

ProSoundWeb **EXPERT** SERIES



**EVERYTHING YOU WANTED TO
KNOW ABOUT SUBWOOFERS**

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CHAPTER 1: IT'S ALL ABOUT THE BASS

The evolution, facts, and theories about subwoofers and the low end of the frequency spectrum. By Andy Coules

Over the last few years I've been fortunate enough to use some of the best sound systems currently available from many of the leading manufacturers, and one of the things that struck me is how far we've come in terms of delivering the bottom end of the mix.

Subwoofer technology and placement techniques have developed to the point where we have a lot more control over how this important band of frequencies is deployed. So I thought it would be good to take a look at how we got to this point and explore how we can deliver a better bottom end.

When talking about bass frequencies we're typically referring to those below about 250 Hz, but I want to focus on the lowest of the low; in other words, sub bass – frequencies typically between 20 and 100 Hz. The nature of the way in which we hear means we don't perceive all frequencies equally

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(this also changes with volume). But generally speaking, humans are much less sensitive to frequencies below 100 Hz, which is why this region requires special attention.

Looking at standard PA loudspeakers or a pair of studio monitors, most of them extend down to a reasonable frequency for reference purposes, but both will always benefit from the addition of subwoofers to enhance the bottom end. Amplifiers designed to power subs tend to be more powerful than those used for mid-range or high frequencies, and the loudspeakers themselves are always larger (usually 15 or 18 inches in diameter) than their higher-frequency counterparts.

A common misconception is that large loudspeakers are needed to produce low-frequency sounds, but reality says otherwise — a simple proof of this is ear buds and headphones. The issue here is the medium through which the sound travels. Air is a relatively inefficient conductor of vibrations, and bass vibrations are relatively slow, so much more power is required to produce bass frequencies that are perceived to be the same level as the corresponding higher frequencies. For instance, if we all lived underwater, a relatively low-powered 2-inch woofer would be quite capable of producing pleasing levels down to about 20 Hz.

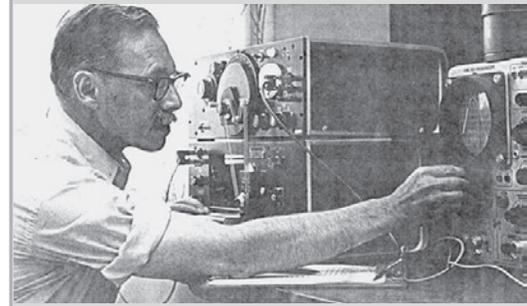
EARLY RUMBLES

The first acoustic suspension woofer was invented by Edgar Villchur in 1954: the AR1 debuted at the New York Audio Fair and quickly went into production for his newly founded company, Acoustic Research. The design utilized the elastic cushion of air within a sealed enclosure to ensure a linear restoring force for the woofer's diaphragm, thus producing louder and cleaner bass frequencies.

