THE SUBJECTIVE AND OBJECTIVE DIFFERENCES BETWEEN SUBWOOFER TOPOLOGIES IN DIFFERING APPLICATIONS

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ABSTRACT:

This paper seeks to compare and contrast the main differing methodologies employed in generating and controlling low frequencies, or sub bass, in Professional Audio applications today.

The different systems offer pros and cons in terms of acoustical output, directivity and bandwidth, and this forms a key part of this investigation. However, while there are many objective means by which the systems can be compared, it is considered that an accompanying subjective approach can provide a better insight into why certain systems are utilised and others are less favoured.

To illustrate the commentary here, and as part of further work on this subject, a practical demonstration will also be made as part of this paper's presentation at Reproduced Sound 23 at the Sage, Gateshead, UK.

1 INTRODUCTION

The use of multi-way loudspeaker systems is, and always has been, common in professional audio. The necessity of generating sound pressure levels necessary to cover large audiences has meant that optimised components covering dedicated areas of the audio bandwidth are essential. This is especially true of very low frequencies or 'sub-bass' as it is commonly referred to.

Today there are numerous methods commonly utilised for the reproduction of sub bass, each with its pros and cons. This paper seeks to differentiate between these models, not only by acoustical output, but also by practical and also subjective means, as used in the 'Professional Audio' market.

In some parts of this paper, other manufacturers are referred to in terms of assessing the state of the art. Their specifications are included as per the data on their websites and are qualified where possible. It is not the intention of this paper to differentiate between the manufacturers, only to use their products as further information on what the market is using at this time.

2 WHAT IS REQUIRED FROM A 'SUB BASS' SPEAKER?

2.1 Bandwidth

Sub bass systems are *typically* referring to speakers dedicated to producing 160Hz and below. However, there is no hard and fast rule here; bandwidth of these systems depends on the 'full range' or 'mid-high' systems with which they are coupled. As with the term "sub bass" the "full range" and "mid high" terms are fairly arbitrary. Below are some examples in current usage and from JBL Professional's recent history:

HLA (3-way horn loaded system)
4895 'Mid High' high passed at 120Hz
4897 companion subwoofer low passed at 120Hz

VerTec (Line Array System)
VT4889 'Full Range' high passed at 40Hz
VT4880A companion subwoofer low passed from 80Hz depending on application.

PD Precision Directivity Series (2 or 3 way horn loaded systems)
PD5200 8"+1.5" 'Mid high' high passed at 204Hz
PD5322 2x12"+8"+1.5" 'Full range' high passed at 60Hz
PD5125 2x15" companion subwoofer low passed from 250Hz depending on application.

VP Venue Performance Series (2 or 3 way internally amplified systems)
VP7212/95 internal high pass filter 50Hz
VP7315/64 internal high pass filter 35Hz
VPSB7118 companion subwoofer low passed from 80Hz to 120Hz depending on application. "Overlap" of the bands rather than strict "crossovers" is more typical with these systems.

As this illustrates, there is significant variation, even within one manufacturer. To make matters more complex, there are also differing types of subwoofer and also some very different ways of using them.

The current trend in the market is to use more "full range" systems with sub bass used driven either as an auxiliary send or for increase in headroom and impact. This is especially common with the larger scale 'line arrays' that are prevalent in the tour and installation market at present. Aside from developing new subwoofers, extensive work [1] has recently been undertaken to develop presets that optimise integration of the subs in this system. This was deemed important due to the way in which these systems are typically operated with the "LF" (Low Frequency) section of the system overlapping significantly with the traditional 'sub-bass' band.

2.2 Directivity, size and acoustical output: Different Sub Choices

Subwoofers are generally omni-directional devices and typically require more power than the rest of the audio band to achieve the desired sound pressure level. Sub bass performance, both in bandwidth and directivity terms is strongly dependent upon the physical size of the speaker enclosure and this creates a number of potential practical issues.

The main types/methodologies in common use today are as follows:
(1) **Direct Radiating Subwoofers**, typically containing one or two 15” or 18” drivers. These can be made to be quite compact and can easily be adapted to different physical form factors to meet practical requirements. Typically these are limited in directivity control and require high power to achieve the required sound pressure output.
(2) **Horn loaded Subwoofers**, loaded with a wide range of components from 12” to 18” depending on the requirements for the system. They offer increased system efficiency in terms of dB out for Watts in, but are typically large and heavy.
(3) **Cardioid Subwoofers**, usually made from direct radiating devices with some ‘rear firing’ transducers designed to reduce the output from the rear of the speaker. Systems gain directional control, but often also gain substantially in size and weight.
(4) **Steered Arrays** (such as FSA from JBL Professional), utilising DSP to control where the sub bass ‘beam’ of sound is aimed, with a view to being more efficient than the standard cardioid approach. They offer a potentially superior alternative solution to the cardioid array but require many more speakers and a more complex system configuration.

