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The Effect of Car Acoustics on Automobile Sound Systems - the Problem and a Solution

by

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People are paying more attention and money for quality sound in their cars. For many commuters, a car stereo is an important part of their daily routine. In terms of listening time, they listen to their car system almost as much as they do their home stereo system.

It's no secret that as a listening environment, the car is less than ideal. It's also no secret that an equalizer can go a long way towards making any sound system more listenable. For several years, accessory equalizers have been available for autosound, however, these have almost universally been sold as fancy tone controls.

Recently, a few manufacturers have been looking at the problem of audio reproduction in automobiles from a system standpoint. That is, they are considering each element of a "car stereo" as one element of a system, and applying system engineering principles towards optimizing the performance of that system in the automotive environment.

The Delco-Bose System

The first system available to the public was made by Delco and Bose (Delco of car radio fame, and Bose of loudspeaker fame). They looked at the problem from an engineering standpoint, and engineered a system that precisely met its design goals. They designed each element in the system to do a specific job, and to do that job well. Then they looked at the acoustical environment existing within the automobile body and optimized the overall performance of the sound system for that environment. Their secret weapons: adequate power and careful equalization.

Statement of the Problem

Here is the problem:

- For all intents and purposes, the listener is "within" the enclosure.
- The listener's location is fairly static.
- The placement of reflecting surfaces and absorptive surfaces is haphazard from an audio standpoint.
- The ambient noise level is fairly high.
- The spectrum of the ambient noise level is not flat.
- People who sit in the front want to be able to hear, without having the people in the rear deafened, and vice versa.
- The choice of mounting locations for loudspeakers is somewhat limited, as is the amount of available space.
- The automobile was designed as a means of transportation first, and as a listening environment last.

The Automobile as a Listening Environment

As a listening environment, the insides of a car leave a lot to be desired. Aside from the limited space, loudspeakers need to be mounted where there is space available first and second where they can be heard. Typically this is in door panels, or in the rear deck, with the interior of the trunk used as a more or less infinite baffle.

The acoustics of a door panel can vary widely, from the rather tinny doors used on less expensive models (they sound like a tin can when you slam them), to the heavy, more mechanically sound ones used on more expensive models. The quality of the door makes a difference, because the door forms the enclosure. In any enclosure (or listening environment for that matter), it's good practice to make the walls as rigid as possible. This helps remove cabinet resonances from the design process. In a flimsy door, the enclosure might actually disappear acoustically at the frequency where the door skin resonates (the door becomes a diaphragmatic absorber).

Next, consider the problem of the ambient noise level present in the car. Figure 1 shows the interior of a typical car, at freeway speeds as viewed on a spectrum analyzer. Notice the rather high noise level at the low frequencies as compared to the higher frequencies. If you want to listen to music in that environment, you'll need a fair amount of low frequency boost just to overcome the ambient noise level.

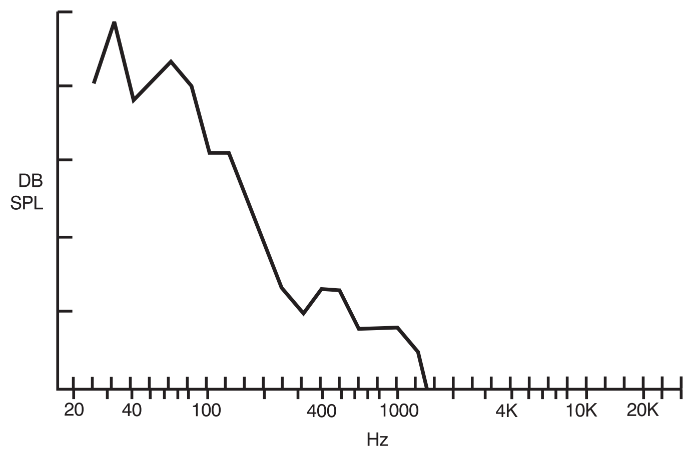

Fig. 1 The 1/3 octave response plot of road noise data for a typical car.

Finally, consider the interface of the installed speakers with the interior of the car. Peaks in the overall response curve can occur when a reflecting surface occurs at odd fractions of a wavelength. Another peak occurs at the resonance of the interior. Of course, the speakers are probably anything but flat and furthermore, the two sets of speakers used probably don't have identical frequency response curves.