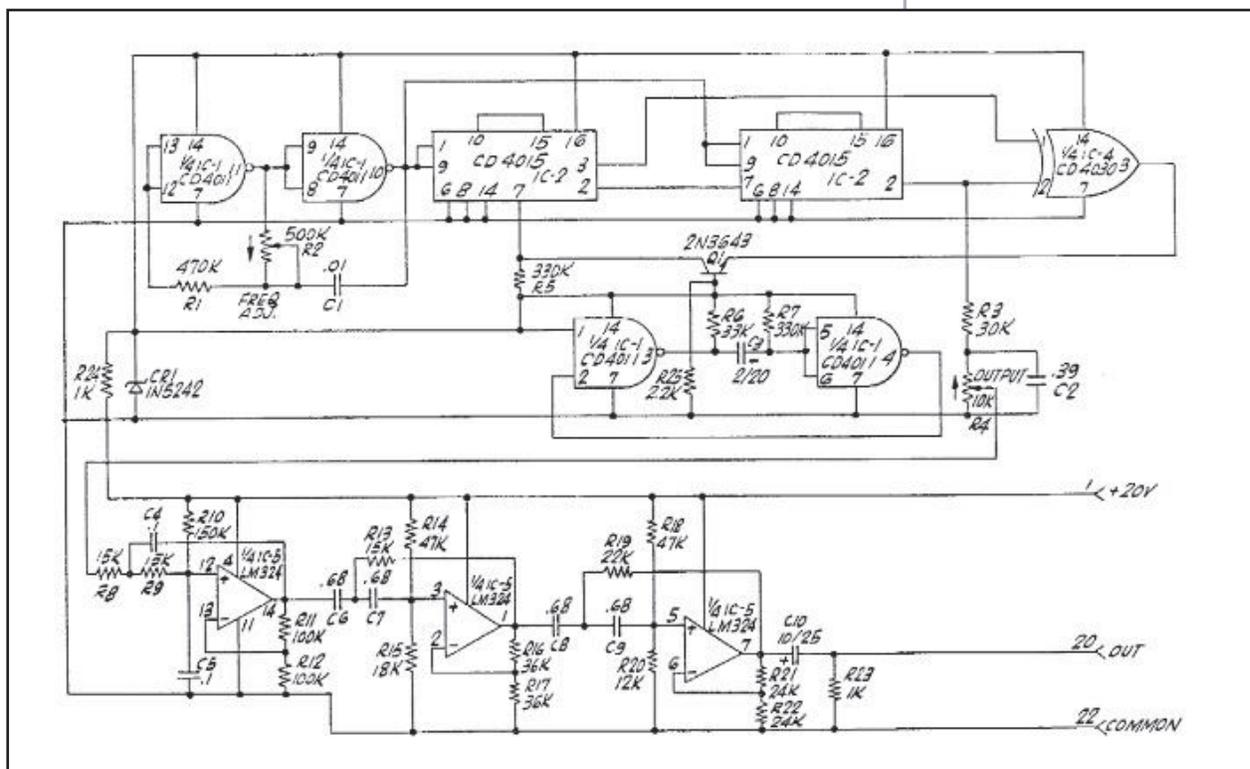
Loudspeakers capable of producing frequencies below 100 Hz with adequate volume and minimal distortion become more common in the 1960s and 70s but weren't commonly applied in the way that they are now (i.e., at concerts, in recording studios and for home hi-fi). The main use was in cinema to enhance the movie-going experience.

One such approach was called Sensurround, a process developed by Cerwin-Vega in conjunction with Universal Studios that used multiple subs powered by racks of 500-watt amplifiers triggered via control tones printed on the audio track of the film to produce energy between 17 and 120 Hz.

The most famous application of Sensurround was to add "realism" to the 1974 film *Earthquake*. The low-frequency entertainment method was credited with making the film a box office success and generated a lot of publicity for subwoofers. (And the film won an Academy Award in the Best Sound category.)



Edgar Villchur, developer of the first acoustic suspension woofer, in the lab circa 1965.



One of the main reasons subs weren't commonly used in the home was due to the limitations of the primary playback medium of that time (vinyl records). Loud and deep bass was difficult because it affected the stylus's ability to track the groove; even a moderate amount of bass (by modern standards) would cause the needle to oscillate excessively until it jumped out of the groove. Truly accurate and deep bass wasn't really possible until the compact cassette tape became a common medium, followed by the compact disc (CD).

MEETING EXPECTATIONS

In the early days of concert sound, there wasn't really an overriding need for a full and deep bottom end. To illustrate, let's take a look at the two instruments most commonly found in the subs in traditional guitar-based rock music: kick drum and bass guitar.

If you stand next to an unamplified drum kit while it's being played, you might notice that the kick drum isn't actually that bass heavy. It moves a certain amount of air, and has the most bass of all the drums in the kit, but it doesn't have that sound that "hits you in chest" like it does when standing in front of the PA at a gig. That sound is actually an artificial construction whereby the drum is close-miked with microphones that are tuned to bring out the bass frequencies — often in a disproportionate way.

The standard electric bass guitar has four strings that are tuned an octave down from the bottom four strings of the guitar. These oscillate at about

Diagram of the Sensurround pseudorandom generator circuit to create low-frequency rumble.