2.3 Which is most suitable?

Much of the driving force behind the selection of these (or indeed any) speakers comes from prior experience and is based on ‘what worked before’, though there are some consistent strong preferences in certain market areas. Leaving aside the more subjective requirements for the moment (we shall cover these more later) there is a stronger requirement for the cardioid or steered array in venues where the reverberation time is significant, or where sub energy must be reduced behind the array. Venues such as sports arenas are particularly likely to have high reverberation times but also to demand ‘high impact’ music for crowd entertainment; this is most common in the USA, though it is showing a strengthening demand in Europe and elsewhere.

The requirement for the directional speaker array is quite clear for highly reverberant venues, but the other systems are less obvious in what their benefits and drawbacks are. We shall now evaluate what the different approaches provide in terms of acoustic output and practical usage.

3 SUBWOOFER TOPOLOGY TYPES IN COMMON USAGE

3.1 Direct Radiating Systems

This is the most prevalent subwoofer system type with virtually every pro-audio manufacturer offering at least one within their portfolio.
One main advantage of this type of system is that it is relatively easy to construct and therefore can, if required, be made to meet the needs of the lower budget end of the market.

Performance of these systems is largely dependent on the drive units that are utilised. Of course the construction should be robust and free from major resonances and the port tuning needs to be appropriate; however the main difference in comparing one direct radiating subwoofer with another will be centred around the transducer(s) used.

Pricing for these systems can vary dramatically from a few hundred pounds/euros/dollars up to a few thousand. (Within the JBL Professional range, the price difference from the entry level "350W" 1x18" system to the premium performance tour sound 2kW 1x18" system is a factor of 8).

Form factor is a big differentiating factor in the choice of these direct radiating boxes. Some are compact, designed to fit in small spaces in installations; some are designed with dimensions to match the "top box" (mid-high or full range) in the system for easy rigging.

Other than this, the major differences are down to the components used, as described. Starting with the most basic of pressed steel drivers with relatively small voice coils up to large output devices, sometimes with two voice coils (such as the NDD Neodymium differential drive).

3.2 Horn Loaded Systems

While horn loading is used extensively throughout the professional audio industry for mid and high frequency reproduction, low frequency or 'sub' systems are much less common. While there are those that prefer the sonic characteristics of this design – and the clear increases in sensitivity that are possible with the correct design, the main objection to use is typically size and weight.

Four manufacturers of horn loaded subs are shown below:

	High Output Horn Loaded	**2x18" Direct Radiating**	Reference Info; Quotes from websites **on the horn loaded designs**
JBL Pro ASH6118 ASB6128	160kg [1x18"] 564x1530x1288 25-250Hz 1200W (AES) 133dB (2pi)	73kg 1094x561x816 28-1kHz 2400W (AES) 136dB (2pi)	http://www.jblpro.com/ Horn loaded device: *Excellent "punch"* 5dB increase in sensitivity for 4 cabinets and 3Hz LF extension.
Turbosound TSW-218	110kg [2x18"] 574x1400x770 35-150Hz 1200W (rms) 135dB (2pi)	Not offered	http://www.turbosound.com/ Horn loaded device: *"high definition bass"* 6dB increase in sensitivity for 4 cabinets
EAW BH822e SB1000	164kg [2x12"] 813x914x1295 21-300Hz 1000W (AES) 139dB (2pi)**	73kg 538x757x1072 28-156Hz 2000W (AES) 133dB (2pi)	http://www.eaw.com/ Horn loaded device: "*high levels of tight, punchy bass"* "The BH822e subwoofer system is engineered for use in arrays of four or more modules". ** "An array of four BH822e's will produce a maximum output of 146.0 dB"
Martin Audio S218+ WSX	95kg [1x18"] 572x1066x936 28-150Hz 600W (AES) 132dB (2pi)	87kg 561x1066x780 28-150Hz 1500W (AES) 136dB (2pi)	http://www.martin-audio.com/ Horn loaded device: *"ideal for reproducing the concentrated bass energy of contemporary dance music*"

As we can see, there is a benefit in either bandwidth or direct SPL from utilising the horn-loaded design. Also, clearly there is a downside in terms of physical size, weight and therefore practical handling.