Equalization as a Solution

Although the situation in most home or studio environments is not nearly as extreme as that within a car, a good many world-class studios and sophisticated home systems use carefully applied equalization. Here the equalizer provides a means of fitting the speaker into the environment, much like the final voicing that a pipe organ undergoes when it is finally installed. In recording facilities that have multiple studios, equalization provides a means for making the rooms sound alike; this provides a more consistent acoustical environment for the recording engineer.

You might say, "My speakers are first-rate, they don't need an equalizer." In some cases, that is true but for the most part, it's a bold statement to make. At home, you have the option of changing the placement of the speakers within the room to vary the bass response. You can alter the treble response to some degree by altering the amount of high-frequency absorption within the room, or by changing the settings of the speaker's mid- or high-frequency balance controls.

In a car, the positions of the speakers are limited, and most installers can't afford to try more than a couple of different positions within the car. If you're an installer, how many times can you afford to replace the door panels or the rear deck panel if the sound isn't quite right? You could add some high-frequency absorption (say...some extra cushions), but they would probably end up in the trunk the first time that the car was used to carry passengers. Last, how many car speakers have high-frequency balance controls?

In most home stereo systems, the supplied bass and treble controls are sufficient for most user-preference adjustments. This is due, in part, to the predictability of an average speaker system in an average living room. In many auto systems, the bass and treble controls provided on the head unit aren't even sufficient to overcome the shortcomings of the installation!

Some autosound installers have even taken to tinkering with the crossover network by adjusting the actual crossover frequencies in an attempt to even out the overall response curve. While there is some merit in this technique, the primary purpose of the crossover network is to keep the individual drivers operating within their optimum frequency ranges.

A user accessible equalizer is the usual solution towards overcoming some of the shortcomings of the automotive environment. Within limits, it's an effective one. Unfortunately, the amount of equalization needed by most installations almost negates the equalizer's usefulness, once you've adjusted it to get the overall frequency response to something resembling high fidelity. Furthermore, there is usually no way to adjust each channel independently. Last, after you've done this, there isn't an easy way for the listener to return to this starting point, unless you physically mark each control setting on the equalizer.

Bi-amplified systems have a slight advantage in this discussion. Typically you can adjust the level of the high-frequency channel in relation to the low-frequency channel (just like at home). If the crossover point is low enough, then you can fudge the crossover point to occur at the usual 200hz buildup that occurs in most vehicles. This can be a real bonus in just getting the system into the acoustical ballpark.

A Solution

Part of the success in the Delco-Bose as well as the Ford-JBL systems is careful equalization of each speaker, measured from several reference positions inside the car. This equalization varies from model to model...thus you'd expect to find quite different equalization requirements for a Corvette as opposed to a Cadillac. In all of these systems, the equalization brings the overall performance of the total system to a standardized reference point, leaving the full range of the tone controls for the owner's personal taste. That is the ultimate benefit of customized equalization.

Here's an idea! Let's use two equalizers and set one of them to overcome the lousy acoustics, and leave the other for the listener to twiddle. When the listener got tired of twiddling, they could just park the knobs back in the middle, and get the same sound that the installer got when he finished the install.

The folks at AudioControl and at least one other company have developed equalizers specifically aimed at providing a solution for this problem (especially applicable if your car isn't a new GM or Ford product). These unique products provide the controls that are needed to really coax a car system into line.

Voicing Technique

Once the system is mechanically and electrically installed, it's time to begin the voicing process. Some folks like to call this tuning but I prefer the term voicing because what we're doing is altering the overall sound of the loudspeaker system to help it:

- Fit into its acoustical surroundings better.
- Accommodate the owner's personal taste.
- Integrate the electronic components of the system.

Essentially what we have to do here is to measure the frequency response of the installed system. Then we'll make the necessary corrections using an equalizer. The net result is a sound system having smooth frequency response, with carefully applied shaping to overcome the limitations of the environment. The simplest way to do this is to use pink noise and a real-time spectrum analyzer.

A real-time spectrum analyzer or RTA looks at the audio spectrum in a series of constant-bandwidth chunks and displays the result on a number of bar graph displays. Each vertical row of the display represents the level of signal strength in that portion of the spectrum. Commercially available RTAs measure the audio spectrum in 1, 1/2 or 1/3 octave bandwidths. Octave-band RTAs are commonly available for the home stereo market but they lack the resolution to really show you what is happening, especially between the bands of the equalizer.