41, 55, 73 and 98 Hz, with the specific sound produced depending largely on the bass amp. (Very few bass amps are able to generate 41 Hz; in fact, most struggle to go below 80 Hz with sufficient level.) Again we use techniques such as direct injection (DI) or close miking the bass amp cabinet to help bring out those lower frequencies.

The point I'm making is that routinely, we artificially enhance the bottom end of key instruments to create the sound we've come to desire and expect. This sound is the product of an evolutionary process pushed forward by a combination of production techniques, advances in amplifier and loudspeaker technology, and the expectations of the musicians and their audiences.

But why do we prefer a full and deep bass sound in our music? According to recent research by Laurel Trainor at the McMaster Institute for Music and The Mind in Ontario, Canada, our ears are much better at discerning subtle timing differences in low frequencies than high frequencies. The study suggests that this effect arises within the physiological mechanism of the ear and not in the perceptual center of the brain. This tells us that we rely much more on the low-frequency content of music to help us lock into the rhythm, and further, it shows how important it is for live sound engineers to get the bottom end right, particularly for dance music.

There's one more important factor that contributes to our enjoyment of low frequencies: they're felt as much as heard. The sheer amount of air movement at low frequencies resonates in our chests and adds a visceral element to our enjoyment of the sound. Much like that early Sensurround system, it helps put us "in" the sound and adds to our enjoyment of the music.

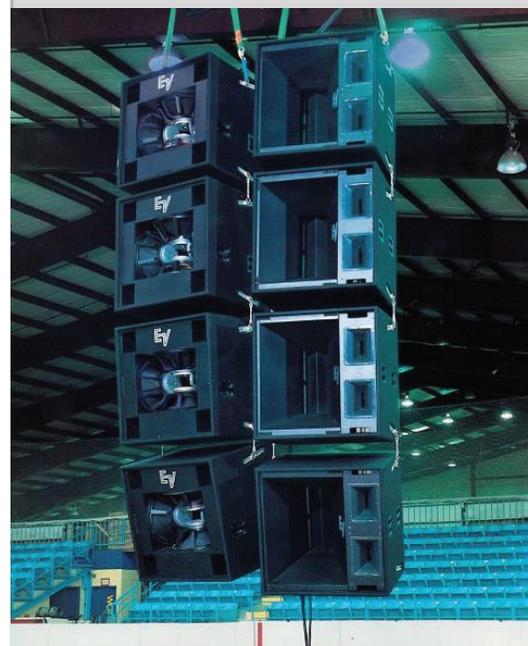
VARIOUS APPROACHES

So how do we get the best out of modern sub bass systems? The first thing to consider is that more is not necessarily better — just because we now have prodigious power at our fingertips does not mean that we need to wield all of it. There's a fine line between levels that induce stomach jiggling excitement and those that induce nausea. Bass coverage is rarely completely even throughout a venue, so it's always a good idea to be familiar with the region where it's at its maximum and then to set levels accordingly, also keeping in mind that the levels at front of house don't always represent the whole.

One of the biggest causes of messy, muddy mixes is bass energy getting into the subs that shouldn't be there. This can be avoided in a number of ways. First and foremost is microphone choice and positioning — putting the right mic in the right position is the best way to ensure getting just the desired sound from the source. Also be aware of how directional mics exhibit the proximity effect; knowing when to exploit this and when to obviate it can help a lot in delivering



A Diatone loudspeaker from Mitsubishi; the first ones were built in the spring of 1945 for the Japanese radio station NH



Iconic Electro-Voice MTL-4 subs (each with four 18-inch woofers), a staple of the touring circuit in the early to mid- 1990s, flying with their mid/high companions.

a crisp and clean bottom end from multiple miked sources.