3.2.1 The subjective 'audio benefit' of horn loaded systems

Almost all pro-audio people who talk positively about the horn loaded system refer to a 'punchy' or 'tight' bass sound. Indeed, all the manufacturers listed above mention the *quality* of the bass when talking about this design, more so that with the direct radiating offerings.

Of course there are some people who do not like this system, even from an acoustical perspective, talking of issues of phase correction and time alignment problems.

In most cases though, the *acoustical* performance is appreciated, but the benefits that this may bring are far outweighed by the practical benefits of direct radiating designs. Some will even argue that the acoustical benefits of one cabinet are lost as it is easier to rig multiples of the direct radiating design.

3.3 Cardioid Systems

The cardioid arrangement of subwoofers is a technique used to create a large amount of rejection to the rear of the subwoofer. It is accomplished by spacing a second source behind the first source, inverting the polarity, and delaying the source by the propagation distance between the sources. It has the advantage of a large, useful bandwidth of effectiveness given a relatively small spacing of devices. How good the 'rear rejection' is depends on the geometry and design of the overall array.

As a design, this is something that many consultants and installation companies have utilised with numbers of speakers from various manufacturers. However, a relatively new option is the "packaged" cardioid system and while these have grown in popularity over the last few years, currently there are still only a few manufacturers actively pushing the concept.

NEXO CD18	132kg [1x18" + 1x18"] 750x1200x750mm 29-180Hz 1500W+1500W (unqualified) 139dB (2pi)	http://www.nexo-sa.com/user/data/CD18.pdf
d&b J-Sub	106kg [2x18" + 1x18"] 540x1100x945mm 32-100Hz 800W+400W (rms) 138dB (2pi)	http://www.dbaudio.com/en/systems/j_series/j_sub/index_html#da
Meyer M3D	179kg [2x18"+2x15" c/w amps] 1372x508x775mm 29-95Hz 1200W+600W (AES) 140dB (2pi)	http://www.meyersound.com/mseries/m3d-sub/

Like the horn loaded systems, they tend to be large and heavy. The acoustic output of the devices is marginally better than for the direct radiating systems but this is largely due to an increase in power rather than efficiency.

In terms of the *quality* of the bass, none of the listed manufacturers overtly discuss this other than mentioning the benefits of reduced excitation of the reverberant field rather than the overall sound. This is in contrast to the horn loaded designs which are actively promoted based upon the subjective 'impact' of the sub bass produced.

3.3.1 Possible issues with cardioid system

Based on what is currently available from different manufacturers, is would seem that the market is largely undecided on whether or not the cardioid system is useful, and this may be in part due to the trade offs in the array design; a penalty is paid in terms of the sensitivity of the resulting array. Rather than summing coherently – that is, +6dB per doubling of devices – the cancelling devices do not add energy to the front of the array and can in fact reduce the level slightly.

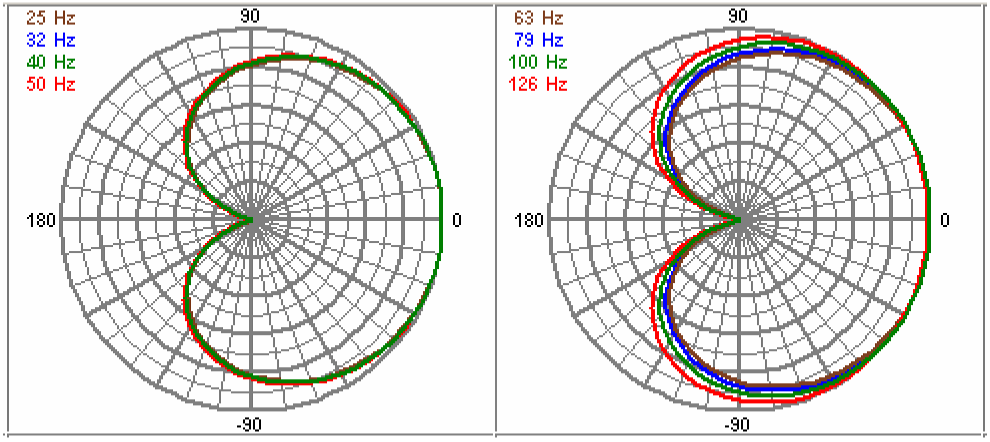


Figure 1: Cardioid Array Polar

Effective spacing of the devices is from 1/8 to 1/4 wavelength. Smaller spacings maintain useful rejection, but begin to degrade sensitivity.

