ProSoundWeb EXPERT SERIES

"RUN & GUN" SUBWOOFER ARRAYING TECHNIQUES

"RUN & GUN" SUBWOOFER ARRAYING TECHNIQUES

Trial and error, plus a willingness to walk around and kick boxes a few feet this way or that, can make a big difference.
By Bennett Prescott

Of all the tweaking I do as a system tech, the most common is fixing mediocre subwoofer setups. Problems in this area are so prevalent that many audio professionals take them for granted or assume there is no room for improvement.

However, there is often a better solution, and further, it's usually free of charge and can be accommodated by most system layouts. Let's have a look at subwoofer response in a free field (i.e., outdoors) to observe how common subwoofer setups can offer inadequate coverage and to discuss ways they can be improved.

First, a quick primer on how a sound wave operates. Typical subwoofer frequencies range from 30 to 120 Hz, a span of two octaves that corresponds to wavelengths from 38 feet to 9 feet. Why is wavelength significant?

Figure 1 represents a common omnidirectional subwoofer. Because this single sound source is acoustically “small” relative to the size of the waves it reproduces, it has negligible effect on them.

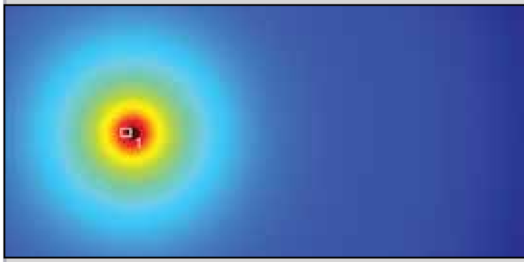

Figure 1

A source is acoustically small when no dimension of the source is larger than one-quarter wavelength at the highest relevant frequency. Any small source will exhibit near-omnidirectional response. This makes it very predictable and easy to work with, and fortunately most individual subwoofers meet this criterion.

Pattern Narrowing

Unfortunately, there is no single subwoofer that has enough output for even moderately sized events, so you’re going to have to use a lot of them. When you take a perfectly good subwoofer that has a lovely omnidirectional pattern and place it next to two, four, eight or more of its peers, the resulting arrangement no longer has an omnidirectional pattern.

What happens is that the dimensions of the subwoofer array have become acoustically “large,” and the collection of sources are no longer within one-quarter wavelength of each other. The increasing size of the array causes something called pattern narrowing, demonstrated in **Figure 2** using two and four subwoofers.

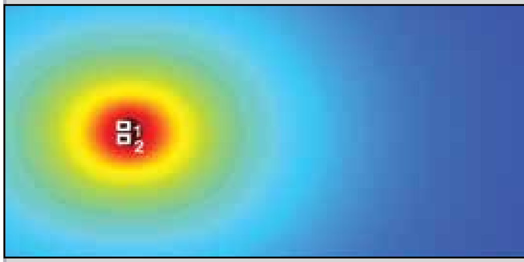

Figure 2

To understand why this narrowing occurs, it helps to have a working knowledge of phase. Phase is the time offset between two waves, measured in degrees, as shown in **Figure 3**.

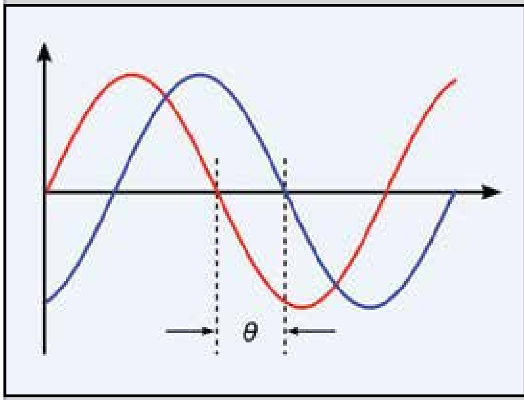

Figure 3

If you imagine a wheel, one full turn of the wheel would be 360 degrees of phase, or one full cycle of the wave. Half a revolution would be 180, or half the wave, and so on. The behavior of two waves interacting depends on their phase relative to each other. That is to say, two waves perfectly in phase (0 degrees difference) will add coherently, for 6 dB of gain. Two waves 180 degrees out of phase will cancel perfectly.

Any other phase relation will result in somewhere between perfect addition and perfect cancellation. Most importantly, up to 90 degrees of phase deviation will result in between 3-6 dB addition, and 120 degrees will result in no level difference (0 dB).

As long as the phase difference between two sources can be kept within 120 degrees there will at least be no loss in level, so this should be our goal. Crossing over the 120-dgree precipice results in rapidly increasing cancellation until 180 degrees is reached and the two waves cancel completely, so this region is to be avoided at all costs!