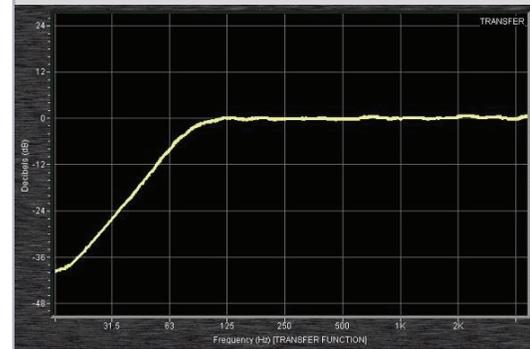
I'm also a big fan of the artful use of high-pass filtering, which serves two very important purposes. It can help reduce the amount of low-frequency leakage, which is inevitable when multiple mics are in close proximity to each other, and it can also help reduce frequency masking, which always occurs in a downwards direction, frequency-wise (i.e., guitars are more likely to mask the bass than the other way round). And if that doesn't help reduce the amount of unwanted bass in the subs, then the aux fed sub method provides further control to ensure only the desired signals are present in the subs.

Sometimes, particularly in small venues, the issue is not too much bass but rather not enough of it. This is where a little knowledge of psychoacoustics can help. There's an interesting phenomenon called the Missing Fundamental where we hear the overtones of a sound but not the fundamental frequency (usually because the sound system doesn't go that low). Under the right conditions, our brains process the information present in the overtones and fill the gap left by the fundamental frequency so that we actually perceive it even though it's not present.

I've often exploited this principle when the PA has a less-than-stellar bottom end. The key is not just to boost the upper reaches of the bass sound but also to reduce the low frequency content, which has the added bonus of stopping the PA from wasting energy trying to produce frequencies it can't.

Hopefully this discussion provides some new insight into a familiar but sometimes overlooked band of frequencies. After all, if you're planning to build a sturdy mix, it always helps to start with a solid foundation.

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A 75 Hz high-pass filter from an input channel of a Mackie 1402 mixer as measured in transfer function mode on Rational Acoustics Smaart software. The filter has a slope of 18 dB per octave.

CHAPTER 2: MOVING AIR

Inside subwoofer designs and configuration in the quest to deliver LF energy with maximum impact and control.

By Craig Leerman

Today's music and special effects (like explosions in motion picture soundtracks) include a lot of low-frequency content. While larger full-range loudspeakers may have a wide frequency range, it takes subwoofers to really reproduce low end with impact, especially for bass-heavy music like electronic dance (EDM) and reggae.

Deployment of main loudspeakers is usually a relatively straightforward matter, but locating and configuring subs presents numerous options and can be a bit of a challenge. Let's start with the basics.

Subwoofers are specialized cabinets that reproduce the extreme low end of the frequency range. Studio and home theater models may operate in the range of 20 to 250 Hz, while subs for sound reinforcement usually operate around 30 to 120 Hz, with 80 to 100 Hz being common crossover points. They can be passive, fed by external amplifiers and processors, or active, with onboard amplification and processing.

Smaller systems may send the subs the same main output feed as the full-range mains, while larger setups might receive content only from the instruments with LF content like kick drum, bass guitar or even a bass vocalist, usually sent via an aux send on the console. This can help clean up "muddy" sounding low end because it eliminates the open microphones on stage sending signals to the subs that can be out of phase with each other.

There are several different types of subs, with each design being a trade-off between bandwidth, efficiency, portability and cost. Designs can utilize single or multiple transducers, almost always cone drivers arranged in a variety of configurations, including:

Sealed/Acoustic Suspension. The driver(s) are mounted in a sealed cabinet. While the transient response of this design is good, it's less power efficient compared to vented enclosures and can be lacking when reproducing very low frequencies, especially at high volume levels. One notable exception is a specific design that utilizes a proprietary electronic processing control system for solid reproduction at extreme low frequencies (under 20 Hz).

Bass-Reflex/Ported/Vented. The most common type in live audio, a bass-reflex design has the driver(s) mounted into a box chamber that also houses one or more vent opening(s). The vent (a.k.a., port) is of a specific size and length to allow sound emanating from the rear of the driver to exit the enclosure, with

For example, one configuration has two drivers sharing a common vented chamber. One driver's frontal radiation is direct, while the second driver is set at 90 degrees and radiates into a second vented chamber. Another take is a cardioid passive dual-transducer configuration with an 18-inch driver in a bass-reflex configuration and a 15-inch driver feeding a folded horn.

THE NATURE OF WAVES

Before we look at various ways to deploy subwoofers, we need to spend a little time on sound waves. Sound is a pressure wave through a medium like air or water.