3.4 'Steered Array' and 'Shaded Array' Bass Systems

These are less common and the FSA (forward steered array) approach is, at present, only currently being furthered by JBL Professional for use with their Precision Directivity systems.

There are several means to create useful directivity control however. These require some combination of organising multiple sources into arrays and manipulating their source signal.

Generally, to create directivity, the spacing of the sources must be on the order of the wavelength being manipulated. Two sources that are spaced one-half wavelength apart will produce a null at 90 degrees from the axis along which they have been spaced.

A column of sources will provide increased directivity as the frequency increases. Once the wavelength approaches the spacing of the devices however, practical use of the array is lost due to lobing and nulls created in the pattern.

Several schemes to maintain consistent directivity throughout a given bandwidth have been used. Most common is a method typically referred to as "frequency shading". This very practical method simply keeps the length radiating portion of the array consistent throughout frequency. This is typically done by low passing the outer portions of the array at a lower frequency than the inner portions.

3.4.1 Shaded arrays:

A simple 4-element shaded array may be constructed with four low-frequency sources. Here, the two outer boxes are crossed over to the two centre boxes at 140 Hz to create an array that matches the requirements of a typical space described above, and extends useful directivity past 125 Hz. (Fig 2)

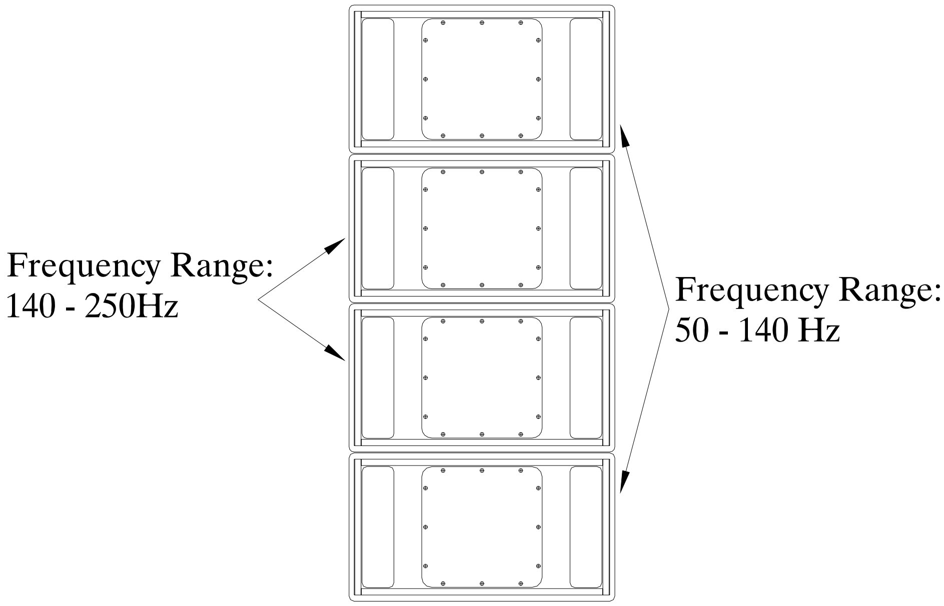
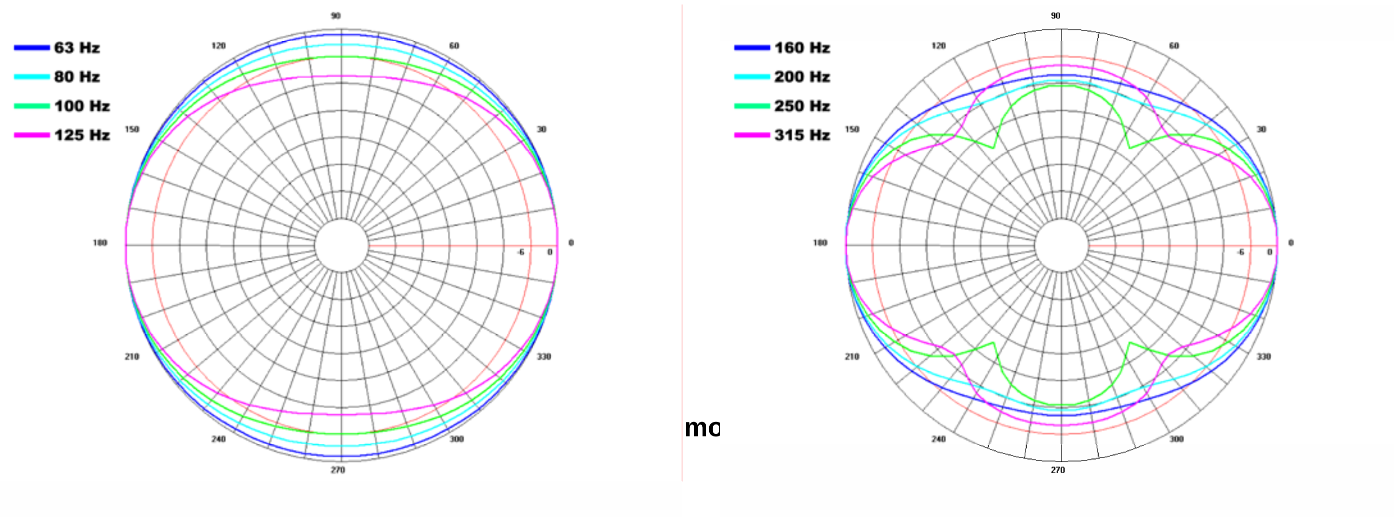