Time & Cycles

Phase can be a difficult concept to grasp because we are used to thinking of time differences in milliseconds (ms). To think in terms of phase, you need to consider frequency, i.e., how many cycles the wave goes through in a given period of time, as they are interrelated. A 60 Hz sine wave is about 19 feet long, and takes about 17 ms to complete (1/60 of a second).

For example, if we have two subwoofers spaced 3 feet apart, how different will the phase of the first subwoofer's wave be when it arrives at the second subwoofer, and will their energy add or subtract?

Table 1 shows us there will be about 60 degrees of phase difference, which will still result in over 3 dB of addition over a single subwoofer. Remember that this is only the difference at the second subwoofer's location, which is the worst case scenario. In any other direction the phase difference between the two subwoofers will be smaller and cause even more addition, so at 60Hz this spacing will still result in a very smooth pattern.

Because the spectrum of live audio covers more than just 60 Hz, however, it is critical to view its operation at more than one frequency. If we view the same example from the last paragraph at 120 Hz — twice the frequency and therefore twice the phase shift over the same distance — things have changed significantly.

Table 1 also shows that at 120 Hz there will be 120 degrees of phase difference for the same 3 feet of spacing, which results in no addition and might indicate that this spacing is becoming problematic. Of course, there may be no audience members in the area of no addition, which might make it a non-issue for your application. (In very wide venues or venues with wraparound seating, for example, this could be trouble, but perhaps not for the majority of audience arrangements.)

Limited Control

With the math out of the way, we return to the subject at hand: why subwoofer arrays behave the way they do, and how to make this behavior work in our favor. Ideally, we would set up our subwoofer array so that it produced even response with perfect addition everywhere in the audience area, and perfect subtraction everywhere the audience isn't.

This would be wonderful, but in the real world we have a limited amount of control over these long low-frequency wavelengths. What control we do have is directly proportional to the length of our array, which is a double-edged sword. As our array grows it becomes acoustically "large" and its pattern starts to narrow, but at the same time we have more control and can use several techniques to rearrange the pattern so it works better for us.

***Determining Wavelength** Wavelength is a function of frequency and the speed of the wave in the medium it is traveling in. In the case of sound waves, which move at approximately 1,125 ft/sec in dry 68 degree air at sea level, the following function may be used: $\lambda = v/f$ where v = speed and f = frequency. At 60 Hz, therefore, the wavelength of sound would be 1125/60=18.75'.*

Phase Effects on a 60 Hz Sine Wave

Phase (degrees)	0	30	60	90	120	150	180	210	240	270	300	330	360
Sum (dB)	+6	+5.4	+3.5	+3	0	-5.75	[illegible]	-5.75	0	+3	+3.5	+5.4	+6
Delay (ms)	0.0	1.4	2.8	4.2	5.6	6.9	8.3	9.7	11.1	12.5	13.9	15.3	16.7
Distance (feet)	0.0	1.6	3.1	4.7	6.3	7.8	9.4	10.9	12.5	14.1	15.6	17.2	18.8

Phase Effects on a 120 Hz Sine Wave

Phase (degrees)	0	30	60	90	120	150	180	210	240	270	300	330	360
Sum (dB)	+6	+5.4	+3.5	+3	0	-5.75	[illegible]	-5.75	0	+3	+3.5	+5.4	+6
Delay (ms)	0.0	0.7	1.4	2.1	2.8	3.5	4.2	4.9	5.6	6.3	6.9	7.6	8.3
Distance (feet)	0.0	0.8	1.6	2.3	3.1	3.9	4.7	5.5	6.3	7.0	7.8	8.6	9.4

Table 1

Figure 4 shows a typical left/right stacked subwoofer setup at 60 Hz. Down the center line of our imaginary audience. the sound from both subwoofers arrives at the same time, or with very little phase difference, and exhibits near-perfect summation. This is where the term "power alley" comes from.

As you walk off-axis, however, you are "walking around" the phase wheel, one subwoofer's signal relative to the other. Energy now arrives 90 degrees out of phase, then 120 degrees out of phase, and finally you walk into the dark zone where the two signals approach 180 degrees phase difference and cancel each other. Depending on the frequency, more than a third of your audience might as well have no subwoofers at all!

This situation cannot be fixed by turning up the subwoofers or equalizing them, the problem is caused by time arrival differences. To fill in those dark areas another subwoofer setup must be considered.

Making It Wider

Looking back at Figure 2, we can begin to see a solution. Putting all of the subwoofers together yields a much more consistent pattern throughout the audience area.

Unfortunately, as subwoofers are added to meet our output needs, the coverage pattern narrows. **Figure 5** shows a 6-foot-long array, and while the response looks a lot better than our left/right subwoofers (Figure 4), it has narrowed to the point that some audience members will be out of the coverage before they are beyond the coverage of the main loudspeakers. This leaves much of the audience with mismatched low-frequency response.

