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SUBWOOFERS and BASS

BY

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Since the inauguration of my web site almost four years ago, I have been both pleased and somewhat surprised by the number of BOXOFFICE articles that visitors have downloaded. All but a few columns written over the past 23 years are available. Right from the start, over 1100 articles were downloaded each month. Within the first year, that number increased to around 2500 per month. In the past year, the number has continued to increase to over 3500 per month including last January when just under 5000 articles were downloaded. The total number of downloads now exceeds 100,000.

In looking at the records, there are a few articles and subjects that consistently get a great deal of attention. One of these is the subject of woofers. Over the years, I have discussed various aspects of both woofer systems themselves as well as their proper use and calibration in motion picture sound systems. With demand for information on these topics as high as it is, I thought it would be helpful to discuss them a little further.

Subwoofers

I must confess that I don't particularly like the term subwoofer. As everyone knows, it describes a loudspeaker designed to reproduce (or simply produce in some of the sadder cases) the lowest audible frequencies. I have preferred to use the term woofer. But since there are now many (too many) so-called woofers that do not reproduce deep bass, I too have accepted the name subwoofer for the speakers that can deliver the lowest frequencies.

Perhaps the strong interest in this subject should come as no surprise. There have been and continue to be many arguments in the audio community about bass in general as well as woofers in particular. One of the most common is how low does bass go? Referring to the common audio bandwidth specification of 20 to 20,000 hertz, many automatically assume that a woofer must have a flat frequency response as low as 20 hertz. Another subject of debate concerns just how loud the bass should be. To at least some degree, this seems to be a matter of taste as there are some that simply like the physical sensations of bass more than others, even if the sound becomes unnaturally boomy.

In my experience, there has been little to no agreement on how a woofer system should be designed. A wide range of preferences can be found from fully horn loaded woofers to direct radiators with vented cabinets to direct radiators with sealed cabinets to direct radiators with sealed cabinets that also employ passive radiators. In the past, some have also argued that woofer distortion is not important, while others firmly state that low distortion is as important with low frequency loudspeakers as it is everywhere else in audio. So there is no shortage of controversy, not to mention myth, when it comes to subwoofers. Still, these debates tend to center on which woofer sounds better than another, rather than which one sounds more natural.

Like everyone else in the sound business, I have listened to a countless number of woofer systems of all kinds over the years. Some were large while others were small. I am also fortunate to have spent countless hours in front of live symphony orchestras in the finest halls in the world. So I have learned quite well, what real musical bass sounds like. The first lesson one learns in such environments is that real bass is very big. That is to say a huge amount of air is being moved. What's more, real bass doesn't sound anything like the sound produced by most conventional subwoofer installations. Another thing one learns is that while deep bass is powerful and fun to hear, the frequencies below 40 hertz become less important as they get lower and lower. For instance, the low D-flat in the organ at Boston's Symphony Hall is tuned to 36.7 hertz, the low C is 32.6. This is a far cry from 20 hertz. While there may indeed be places where we are exposed to frequencies of 20 or 25 hertz, such as when we fly, it's not something we are conscious of. Such low frequencies need to be much louder than we generally encounter to be noticeable.

Gallons and gallons of air must be moved to achieve a high quality and spacious sound reproduction.

One particular aspect about bass that gets very little discussion is its contribution to spaciousness. Indeed, while it would seem to go without saying, as one diminishes the lower frequencies, the sound not only gets "thinner," but smaller as well.

Loudspeakers are air pumps. If they do not recreate the pressure waves that went into the microphones, they will be unsuccessful in recreating the sound produced by the waves in the first place. Perfect loudspeakers would deliver the exact pressure waves to our ears that we would experience live, without sound systems. Unfortunately, there is no such thing as a perfect loudspeaker. Loudspeakers are a host of tradeoffs. There are as many compromised loudspeaker designs as there are speakers. To find the best, that is to say those that come closest to live, one needs to study what live music and other sounds sound like in various acoustic environments.

When it comes to voices, we hear them live all the time. If we listen critically to voices reproduced over speakers, we can readily hear any differences in tone between the natural sound and the reproduced sound. In day to day life, we can be quite forgiving and uncritical when listening to speech as long as we can understand it. This perhaps can help explain why complaints about speech through speaker systems are heard more often for poor intelligibility than for the unnatural tone that is far more common.

When it comes to music, most people listen to music most often through loudspeakers. Relatively little music is heard live. Since no speakers can reproduce the live experience, we have become accustomed to their compromises and learned to live with them. We even develop preferences and can grow quite attached to the speakers we come to like the most. There are some who actually dislike the sound of a live orchestral concert the first time they hear one. After years of listening to their home stereo systems, they are somewhat unprepared for the real thing.

When it comes to bass, it seems that beyond the concert hall experience, one of the few opportunities people have to hear big clean natural bass that really gets our attention may be during thunderstorms. This is because woofer systems are the most compromised part in all loudspeakers and therefore the most unnatural sounding.

