some technical skills and a desire to DIY, you can certainly do better than the car audio shop down the road, which likely don't know their elbow from a transfer function. There are lots of free and low-cost tools like WinISD, Liberty Audiosuite, and ARTA, to name a few, that you can use to help you get a rough measure of your vehicle's transfer function and model speaker/enclosure response [Tip: take multiple measurements and average them or your results won't make sense]. Unless you are a very experienced hobbyist, however, you may not want to mess with them. All too often I see folks who have been lulled into a false sense of security by the impressively-precise looking output of the tools, and never realize that they've made an error somewhere along the way. So where does that leave everyone else? When at all possible, listen to a subwoofer system in your vehicle before deciding. Check for significant problems by listening with a test tone disk: with the volume at a fixed-level, start at 20Hz and go up, listening for relative changes in volume from one frequency to the next. Even making a chart of the relative perceived differences can give you a rough approximation of the graphs above. If you are getting too much low frequency response try a smaller enclosure, and vice versa.

(*Ed:* Kevin Bennett is President of Integral Audio, a leading audio company where he oversees all R&D and engineering of their acoustically-tailored, vehicle-specific audio systems. If you have question, you can reach him at kevin.bennett@integralaudio.com) ■