# A New Approach To Automobile Stereo Systems

## By Leonard Feldman

THE acoustic environment inside an automobile is often described as "hostile." At first glance, high-fidelity sound reproduction inside a car seems like an impossible achievement: the car's upholstery absorbs a lot of the treble frequencies; road and wind noises seem to drastically limit dynamic range (the difference between softest and loudest musical passages); and positioning of the driver and passengers would seem to rule out satisfactory perception of stereo separation and so-called imaging.

Despite all of these problems, car stereo systems have become very popular in recent years, with many music enthusiasts installing systems whose costs represent a fairly high percentage of the total cost of the automobile. They have traditionally snubbed the "factory equipped" radio-tape player combinations available from the automobile maker, preferring to install (or have installed) other systems.

A recent development may change this attitude, however. Some 1983 General Motors automobiles will include the option of a car stereo system that is custom-designed for a specific automobile acoustic environment. This was achieved through a cooperative effort between General Motors and the Bose Corporation.

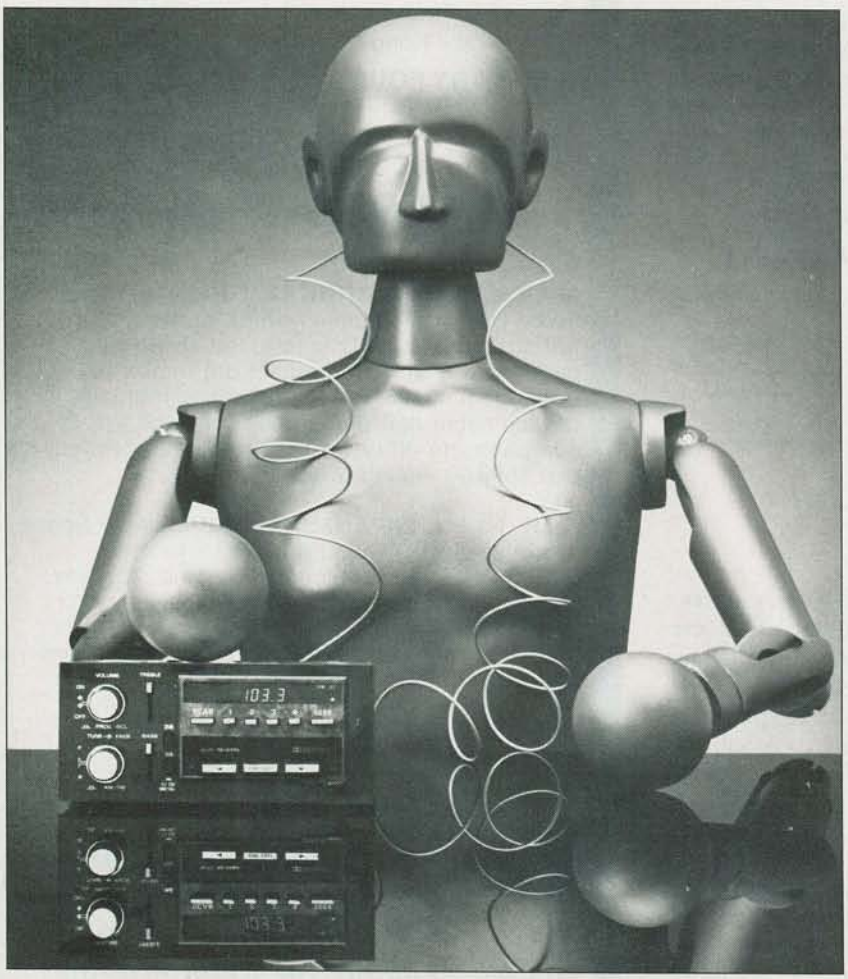

*Fig. 1. Morgan's microphone/ears helped in the design of the new Delco-GM Car Stereo Systems for top-model 1983 cars.*

**Elements of the System.** The first consideration in designing the system, after ensuring that the car's interior would be free of unacceptable resonances, was to determine where to put the speakers. If they were located in the most convenient area, the driver would hear mostly the left speaker, while the passenger in the front seat would hear mostly the right speaker. No balance control can provide proper stereo reproduction for both listeners!

