The Physics of Loudspeakers

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The physics of the loudspeaker need to be understood before one can create a high quality sound system. Elements such as frequency response, damping, quality factor, efficiency, and impedance work together to determine the characteristics of a loudspeaker. Each factor needs to be considered in detail in order to bring out the full potential of a high-fidelity system. Frequency response, damping and quality factor effect one another very dramatically. Basically, a flat frequency response requires high damping and a low quality factor. Loudspeakers are terribly inefficient, but this does not cause a problem in most applications. Though efficiency is not a major concern, a precise impedance match is needed in order for the speaker to produce a high quality sound. As the final stage in a stereo system, the loudspeaker must adhere to these criteria in order to perform with precision.

When dealing with frequency response, a flat response is best. Every frequency, from the lowest that the woofer can produce to the highest that the tweeter can produce, needs to be equally represented. If the speaker is designed poorly, the response will be uneven and certain frequencies will resonate more than others. A poor response can be corrected through the use of an equalizer which can flatten large resonant peaks or boost weak frequencies (Borwick, p. 314). It is often said that the "smoothness of response is more important than range" (Weems, p. 14), though frequency range also needs to be considered. The range over which frequency response is most important is 50Hz and 10kHz (Borwick, p. 369). To achieve such a range, a woofer is needed for low frequencies and a tweeter for high frequencies. Both the quality factor (Q) and damping have a large effect on the frequency response of the speaker. Frequency response often changes when operated at various Q values (Weems, p. 64). If the device has a low Q, the frequency response will be relatively flat and even, but if the Q is high there will be resonant peaks. In turn, the Q is affected by the damping of the speaker. With the proper damping, the Q of the speaker can be lowered and a flat frequency response is achieved.

Damping is basically the "loss of energy of a vibrator, usually through friction" (Rossing, p. 31). When it relates to speakers, damping is a good thing. There are two kinds of damping in speakers: mechanical damping controls the suspension and air load in the cabinet, and electrical damping consists of the magnetic system (Weems, p. 17). If a speaker has poor mechanical damping, the diaphragm motion will get out of control and the sound will become blurred. The damping restores the vibrating mechanism after the signal ends, and prevents this from happening (Weems, p. 17). The damping material, usually acoustical fiberglass or polyester batting, "absorbs [the] sound that would otherwise bounce around the box…" (Weems, p. 58). Thus, a good damping mechanism with the proper material allows for a clear sound and an even frequency response. Electrical damping relies on magnets to act as the restoring force in the speaker. Cheap, small magnets result in multiple resonance's in the diaphragm because they are too slow in restoring the vibrating mechanism to its equilibrium point. This causes a poor transient response (Weems, p. 18). Damping is most closely related to the Q of the speaker, in that by adding the proper damping material, the Q of the system can be lowered (Borwick, p. 254).

The quality factor is "a parameter that specifies the sharpness of a resonance" (Rossing, p. 553). A high Q indicates a peak at the resonant frequency whereas a low Q implies a more flat response. The sound is very focused when the Q is high, but it is also hard to control because of its loose coupling. In this case, the diaphragm is able to vibrate very freely at a certain frequency. This is undesirable in speakers because every frequency needs to be reproduced uniformly. Q is defined as the center frequency over the bandwidth ($Q = f/\Delta f$). The center frequency, also known as the resonant frequency, is where Q has its maximum amplitude. There is a range of 3dB around this frequency, which is called the bandwidth. Some typical Q-levels are 0.7 for closed-box systems and 0.2-0.4 for vented-box systems (Weems, p. 22). These Q values are extremely low when compared to those of acoustic instruments such as the violin, which has a Q value of 30-50. These instruments tend to have many resonant frequencies that give them a singing quality, but this is not desirable in speakers. Thus, a low Q value is favorable in loudspeakers.

Speakers are seen as the weak link in a high quality sound system because they have very low radiation efficiency. They convert the electrical energy from the amplifier into mechanical energy and then radiate this energy acoustically. Unfortunately, 90-99% of the energy in this system ends up as heat (Rossing, p. 413). This poor radiation of energy makes speakers inefficient. While cone speakers can only radiate at 0.5-5% efficiency, horn speakers able to convert 10-50% of the electrical energy into acoustical power. (Borwick, p. 92). But Rossing says that “horn loudspeakers are much more efficient than cone speakers, but low-frequency horns are considered too large for most home sound systems” (Rossing, p. 414). When dealing with cone speakers, the efficiency is determined by such factors as the magnet strength, and cone area, to name a few. Efficient speakers will have a powerful magnet and a large cone diameter (Rossing, p. 414). Efficiency is most important at large gatherings such as music concerts and public speeches. Musical instrument speakers, such as Marshall guitar amplifiers, are designed to have high efficiency, but at the expense of a clear sound (Weems, p. 31). As long as the basic idea gets through at an extremely loud volume, most rock musicians are happy. Though efficiency is necessary is in some fields, most are satisfied with low efficiency for the time being.

Impedance in loudspeakers is similar to that of acoustic instruments. Acoustic impedance relates the "pressure to [the] volume velocity at the surface of the source" (Borwick, p. 4). Likewise, electrical impedance is the ratio of voltage to current, and the input impedance in loudspeakers is the current that is drawn from the source (Rossing, p. 416). The voltage forces the current to flow, as the lips of a trumpet player force wind through the instrument. Though the most common impedance values are 8Ω and 4Ω (Borwick, p. 431), these are only nominal values. The impedance actually "varies depending on the frequency of the music, and may range from 3 Ohms up to 20 Ohms across the auditory spectrum" (http://www.djsociety.org/Speaker_3.htm, Impedance). For example, in the high frequency range of a woofer the impedance rises with frequency because of the energy stored in the voice coil (Weems, p. 143). Just as musical instruments require a certain amount of impedance to function properly, loudspeakers must be correctly impedance matched with the other equipment in the system.

As the last component in a high-fidelity sound system, the loudspeaker determines the quality of the final product. Such elements of the speaker as the frequency response, damping and quality factor work together to provide an even response through the entire frequency spectrum. A high efficiency is desirable, but not always achievable, and good impedance matching is crucial. When properly implemented, these aspects of physics can yield a high quality sound.

Bibliography

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