At sea level in dry air at 75 degrees (Fahrenheit), the speed of sound is approximately 775 miles per hour (1136.6 feet per second). Humans can hear these vibrations if they're in the frequency range of our hearing, usually considered between 20 Hz to 20 kHz. The wavelengths (one cycle of a tone or pitch) for bass frequencies are longer than higher pitched frequencies. Because subwoofers operate in a general frequency range of 30 to 110 Hz, it means we're dealing with wavelengths of about 10 feet to about 35 feet long.

Long wavelengths aren't usually affected by slender items in their path, like a support column in a building, unlike smaller high-frequency wavelengths that can be redirected and reflected off even small obstructions.

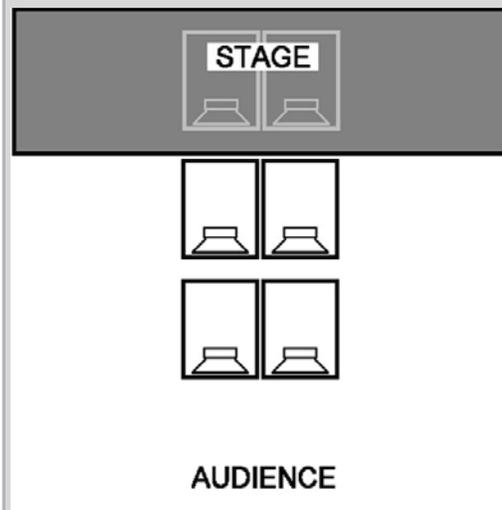
Anything within one-quarter (1/4) of the wavelength in distance can affect the output, including floors and walls (a.k.a., boundaries), as well as additional subs stacked next to each other. Most subs radiate energy in an omnidirectional pattern, as shown in Figure 1.

If we suspend a sub above the ground, its output emanates in all directions, and if it's more than 8.75 feet away from any surface (a one-quarter wavelength of 30 Hz or 35 feet), it does not get any gain in output from a boundary. Place the sub on the floor (called half-space loading) and there's an additional (theoretical) 3 dB of output because the energy that would have traveled down is now reflected up from the floor.

Placing it on the floor next to a wall (quarter-space loading) adds 6 dB more output, and moving it to a corner (eighth-space loading) adds 9 dB. (While this looks great on paper, in the real world the numbers won't be that high because of interference from the boundary and the acoustic space.)

Now, place the sub one-quarter wavelength from a rigid wall, and its output will bounce off the wall and return to the sub, making it about one-half wavelength, with the phase about 180 degrees from the original signal. This results in destructive cancellation. Depending on distance from a boundary and the pitch of the signal, frequency response is affected.

A common phenomenon is a bass "power alley" where LF output is strong



A common end-fire configuration.

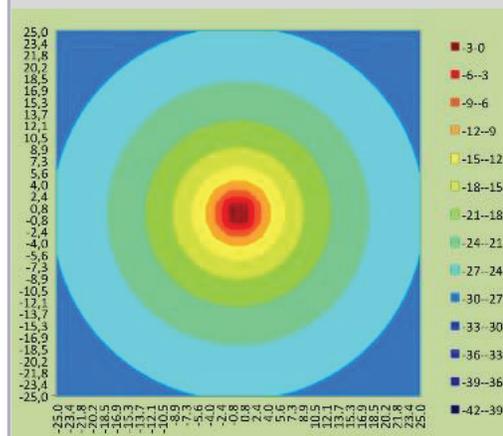


Figure 1

between left and right stacks because the output from each sub combines to add power. However, as you move off center, phase and time delay issues cause cancellations. This effect is most pronounced outdoors where walls and ceilings are not adding reflections and destructive cancellations.

INTERESTING ARRANGEMENTS

Let's move on to a variety of ways to deploy subs. Prediction software can be very helpful in this regard, allowing us to model various configurations as well as see the impact of things such as signal delay and high-and low-pass filtering. The plots we're presenting here were done with the Subwoofer Array Designer Calculator (www.merlijnvanveen.nl) by the software designer himself, Merlijn van Veen. (Thanks Merlijn!)