The solution required a great many acoustic measurements, modeling, and much trial-and-error. One of the techniques used in making these measurements involved the use of "Morgan," whose photo is shown in Fig. 1. This "acoustic listener," equipped with a pair of sensitive microphone/ears, enabled Bose engineers to determine the acoustic characteristics of any vehicle model. Sounds picked up by the instrumentation microphones in Morgan's ears were processed through a digital computer and studies were made using a computer program called "Interval" (Interpretive Visual Analysis Language). This aid-

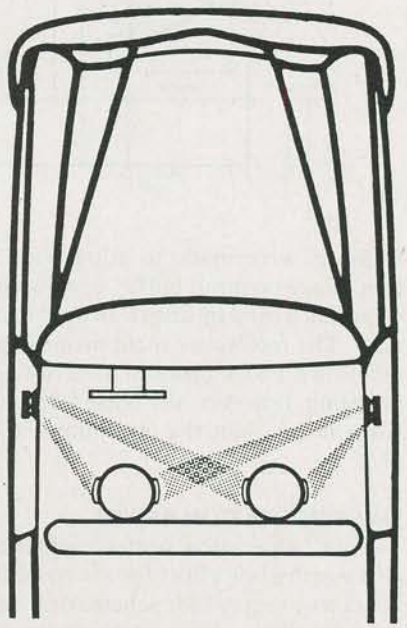

*Fig. 2. Precise positioning of speakers creates proper balance.*

ed the engineers to develop high-performance speaker/amplifier modules for what has come to be known as the Delco-GM/Bose Music System.

Figure 2 shows how the placement and directional characteristics of the speakers were chosen so that the driver is closer to the left-hand speakers but also directly on the radiation axis of the righthand speaker. Thus, only a front-rear balance control is said to be required; there is no left-right balance control in any of these new automobile systems.

Especially useful were the "Interval" computer-aided design techniques employed to study the acoustic requirements of the various car models. Among them: the fast-Fourier transform (permitting meaningful frequency measurements in the actual environment of the car's interior) and interaural cross-correlation measurements (when and how sounds arrive at each ear).

**Equalization—A Key Element.** Bose was among the earliest speaker manufacturers to incorporate fixed equalization into home speakers. That approach was put to good use in the design of the Delco-GM/Bose Music System. The strategy here was to carefully measure the response of the system within the car's environment and then to apply active equalization to remove some of the anomalies in response caused by the car's acoustics. To illustrate this principle, consider the "car response" shown in Fig. 3, taken without any equalization. By combining this less-than-impressive response with the active equalization curve of Fig. 4, the result in Fig. 5 can be obtained.

Equalization was only one aspect of the system design. The tuner had to be matched to the antenna. The loudness control could be optimized only with a knowledge of what sound pressure level would be created by a given audio signal. Overload protection circuitry had to be tailored to the maximum output of the power amplifiers. The