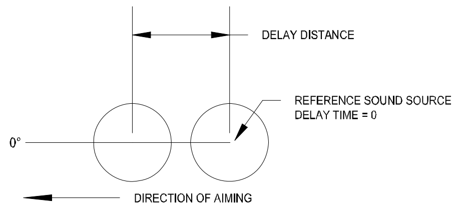
Fig. 2: Four-element shaded array

The resulting polar pattern is shown below:



3.4.2 Steered Arrays

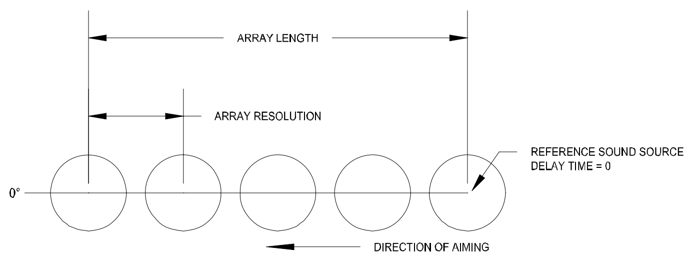
The use of end-fired arrays is an effective way to improve off-axis rejection. The simplest example to consider is where two drivers are spaced on-axis to the direction of aiming. When the front driver's signal is delayed corresponding to the sound propagation time between the drivers, there is coherent summing in the direction of the array.



TWO–DRIVER END–FIRED ARRAY

If the spacing of the two drivers is chosen to be one-quarter of a wavelength, then at that frequency there will be a null behind the array. This is the result of the forward element being delayed ¼ wavelength added to the physical separation of ¼ wavelength. The energy directly behind the array is then offset ½ wavelength creating a null at that single frequency. With a two-element array, this null changes into useful attenuation for about half an octave or so centred on this frequency centre.

When multiple elements are used in an end-fired line-array configuration, the length of the array determines its low-frequency useful limit and the resolution or spacing of the elements determines its useful upper limit – that is, where the side lobes are at least 6 dB lower than the main lobe. At the lower limit, approximately 6 dB of off-axis rejection is provided when the length of the array is approximately ¼ wavelength. At the upper frequency limit, the side lobes remain 6 dB less than the main lobe when the resolution or spacing of the array elements is less than approximately half the wavelength.



FIVE–DRIVER END–FIRED ARRAY

This concept can be expanded to two dimensions. This technique, also called a "forward-steered" [2] array can begin to develop very high-powered subwoofer arrays due to the sheer number of sources that can be effectively arrayed.

