TECH TALK

Advanced Sub Techniques

Directing and controlling LF energy. ***by Bennett Prescott***

THERE ARE A FEW tricks you can pull out of your sleeve to make your low frequency arrays work better. By building directional subwoofer arrays, energy can be kept off the stage and walls and kept on the audience where it belongs. These arrays require a little more signal processing and planning to implement, but the reward can be as much as 20 dB less energy where it isn't wanted.

We're going to explore two kinds of arrays, cardioid and end-fire, both of which create wideband rejection to the rear and sides of the array. The name "cardioid" means the same thing as it does for directional microphones: the polar response of the array has a heart-shaped pattern. While technically this is describing a desired pattern shape rather than a specific type of array, it has become common in the live sound industry to describe this first type of subwoofer array as cardioid.

An end-fire array is so named because a number of subwoofers are arranged in a line and delayed so that they "fire" in order, beginning at the end furthest from the audience.

A cardioid array (**Figure 1**) uses a mixture of polarity and delay to create directionality. The technique requires two sources physically separated relative to the desired direction of cancellation.

Placing three subwoofers next to each other but flipping the middle one so it faces backwards can easily achieve this. Delay is then applied to the rear-facing subwoofer to time-align all loudspeakers towards the rear of the array.

Inverting the polarity of the rear-facing subwoofer then creates cancellation as the energy from the front-facing subwoofers arrives only to be met by the inverse energy radiated by the rear-facing subwoofer, which nullifies it. This is certainly non-intuitive behavior, using sound to cancel sound, but it works!

Meanwhile, in the forward direction we have created a large time misalignment by not only separating these sound sources, but also delaying one so it appears even further away. If we choose the distance between front- and rear-facing sources carefully, we can make this misalignment work in our favor once again.

At a certain frequency, the energy from the rear-facing driver arrives at the front of the array one-half wavelength (180 degrees) out of phase. Ordinarily this would create cancellation, but remember that we inverted the polarity of the rear-facing subwoofer. What was 180 degrees of phase difference is now 0 degrees and cancellation becomes addition in front, just as addition became cancellation to the rear courtesy of the same polarity inversion.

The physical distance between drivers defines one quarter-wavelength of this frequency, while the alignment delay defines the other quarter-wavelength. A spacing of 2.5 feet, for example, will provide near-perfect addition towards the audience at approximately 110 Hz.

However, as frequency changes so does wavelength. Keep in mind that an octave above or below this frequency (55 Hz and 220 Hz, respectively) there will be 90 degrees of phase difference relative to the center frequency, which results in less contribution from the rear-facing subwoofer.

In practice, subwoofers rarely operate over two or more octaves bandwidth, so this is usually not an issue. Since the cancellation to the rear is provided by polarity inversion it is equally effective at all frequencies.

Determining the delay to apply to the rear-facing subwoofer is not intuitive, since the cabinet depth alone is not an accurate representation of how long it takes the energy from the front-facing drivers to reach the rear-facing driver.

The correct delay can be determined by taking a tape measure and measuring the shortest distance from the center of one driver around one side of the cabinet to the center of the other. This represents the actual path the sound must take and therefore the actual delay.

For the sake of simplicity, however, one can usually get

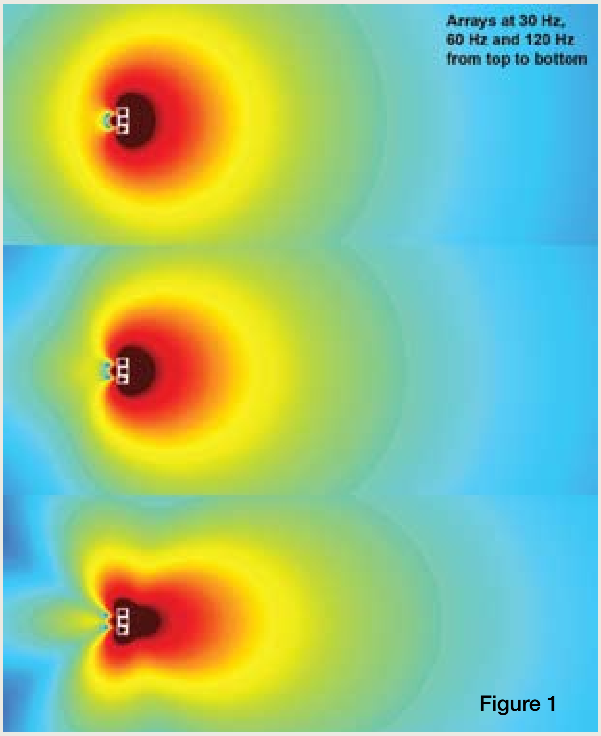

Figure 1

a perfectly functional approximation by taking the cabinet depth and multiplying by two. To convert from distance to delay, remember that sound travels approximately one foot every 0.9 millisecond.