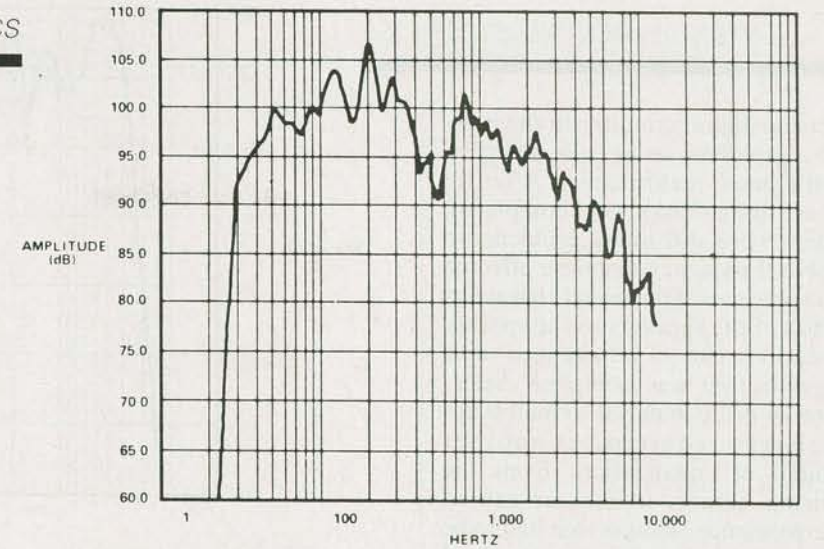


*Fig. 3. Response measured in a car without equalization.*

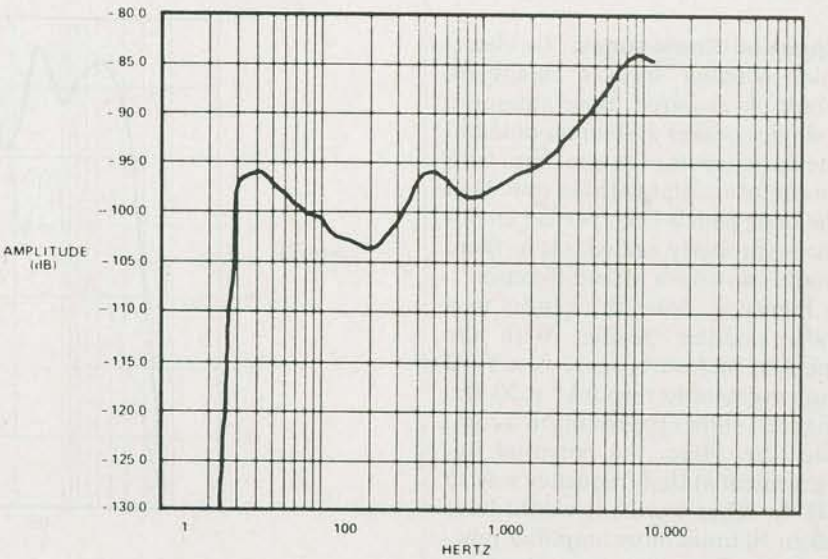


*Fig. 4. Equalization curve to be used on response.*

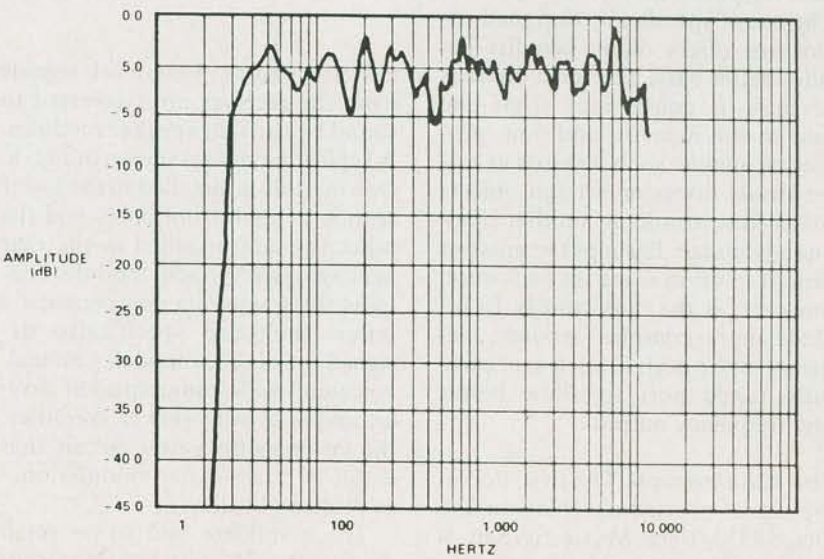


*Fig. 5. Response of car with equalization applied.*

special digital circuitry in the power amplifiers must not interfere with tuner performance. After all these design tasks were completed, there were still many problems to solve. Frequency response affected the perceived directional characteristics of the speakers so the speaker locations had to be changed after equalization was complete. Selection of grille material to match upholstery required yet another round of equalization. Even the wiring harness in the car caused performance changes that had to be evaluated before freezing the final design.

**Speaker Enclosures.** To determine whether speaker enclosures would be required, Bose measured a single speaker system mounted in the door panels of several cars with an enclosure and without one. Had the door panels been perfect enclosures (properly sealed, etc.), there would have been little difference.

Figure 6 shows the results in a 1983 Cadillac Seville. With the speaker enclosure, there is a 5-dB improvement in response at 50 Hz. Figure 7 shows the results in a compact car. Here, the potential improvement at that frequency was 15 dB. In other words, it would have taken 30 times more amplifier power at that frequency to get the same bass output without the enclosure. The use of specifically designed enclosures offers many benefits besides better bass. The most obvious of these is consistency from one unit to the next. In addition, protection against such hazards as water inside doors or foreign objects tossed into trunks is another obvious advantage. Perhaps the greatest benefit of all in using an enclosure, however, is the opportunity to include more complex acoustic elements in the design, such as a carefully tuned port to allow better low-frequency output.

**The Electronics.** The first step in the signal-processing chain of the Delco-GM/Bose Music System is Delco's Electronically Tuned Receiver (ETR) with its integrated cassette player. Low-level signals from the receiver are converted to sound by the four speaker modules. A typical module is shown in Fig. 8. One module is installed in the lower section of each front door, and the other two are installed in the rear package shelf. Each module contains three separate components: a reflex enclosure specifically designed for each car model, a helical-voice-coil wide-range speaker driver, and a 25-watt power amplifier, the latter using a new circuit that employs "two-state modulation," as discussed below.