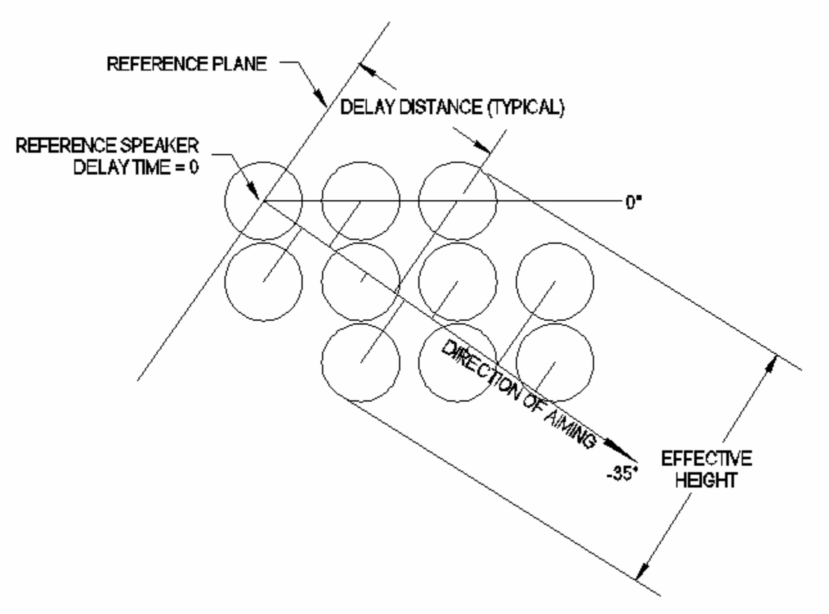


Fig. 4: Forward-steered array

An array such as this not only provides rejection from behind the array, but, if made large enough, can also provide useful vertical directivity. The resulting main lobe direction may be steered digitally simply by modifying delay times.

The array is designed to be steerable in the vertical direction. Note that when the arrays are steered downward, the apparent spacing between drivers is reduced – a fortuitous event that pushes the theoretical upper working frequency limit of the arrays upwards. So that the horizontal polar is kept wide, the horizontal driver to driver spacing is minimized. Horizontally, the array behaves like a spaced pair of sources. This configuration, when steered at an angle of 35 degrees, creates a polar response as shown in Fig. 5.