Having said all this, it still needs to be remembered that while there can be some satisfaction when listening to compromised speaker systems and woofer systems, there is far more satisfaction when we hear something live. There is simply no escape from this. The best sound system is no sound system. Therefore, it becomes incumbent on a sound system designer to design and build audio systems that come as close to the live experience as possible. To do so, one must accept that the sound system, that is to say the loudspeakers themselves, will need to be big.

Of course, movie theatres are more than places where we listen to music. We hear things in theatres that we never hear in concerts -- things like helicopters, explosions, dinosaurs and spaceships. The sounds of these and other large sound effects can present far greater demands on motion picture sound systems than music alone.

In today's movie theatres, I believe that one of the most common compromises found in the sound systems is inadequate woofer size. They are simply too small. Imagine for a moment an orchestra. There are likely to be 60 to 100 musicians or more. Then imagine the collective size of all the instruments -- strings, brass, drums and winds -- that contribute to the bass. Now scale the concert hall or scoring stage down to the size of the front end of a movie theatre (or even a living room). It's hard to be precise here, but one can easily imagine that the total radiating area of all the bass producing instruments

would be considerably greater than a mere 6.4 to 9.7 square feet. Yet this is exactly the total combined low frequency radiating area of all the woofers and subwoofers behind the screens of most of the larger sound systems in movie theatres today. To make matters worse, the low frequency sound waves created when the orchestra played were planar waves. The sound waves created by woofers with too few round paper cones flailing away at the air in the room, are spherical. This difference alone places significant distance between what we hear when listening to loudspeakers versus a live experience. It is also one of the characteristics that has given rise to the reputation of many woofers as nothing more than boom boxes. A subwoofer's tone should never call attention to itself. When you hear them groaning away and you find yourself thinking "there are the subwoofers," it's not good.

Size Does Matter

Subwoofers come in various shapes and sizes. However, one cannot assume that a subwoofer with a cabinet volume of say 36 cubic feet will perform or sound the same as another cabinet of the same volume. This is especially true if one subwoofer is a horn loaded type and the other is a direct radiator. While both may even be outfitted with two 15 inch woofer drivers, the horn will have over 6 times the radiating area and deliver 40 times the acoustic power output per electrical watt of input. The direct radiator's radiating area is limited to the piston area of the moving speaker cone(s). The horn's radiating area is the mouth of the horn. This is why the horn with a typical mouth area of over 10 square feet can get control of so much more of the air in the room.

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Using dual 15 inch driver equipped direct radiator cabinets with their 1.6 square feet of piston area, one would need about 6 1/2 such systems to equal the radiating area of a single horn loaded woofer. A typical 80 foot long theatre would normally be equipped with two such horn loaded subwoofers powered by a total of 1370 watts to deliver peak levels in the theatre's center of 121 dB SPL -- the required 115 dB plus a safety margin of 6 dB. Such a pair of subwoofers would have a total radiating area of over 20 square feet. Conversely, installing 10 direct radiator subwoofers each equipped with two 15 inch drivers and powered by a total of 10,900 watts would also deliver 121 dB in the center of the theatre and would provide a radiating area of 16 square feet.

Obviously I have always preferred to use horn loaded woofers for a reason. But again, gallons and gallons of air must be moved to achieve a high quality and spacious sound reproduction. This can be accomplished with either type of subwoofer design. It simply

takes a lot more conventional subwoofers than anyone installs. Since most movie theatres are typically equipped with only one or two direct radiator subwoofers, one can understand my suggestion that such theatres are "under-woofered," depriving audiences of the considerable and exciting dynamic range of today's digital soundtracks. In addition, these systems lack enough amplifier power to do their job. An 80 foot long theatre with two conventional subwoofers as described above with two 1000 watt amplifiers would "run out of gas" at just under 107 dB in the middle of the theatre -- a full 8 dB below the 115 dB minimum required by digital soundtracks. These figures are all based on typical woofer one watt / one meter sensitivities of 93 dB for the direct radiator and 109 dB for the horn. The fact than many of today's subwoofers now employ dual 18 inch drivers does help, as they have about 53 percent more radiating area. But it is still too little to do the job really well. When inadequate woofer systems become over driven, things get ugly fast. Yet having heard so many distressed low frequency systems for so long, many believe that the bloated and extremely unnatural sound they are hearing is perfectly normal real bass.

Distortion

Another boom box characteristic is distortion. In the 1970s, several manufacturers were promoting acoustic suspension speakers for home use. These systems had the advantage of perceived deep bass from smaller cabinets. Such systems remain popular today due to their size. However, the inherent inefficiency of such small speakers presents us with a tradeoff requiring anywhere from 10 to 100 times the amplifier power. The other tradeoff comes in the form of speaker generated distortion -- defined as frequencies in the speaker's output that are not present at the input from the amplifier.

There are two principle types of such distortion in loudspeakers: harmonic distortion and modulation distortion. Of the two, harmonic distortion is less offensive because it is harmonically related to the program material. Modulation distortion is not harmonically related and is thus more audible and deleterious to the quality of the sound. While both types of distortion should be minimized as much as possible, it is the opinion of many that modulation distortion of more than a few percent can render a speaker incapable of accurately reproducing music.