White noise (sounds vaguely like the noise you hear on your FM tuner between stations) has equal energy per cycle. For example, the region between 20 and 40Hz has 20 cycles of noise, whereas the region between 10kHz and 20kHz has 10,000 cycles of noise. When viewed on an RTA, white noise has a rising frequency response characteristic (rises at 3dB/octave). Pink noise is white noise that has been filtered to undo the rising frequency response characteristic. It has equal energy per octave. When connected to an RTA, the output of a good pink noise generator looks like a straight line on the RTA display.

For acoustical measurements, the combination of pink noise and an RTA make a powerful measurement tool. Here's what we do:

1. Connect the output of the pink noise source to the amplifier input or use a calibrated pink noise tape.
2. Connect a known flat-response microphone to the input of the RTA.
3. Adjust the output of the amplifier so that the average sound level in the space to be measured is at least 6dB above the ambient (background) noise level.
4. Place the microphone at the listening position.
5. Observe the display of the RTA.

The RTA's display now represents the overall frequency response, measured at the microphone position. This measurement technique takes into account both the acoustics of the space as well as the characteristics of the amplifier/crossover/loudspeaker chain. It's a good idea to make measurements at several points within the space, averaging the results. (The FORD/JBL folks use 6 points representing the average of a statistical model of adult ears.)

Now if you use an equalizer to provide a frequency response curve that is the inverse of what you're seeing on the RTA, you'll have flat frequency response. Now add bass boost to suit personal taste. Remember that you can always change the amount or placement of the boost to accommodate the owner's taste.

You might ask, "Ok, you've just made the system flat using the equalizer, and now you tell me to make it un-flat because I won't like it flat..." Right. While flat response may not be beautiful, smooth response is. That's the nature of the ball game.

Why not just do the whole job by ear? Good question. The whole point of using electronic instrumentation to make the measurement is to remove the variable of human hearing. It's an established fact that our long term memory for sound isn't all that hot. It's easy to get used to listening to something, even if it doesn't sound particularly good. Couple this with the fact that our hearing changes gradually from day to day, depending on the stimulus presented to our ears and you have a good, but un-reliable test instrument. On the other hand, once we've used the instruments to get the system to a known reference point, our ears and personal judgment are exactly what's needed to make the final, finishing touches.

As simple as this sounds, there are (of course!) a few pitfalls. The actual equalization process is not quite as simple as just using the equalizer to make things level and smooth. Here is a simple procedure:

1. Start with the highest peak in the overall response and reduce it to approximately that of its neighbors. You may need to use several adjacent controls to control and overall response trend.
2. Repeat step 1 until the overall response is relatively flat, within your desired limits.
3. Once you've achieved relatively flat response, add in the low-frequency boost.
4. After you've got the response curve smoothed out, Listen, Listen, and Listen. Do this both stopped and with the car in motion.
5. Apply any corrections needed for personal taste. You may need a rather substantial boost in the low frequencies to overcome road noise.

It's tempting to try to make the overall response curve as smooth as glass. One distinct danger is trying to boost a particular frequency band to overcome a dip in the frequency response. You may be trying to overcome a diaphragmatic absorber in the car body (remember the flimsy door skin?). From an amplifier power standpoint, this can be likened to trying to light up a black hole. Fortunately, our ears don't hear dips nearly as well as they hear peaks.

If you do decide to go after a dip in the frequency response, use the least amount of boost necessary to do the job. A 3dB boost means that your amplifier must deliver twice the power at those frequencies. Large amounts of sub-sonic low frequency boost wastes power and can damage woofers. Beware of using large amounts of boost below the free-air resonance of your speakers.

Although it seems reasonable to use an octave-band analyzer to adjust an octave-bandwidth equalizer (and it certainly works), using a one-third or one-half octave bandwidth RTA to adjust a wider bandwidth equalizer has some distinct advantages. Most important is the ability to see much more than just the individual band-centers. Being able to see the response characteristic in the regions between individual frequency controls on the equalizer helps make the adjustment process easier because of the normal interaction between adjacent frequency controls.

Figures 2 and 3 show before and after curves for an optimally placed loudspeaker. Note that in figure 3, the response correction for high-frequencies (rolloff) has not yet been applied. Figure 4 shows the overall response, in the vehicle, for the FORD/JBL ESP system. Not the low frequency boost, which partially overcomes the low-frequency road noise shown in Figure 1, and also supplies some degree of loudness compensation.