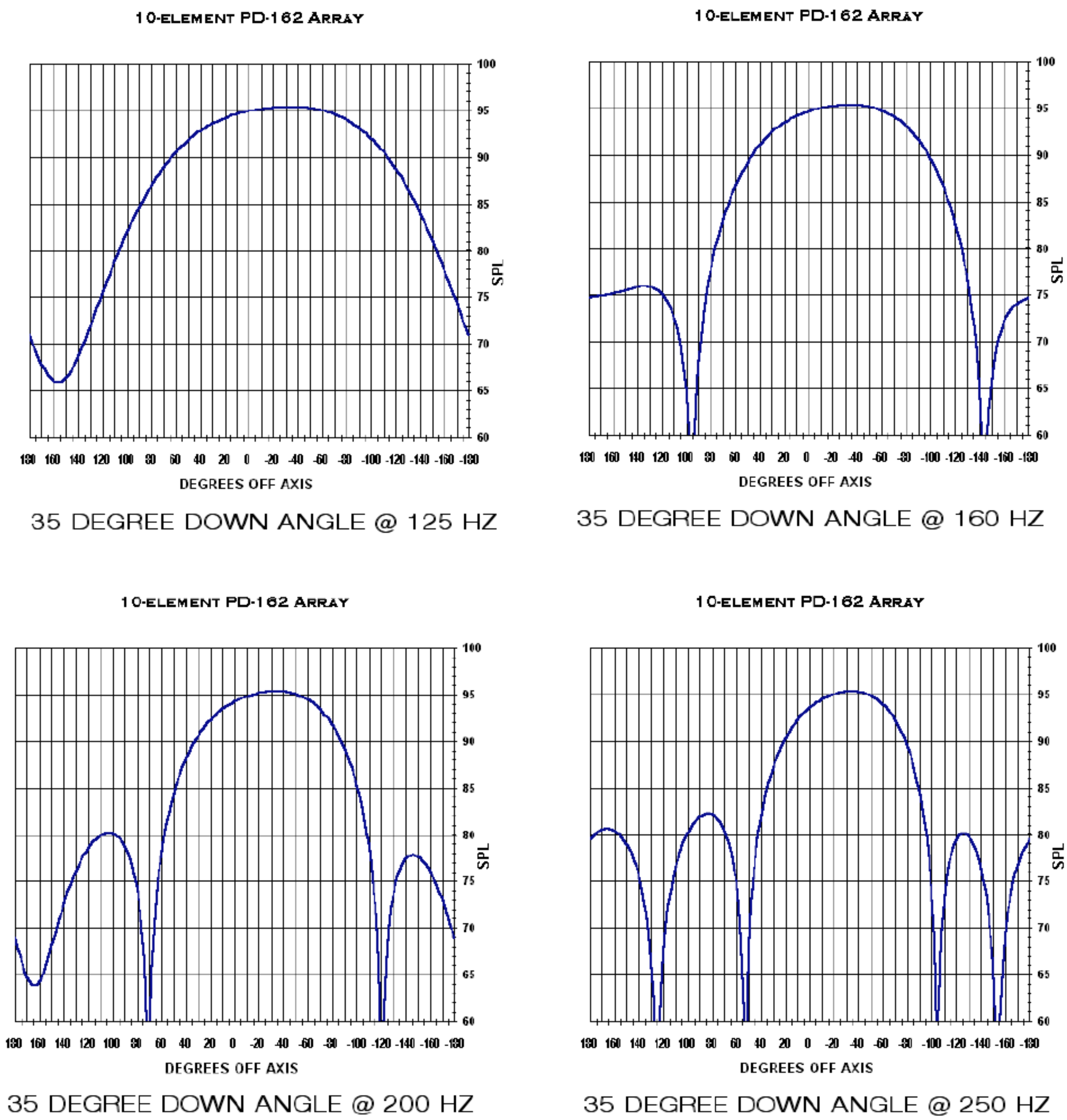


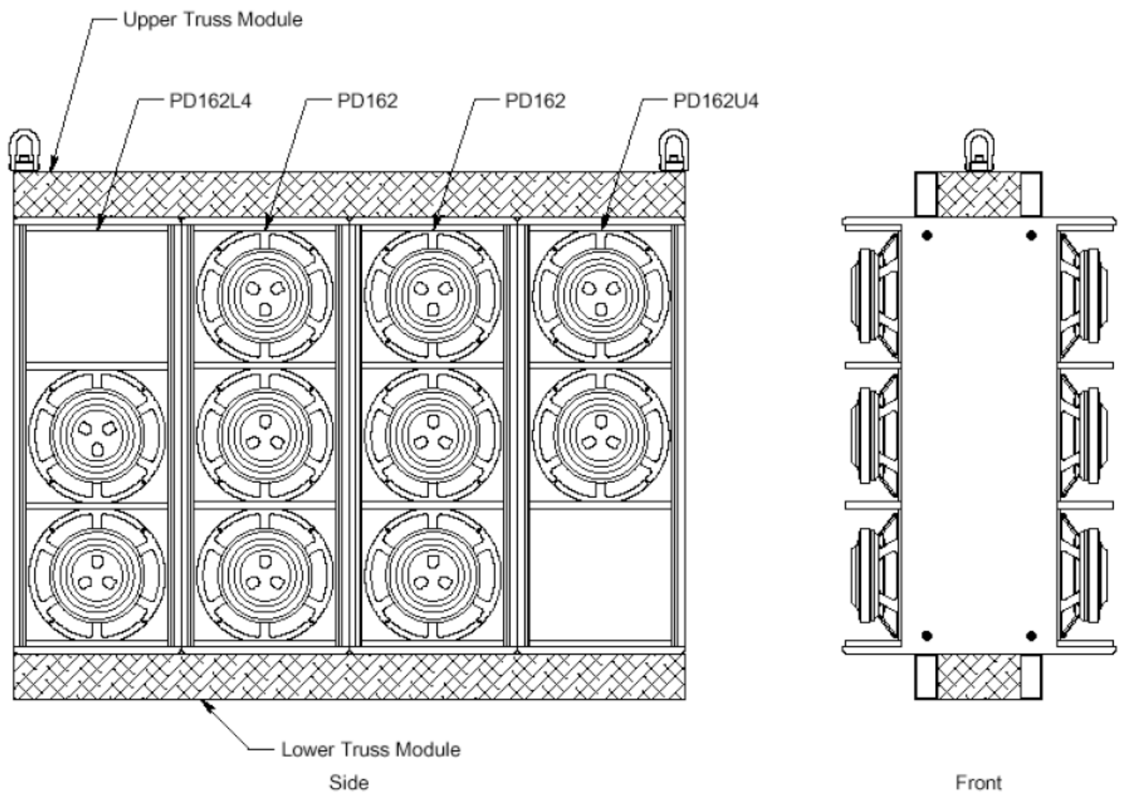
Fig. 5: Response of a 10 element forward-steered array

One advantage of end-fired or forward-steered arrays over a cardioid array is that all sources sum coherently – with each doubling of sources a +6dB increase in SPL is achievable. However, to achieve similar off-axis rejection, the array must be deeper.

3.4.3 Practical problems with steered arrays

The forward steered arrays are acoustically very effective, but are necessarily complicated and physically large. They are therefore only typically employed in large sports arenas and can be impractical for smaller venues.

The PD162 Based Low-Frequency Array:



PD162 Family FSA Array
1x PD162L4, 2x PD162, 1x PD162U4
Showing Arrangement of Modules and Truss Components

4 'LINE ARRAY' COMPANION SUBWOOFERS

These are a specific subset of the fore mentioned topologies and are worthy of mention mostly due to how widely used they are in the market today. Typical array sizes are 6-18 elements with each element around 500mm deep. Thus the total line is around 3-9m long – only sufficient to achieve limited directivity in the sub 125Hz band.