Single. Placed in a convenient spot, output will only be affected by the room and not other subs. A corner location can be better as it affords a boost in output. A downside is lack of pattern control, with the possibility of too much LF energy on stage and/or in other areas.

Multiples. This will "move more air" than a single sub, but stacking or lining up the enclosures will effect the pattern because the group produces longer than a one-quarter wavelength, which in turn will narrow the coverage pattern. Placing them near a wall or corner will additionally alter the pattern.

Left/Right (Ground). In Figure 2 we see the result of an L/R placement at 40 Hz. The power alley is clearly in evidence, and also note that on each side of the power alley, there are power valleys or null zones where destructive interference has reduced the output level.

Compare this to Figure 3, which shows the same configuration at 80 Hz. Note the destructive interference has resulting in multiple null zones in the output.

Left/Right (Flown). Particularly popular at larger events, subs can fly above a loudspeaker array, as a part of a horizontal array, next to an array, and behind an array. The behind configuration minimizes the overall width of the loudspeaker hangs and doesn't intrude on audience sightlines. Flown subs can be configured in directional arrays as well as be joined by additional subs on the ground.

Vertical Array. Subs stacked vertically (usually flown beside or behind an array) will develop some vertical pattern control, with the length of the array determining how much. Longer = greater control.

Center (Ground & Flown). A center location with one or more subs can be ideal for providing a smoother coverage pattern over an L/R placement, but this method may result in putting too much bass back onto the stage unless cardioid cabinets or configurations are implemented. Center flown subwoofer arrays

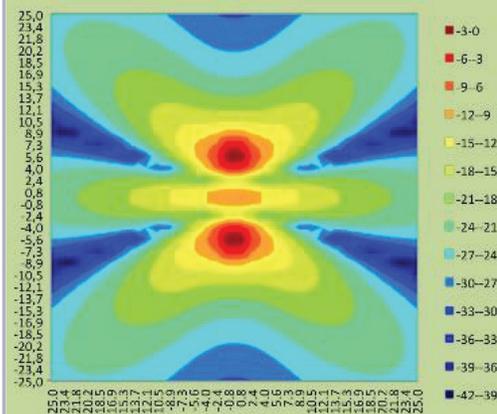


Figure 2

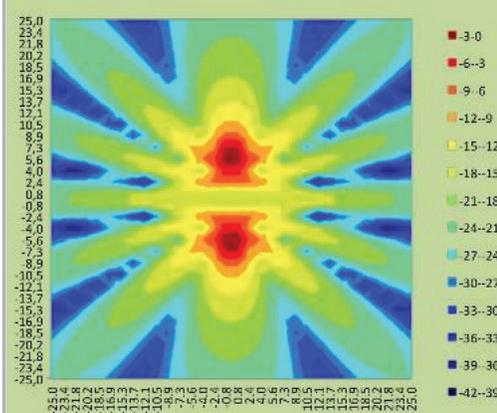


Figure 3

are popular for installs, especially in theaters, but not so much for live events.

Horizontal. This arrangement places loudspeakers next to each other (or with small intervals between boxes) in a row, usually across the front of the stage. The effect of using a large line of cabinets will narrow the horizontal pattern, but unless the array is made up of cardioid cabinets, the stage will still be awash in low frequencies.

Curving the array instead of placing the cabinets in a straight array can offer more constant directivity. Figure 4 shows a horizontal array at 40 Hz, while Figure 5 shows the same configuration using cardioid cabinets.

Distributed/Delay. Uses multiple subs in various locations (such as hidden beneath a runway stage along its length), and may employ time delay to achieve a coherent arrival time at various audience locations. This approach is popular for corporate-type events where a large stack or wall of subs is not desired for aesthetic reasons, while a number of subs spaced apart down the walls, flown, or hidden under a stage is better received by event planners. Distributed-type systems can also be found installed in venues where a single subwoofer placement would not cover the intended audience area.

MAKING IT DIRECTIONAL

As previously noted, a primary goal is keeping excessive LF energy out of areas where we don't wish it to be. With select placement/arrangement of subs and the application of processing such as signal delay, various radiation patterns can be attained. Some of the more popular directional array techniques include:

Delay Shaded Array. This reduces the output of the boxes at or near the ends of an array (like a horizontal array), with the intent to make the coverage pattern more regular and less frequency dependent.