I've been using three cabinets throughout this example because most subwoofers are slightly directional due to their size, so the energy arriving at the rear of the array is already down 2-3 dB. For ideal cancellation with just two subwoofers we would therefore need to turn down the input to the rear-facing cabinet.

Figure 2

I prefer to simply use three cabinets, two facing forward and one facing backwards, which elegantly accounts for the level difference. The same setup works using subwoofers stacked three high with the bottom one reversed, as in **Figure 2**. This can get you a lot of output and directivity from a very small footprint if height is not a concern.

END-FIRE PRINCIPLES

The second basic type of directional array is an end-fire array (**Figure 3**), which operates more like a shotgun microphone. The basic mechanism is to line up a number of subwoofers in the direction of the audience, and then delay each forward subwoofer back to the rearmost. As the energy travels down this line of subwoofers each contributes in time, creating forward addition.

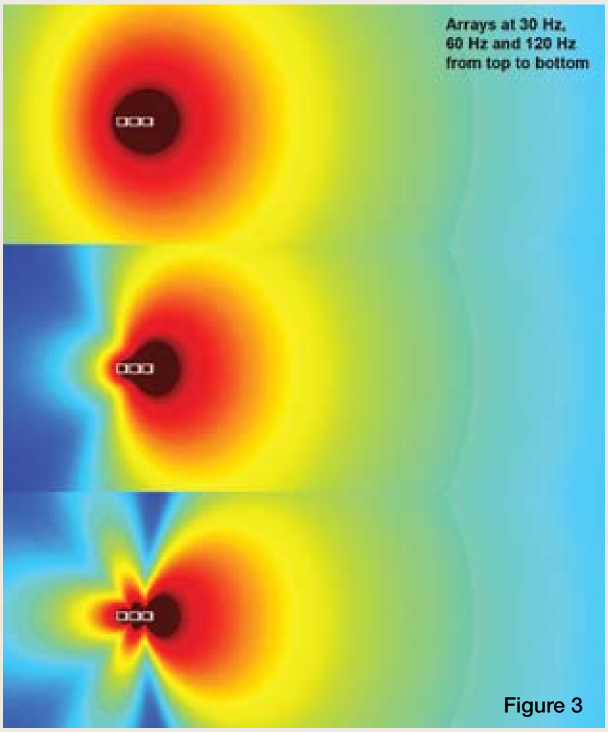

Figure 3

Simultaneously, rear-ward energy becomes a jumble of mixed time arrivals, which tend to cancel each other out. As loudspeakers are added to the array, the rejection to the rear and sides increases along with the output towards the audience.

To build an end-fire array you're going to need a number of identical subwoofers and a few channels of digital delay. Build a line of subwoofers spaced an equal distance apart (I find as little as 4 inches of separation to work very well). The subwoofer furthest from the audience will be time zero, so for every subwoofer closer to the audience add delay equivalent to the distance between it and the furthest.

There is a practical limit to the length of the line, as very deep arrays may cause more rejection to the sides than is actually desired, so it may be helpful to determine ahead of time what kind of pattern you require.

For an extreme example, **Figure 4** shows an 8-element deep end-fire array at 60 Hz. There are some lobes to the side of the array, but the forward behavior remains excellent while the rearward rejection is tremendous. I find 3-4 subwoofers deep to be a reasonable compromise between rejection, size, and complexity for these arrays.

PROS & CONS

Both methods create rejection, so the important question is where and at what frequency? Cardioid arrays tend to have a very stable pattern because of their use of polarity inversion.

They can also often be built within the same footprint as a traditional array. Further, by slightly varying the delay for the rear subwoofer it is possible to narrow or widen the pattern in order to fit your exact application.

The trade-off with a cardioid array is reduced output as frequency drops; since one subwoofer is polarity inverted, as the wavelengths get longer the subwoofers begin to behave like a single source and cancel in all directions. In practice, this reduction in output is not critical as long as the array is built with a reasonable center frequency in mind.

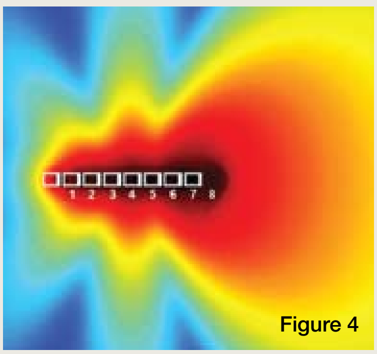

Figure 4

End-fire arrays have their own set of compromises. The primary advantage is near-perfect addition in the forward direction, and the primary disadvantage is the physical space required to implement them.