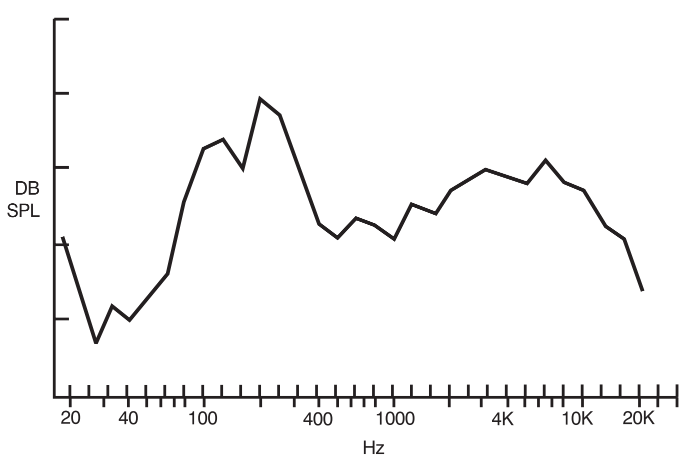

Fig. 2 The un-equalized 1/3 octave satellite response for an "optimally" placed driver.

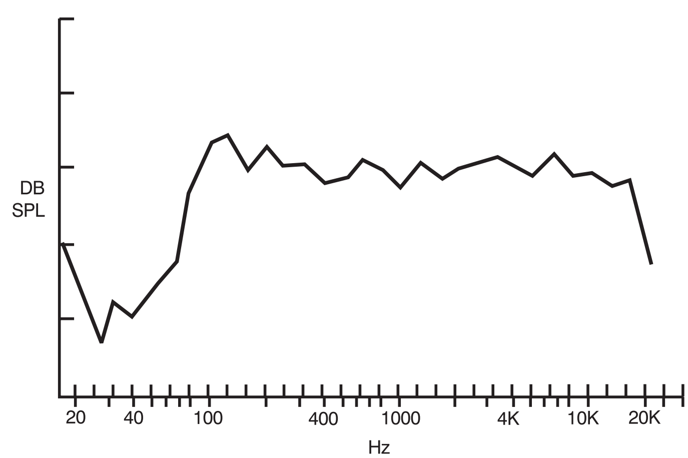

Fig. 3 The equalized 1/3 octave response for the same satellite as in figure 2.

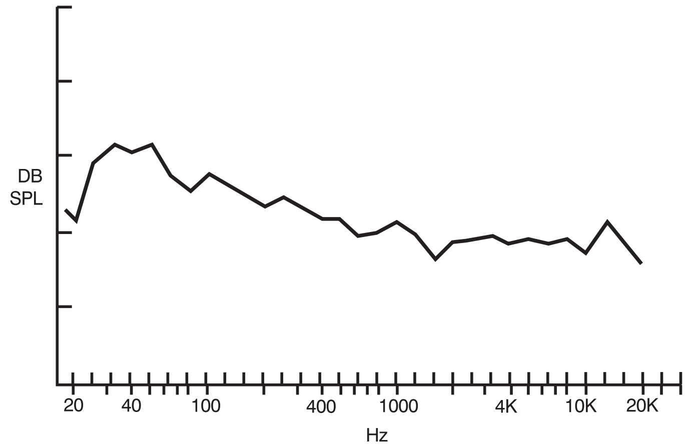

Fig. 4 The total system acoustic 1/3 octave system response.

Conclusion

A user-accessible equalizer can make a marked difference in any autosound installation. Unfortunately, such systems rarely extract the full potential of their component parts. A carefully equalized system can help the user realize the full potential of the components in his or her autosound system. Careful equalization requires electronic instrumentation because human long-term audio memory is too adaptable to be as reliable as electronic instrumentation.

Careful equalization can make the difference between a sound system that sounds ok, and one that sounds GREAT. For the installer, designing in an overall system equalizer can:

- help make the installation sound more like it did on the board in the demo room
- make your installations sound more consistent from car to car
- give you more freedom in picking the loudspeakers for the system
- help make up for the lousy acoustical environment inside the car
- accommodate variations on owner preference and taste
- reduce the chances of a poor sounding installation.

References:

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2. *Equalized Sound Power (ESP) Auto Sound System*, Henry Blind and Earl Geddes, Ford Motor Co., Dearborn MI, AES Preprint 2126, 76th Convention, October 1984.

3. *In Situ Measurement and Equalization of Sound Reproduction Systems,* Robert B. Schulein, Sure Brothers, Inc., Evanston IL, Journal of the Audio Engineering Society, April 1975.

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