Cardioid Array. Two popular cardioid approaches are stacking and side by side. Stacking places the boxes on top of each other, with one cabinet (usually the middle cabinet in a stack of three) reversed to point to the rear. Side by side places the boxes next to each other and reverses one (again normally the middle one of three).

Further pattern control can be attained by applying delay, either by delaying the output of the front-facing cabinets to arrive at the same time as the output of the rear-facing cabinet, or by delaying the rear-facing cabinet to the output of the front-facing cabinets while also reversing the polarity of the rear-facing cabinet so that it's signal is 180 degrees out of phase with the front-facing cabinets.

End Fire Array. Multiple cabinets are aligned in a row, arranged one in front of the other with all pointing forward. All cabinets are delayed in relation to the rear-most cabinet. This approach makes it possible to project powerful, directional bass over long distances. Figure 6 shows how an end fire array

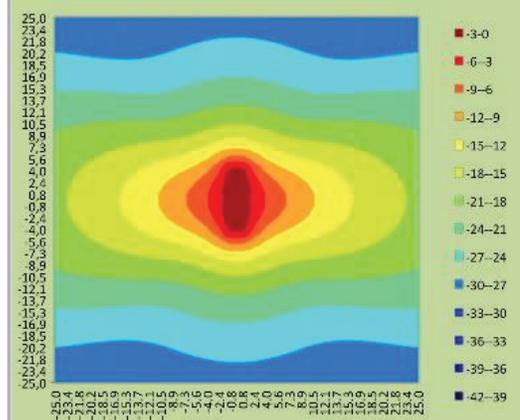


Figure 4

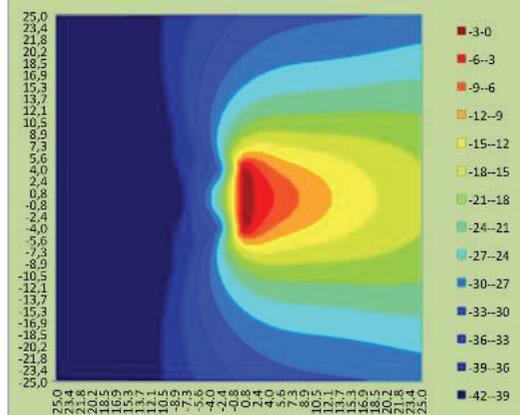


Figure 5

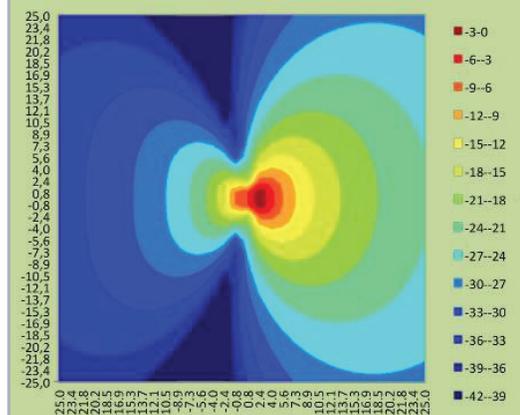


Figure 6

provides very good pattern control at 80 Hz.

Obviously, there's a lot to discuss when it comes to subwoofers, and what I've presented here is intended as a primer, really just scratching the surface. I recommend further research to enhance your understanding — for example, ProSoundWeb offers dozens of articles on subwoofers and related topics, while the LAB Subwoofer Forum on PSW is an excellent resource for both information and getting questions answered.

It's well worth your time, as delivering LF energy with maximum impact and control is one of the defining factors of a successful sound reinforcement experience.

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About Fulcrum Acoustic:

Founded in 2008, Fulcrum Acoustic is a professional loudspeaker manufacturer known for its unique approach to loudspeaker design. Employing the research of company co-founder David Gunness, Fulcrum Acoustic combines proprietary coaxial design and Temporal Equalization™ processing power to create the most powerful and versatile line of loudspeakers available.

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