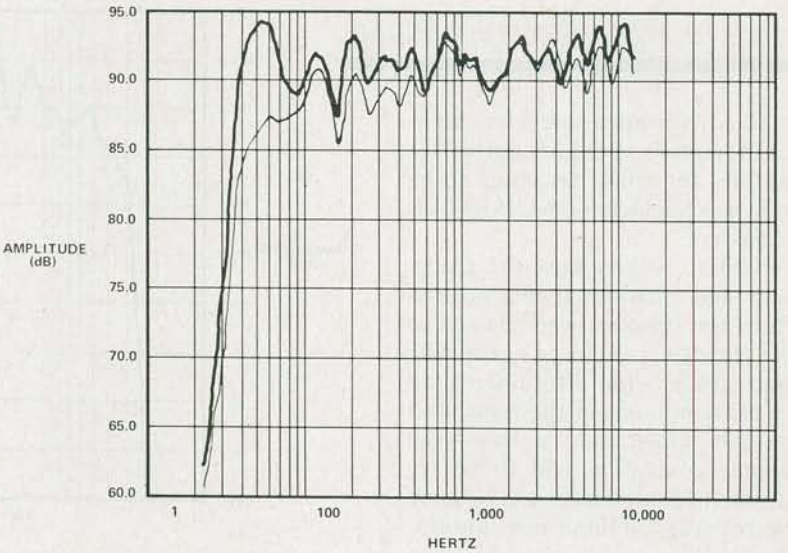


*Fig. 6. Response of a standard car with (heavy line) and without a tuned enclosure.*

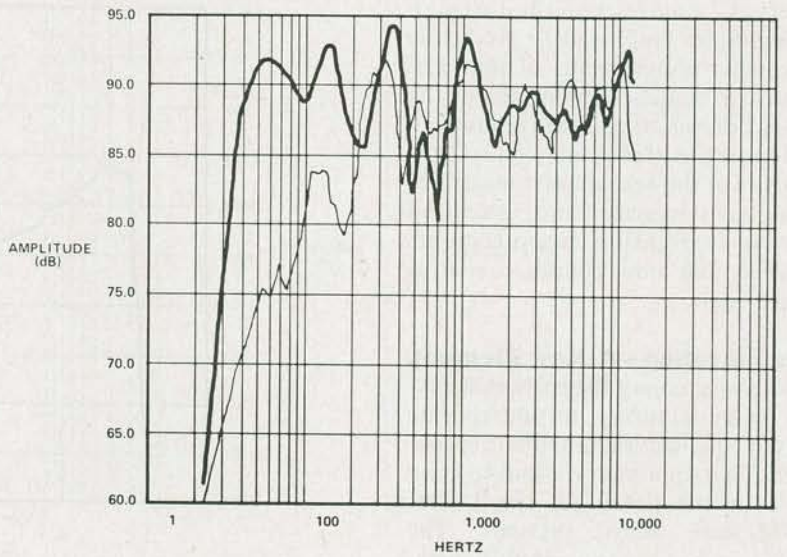


*Fig. 7. Effect of a tuned enclosure (heavy line) in a compact car.*

The amplifiers had to be small despite the 25-watt power output requirement. Furthermore, the car itself had to be assembled in such a way that no direct "heat sinking" to the car body was used to cool the amplifier. Known as two-state amplifiers, these systems operate by switching very rapidly between two "states," with the output transistors either fully on or completely off.

When a transistor is fully on, load current flows but no voltage appears across the transistor; hence no power is dissipated in the transistor itself. When the transistor is off, voltage appears across it but no current flows, so again no power is dissipated. While this description also fits earlier "switching" or Class D amplifiers, one of the chief

differences is that earlier units operated in an "open loop" manner without any negative feedback. In this design, negative feedback is used to ensure flat response and low distortion, just as in conventional high-fidelity solid-state amplifiers. Since virtually no power is dissipated in the output stages of these amplifiers, they are ideally suited to this new application. The on-off switching in a two-state amplifier is essentially digital in nature, hence the designation "digital mode."

In addition to power amplification, the active equalizatiion circuits included with the amplifier provide the audio-signal processing needed to match the acoustic requirements of a specific model car with the requirements of a particular location within the car. The signal processing circuits are actually different between the front and rear amplifiers.

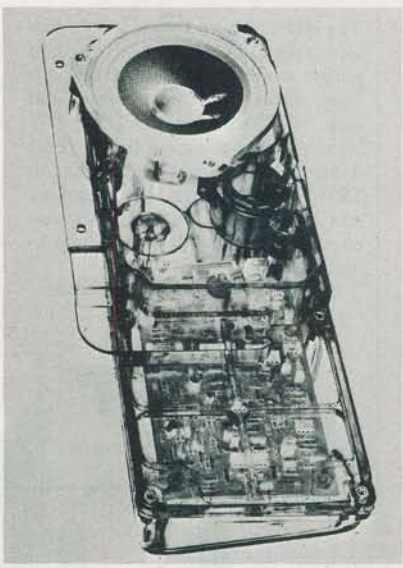

*Fig. 8. Speaker modules are designed for specific locations.*

Check out this option in a 1983 Cadillac Seville or Eldorado, Buick Riviera, or Oldsmobile Toronado, the first cars to employ this integrated car stereo system. It may well shatter several myths and misconceptions concerning the limitations thought to be inherent in car stereo. ◇