Additionally, as

subwoofers are added to the line, more separate delay taps are required, which may require more amplifier or processor channels than are available.

Most importantly, an end-fire array depends entirely on phase interaction to create rejection and therefore has a different pattern at every frequency, as the wavelengths involved are different at every frequency. This can create uneven frequency response off-axis, which exacerbates the issue of where in the audience area to equalize the PA.

APPLICATION PRIMER

Once you've built a few directional arrays. you're naturally going to want to integrate them into a larger system. This is where acoustic modeling software comes in very handy, since in some cases arrays of directional subwoofers don't behave like arrays of conventional subwoofers.

Especially when integrating traditional and cardioid arrays, extra care must be taken to verify that the results are as expected. We all have a lot of experience working with conventional subwoofers - it can be frustrating to put together an array only to find it does not behave the way you predict.

For an example of unexpected but beneficial behavior, imagine that we are in a venue that has a very wide audience area. Traditional left and right stacked subwoofers (**Figure 5**) provide inadequate coverage: too much bass down the middle and to the extreme sides relative to the majority of the audience area.

By substituting end-fire arrays at 45-degree angles (**Figure 6**), coverage is dramatically improved for all but those just off center! Where audience members to the sides were hearing both subwoofer arrays but at different times, now where one array is the loudest the other has significant rejection, reducing interaction and improving coverage - especially 45 degrees off axis where before there was no energy at all. (This works just as well with cardioid arrays, of course!)

All of these arrays can be used to create a low frequency system that provides very even coverage over large or small audience areas, with the added possibility of keeping a lot of that arena-rattling bass off your stage and out of your microphones.

GETTING ALONG

It's important to recall that the subwoofer system is but one component of a series of systems all working in concert to create even energy over your audience area. Just because you have a flawlessly designed and deployed low frequency system doesn't mean that it will operate the same when integrated with other acoustic sources.

Critically important and notably left out of most subwoofer discussions is how the subwoofer and main PA arrays behave together. At 30 Hz this is not a concern, but up near the crossover frequency it can be a serious problem.

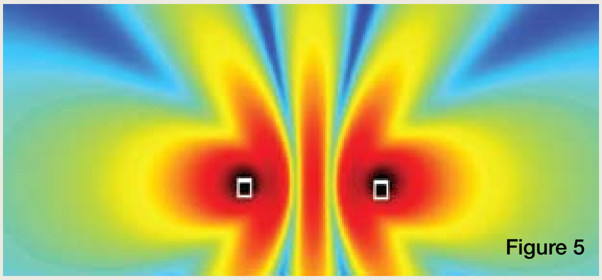
Figure 5

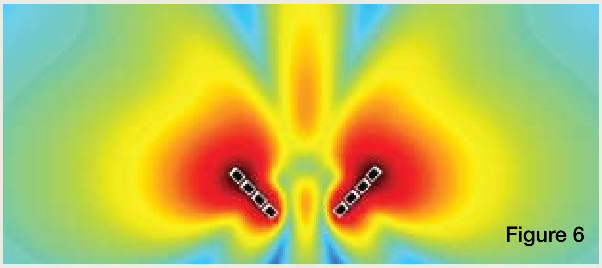
Figure 6

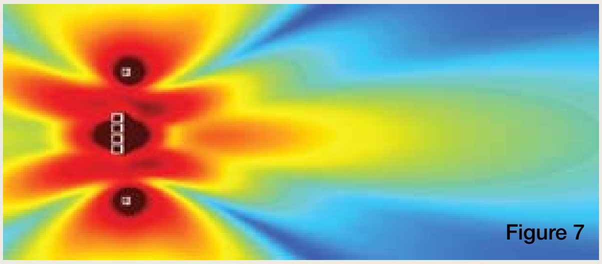
Figure 7

Consider that at the acoustic crossover frequency, by definition the mains and subs are producing equal level. This means that in the crossover region the mains act as a subwoofer system all to themselves! In short, your formerly perfect subwoofer system is now compromised by left- and right-stacked subs anyway, in the form of the main loudspeakers (**Figure 7**).

Unfortunately, discussing that issue, and the many others that arise with system integration, could take another 100 pages. Some solutions I've employed include utilizing both center clustered and left/right subs, or deploying a very wide center sub array (i.e.. the width of the stage and/or venue). In this case there is not one definitive answer, but another excellent reason to get your hands on some acoustic modeling software and play around.

Not all software will work below 100 Hz, but there are several programs that will and many of them are also free. (Most images for this article were generated by G.P.A. 2.2, http://gpa.hms2k.cl/.) I highly recommend modeling first, using realistic numbers of loudspeakers and distances whenever you consider deploying advanced subwoofer arrays. ■

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