However, "a little delay will do you." This pattern widening technique works either with electronic delay (**Figure 6**) or by physically moving the subwoofers (**Figure 7**). The major difference is that physical delay focuses the sound behind the array (i.e., on stage) while digital delay affects both sides of the array equally, widening the pattern behind and in front.

Since many of us aren't carrying several extra channels of digital delay, or additional amplifier channels to use it, the physical solution is cheap and cheerful. I've reduced the arrival time difference for listeners off-axis without damaging the response for those in the center of the audience.

By moving the outside subwoofers backward by as little as a foot and a half, the array's pattern is substantially altered. You can experiment with varying amounts of arc to meet your specific needs.

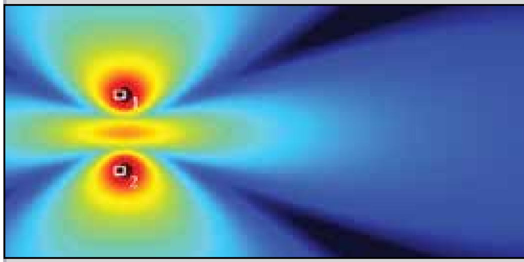

Figure 4

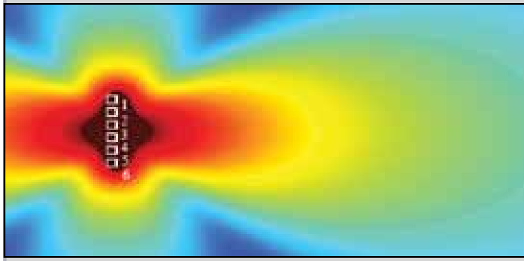

Figure 5

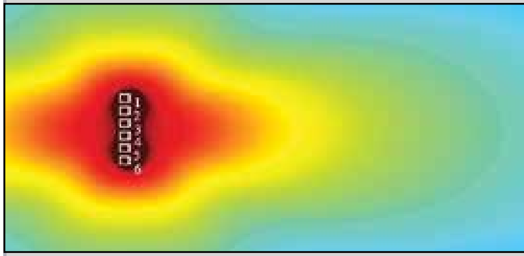

Figure 6

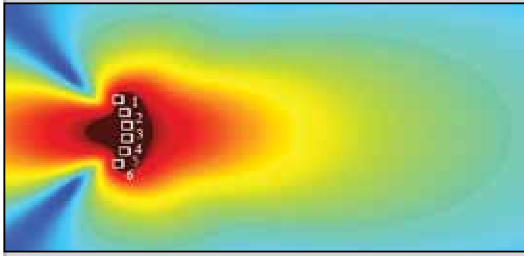

Figure 7

Other Avenues

There are a few other ways to attain better response than left/right stacked subwoofers, even if you don't have a whole lot of subs. **Figure 8** shows one possibility. I find that putting 50 percent of the subwoofers in the center is a large improvement.

Another option is to spread out available subwoofers as shown in **Figure 9**. The predicted responses may not look as pretty as the center clustered subwoofer setup, but remember that we're only looking at a single frequency here. The pattern will look very different elsewhere in the subwoofer array's frequency response, but either way it's a heck of an improvement over "traditional" left/right stacked subwoofers.

These are just a few of countless ways to skin this cat. The best way to get better at subwoofer arraying is to do it a lot, and to experiment with prediction software. Trial and error, plus a willingness to walk around and kick boxes a few feet this way or that, will help you understand these systems better. I still learn something every time I put a system together.

Next time I'll be looking at directional subwoofer arrays and integration with the main PA.

Editor's Note: *Most of the images for this article were generated by G.P.A. 2.2, a freeware product of Chilean coder Sebastian Rivas Godoy. For more info go to http://gpa.hms2k.cl/. The phase shift graphic is courtesy of Wikipedia user Peppergrower.*

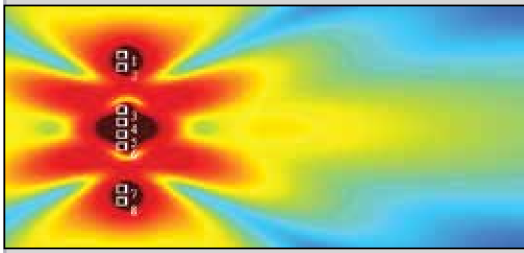

Figure 8

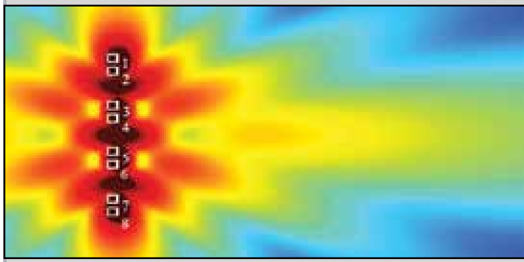

Figure 9

BENNETT PRESCOTT *is an independent engineer/technician specializing in sound system design and deployment.*