Whenever the subject of speaker distortion comes up in the audio world, old arguments that it doesn't matter appear, often from those promoting inefficient speakers. Recently, new computer generated analysis software has been introduced that can ignore all the signals loudspeakers are being asked to deliver and measure the total distortion of complex program material. This sort of comprehensive analysis can show just how much distortion speakers actually produce. One writer I know was absolutely shocked at what he was measuring when he began testing loudspeakers this way. His conclusion was that

speaker generated modulation distortion should not be allowed to exceed 3 percent. About 50 years earlier speaker pioneer Paul W. Klipsch said pretty much the same thing without the benefit of a computer.

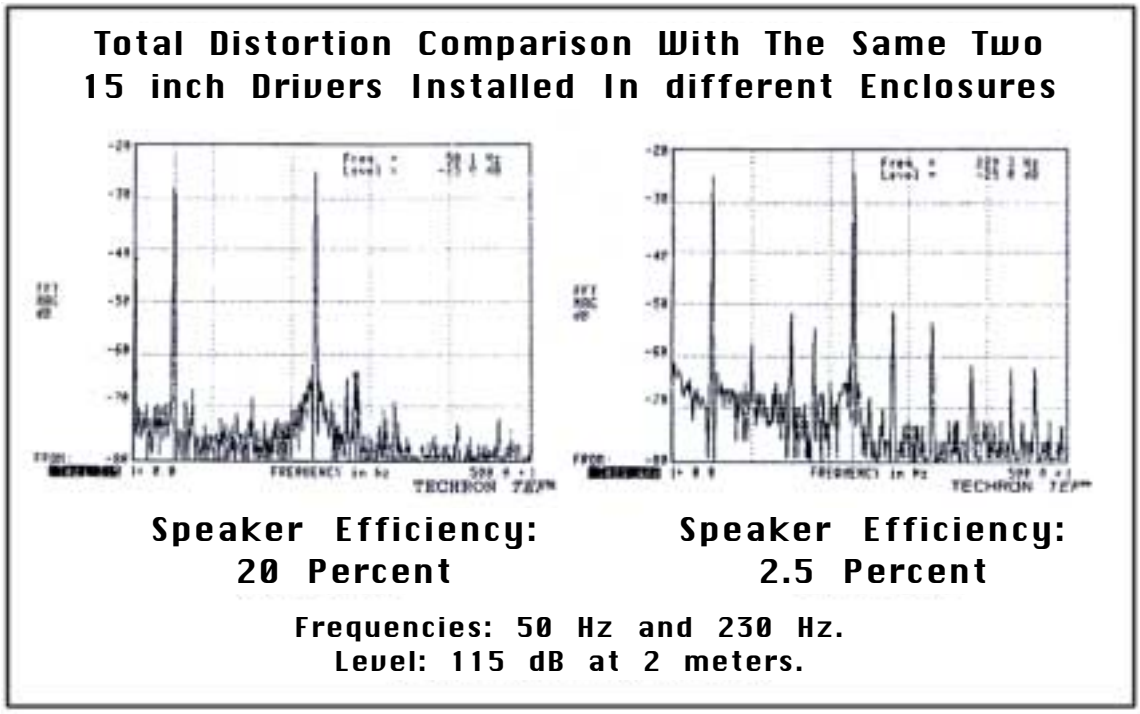

Figure 1.
The tallest spikes represent the only two frequencies that should be seen. When playing at the same levels, the less efficient system produces about 10 times more distortion.

Modulation distortion in loudspeakers in inversely related to efficiency. See Figure 1. If you cut the speaker's efficiency in half, the modulation distortion will nearly double at any given sound pressure level. The levels of distortion are directly related to the velocity of the driver's motion. The greater the distance a speaker cone must travel, the faster it must go and the greater the modulation distortion. In motion picture sound systems, the options for minimizing this kind of clarity robbing distortion are the same as those for increasing efficiency and low frequency radiating area mentioned earlier. This reinforces the notion that the sound systems in most theatres need more and/or bigger woofers and subwoofers.

Setting Subwoofer Levels

When subwoofers first appeared in movie theatre sound systems, the methods for setting levels were confusing and unreliable. After some years of experience, Dolby Laboratories suggested a new "In Band Gain" method for calibrating subwoofers. Rather than using

Sound Pressure Level meters, this new method relied on Real-Time-Analyzers. The SMPTE has also published a Recommended Practice, RP-200, that describes the In-Band-Gain approach and how to use it. The bottom line is that subwoofer levels must not be set with SPL meters.

For further information on the topics discussed in this article, the following articles may be downloaded:

http://www.hps4000.com/pages/spksamps/subwoofer_levels.pdf
http://www.hps4000.com/pages/special/woofer_distortion.pdf
http://www.hps4000.com/pages/digital/digital_subs.pdf

John F. Allen is the founder and president of High Performance Stereo in Newton, Mass. In addition, he serves as the sound director of the Boston Ballet. He is also the inventor of the HPS-4000® motion picture sound system and in 1984 was the first to bring digital sound to the cinema. John Allen can be reached by E-mail at johnfallen@hps4000.com. Mr. Allen's 23 year series of articles written for BOXOFFICE are available for download at http://www.hps4000.com.