However, these arrays *can* subjectively achieve something similar to the 'horn loaded effect' in terms of 'punch' though this is something considered a topic outside this paper. Nonetheless, although these 'sub arrays' are often created for practical or even aesthetic reasons, their performance and flexibility means that they have become the system of choice for many touring companies around the world.

5 MARKET PERCEPTION

A simple survey of professional audio distributors within Europe revealed that over half of those polled preferred 18" direct radiating subs for their professional audio work with Cardioid based systems in second place with around a quarter of the vote. However, when questioned on their perception of the market their responses suggested that their preferences were not always in agreement with in the general market. [See Appendix 1]

It is also clear from the survey that the key objections to the more sophisticated steered and cardioid systems are cost and complexity. While the other objections tend to be based upon poor personal experiences with specific design types.

The most prevalent type of speaker currently sold and used in the market for tour sound and medium to large size installations is the line array. The companion subwoofers for these arrays also tend to hang in a line and this does provide some additional directional control.

6 CONCLUSION

Two processes drive the Professional Audio market. One is acoustical and practical benefits of certain systems for certain applications. The other is simply perception and historical use.

Where 'high level' users are employed to look at situations afresh, some interesting and exciting developments occur. However, with the ever present fear of failure in live audio and the conservative nature of the industry in general, it is often difficult to move a client or user to adopt or try an 'application specific' subwoofer if they have no prior experience. Getting experience requires somebody to be the first user, and this brings us full circle to overcoming fear and prejudice.

In tackling the issues of low frequency control, there is still much work to be done. Some simply on the acoustical performance of the devices, but much also on the practical handling aspects and form factor of the systems involved.

To summarise:

(1) **Direct Radiating Subwoofers**, Are still the market leader and this does not look like changing. They are practical, easy to use and widely accepted.

(2) **Horn Loaded Subwoofers** are popular in many applications not only for their increased acoustic output, but also for their perceived 'punch' and particular tonal quality.

(3) **Cardioid Subwoofers** are great solutions for acoustically difficult environments and situations where sound from the rear of the array needs to be reduced. There are few champions for them in terms of their *inherent* audio 'quality' at present.

(4) **Steered Arrays, Forward Steered Arrays [2]** While offering a potentially superior alternative solution to the cardioid array these systems are not widely used due to their physical size and complexity. However, these arrays are at the leading edge of low frequency directional control at present and offer a useful solution for installations where steerable low frequency directivity is required.

7 FURTHER WORK

It was hoped to be able to make some more experimental data available for this paper. However, the data is still not ready for publishing at this point. Further work will be done on the subjective perception of the impulse response of the differing subwoofer types mentioned and this will be published at a later date.

Demonstration and education are crucial. That way we can move the industry forward to make informed choices to use the best system for the application they are facing. Demonstration work, due to be undertaken at Reproduced Sound 23 will better define these differences.

APPENDIX 1 – Survey of 65 Professional Audio Distributors in Europe

Countries Included in this Survey: Austria, Belarus, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Israel, Italy, Latvia, Netherlands, Norway, Poland, Portugal, Romania, Russia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom, Yugoslavia

Respondents were asked to answer with their personal opinion
My favourite design of subwoofer is:
The market in my country seems to prefer this design:
My LEAST favourite design of subwoofer is:
The market in my country seems to LEAST like this design:

[ ] Direct Radiating with 18” drivers
[ ] Direct Radiating with 15” drivers
[ ] Horn Loaded with 15” drivers
[ ] Horn Loaded with 18” drivers
[ ] Cardioid based systems
[ ] Steered arrays (like JBL’s FSA Forward Steered Array)

Personal Favourite		**Personally Least Preferred**	
Direct Radiating with 18” drivers	55%	Direct Radiating with 18” drivers	6%
Direct Radiating with 15” drivers	8%	Direct Radiating with 15” drivers	13%
Horn Loaded with 15” drivers	0%	Horn Loaded with 15” drivers	31%
Horn Loaded with 18” drivers	6%	Horn Loaded with 18” drivers	16%
Cardioid based systems	24%	Cardioid based systems	16%
Steered LF arrays	6%	Steered LF arrays	13%

Local Market Favourite		**Market's Least Preferred**	
Direct Radiating with 18” drivers	26%	Direct Radiating with 18” drivers	6%
Direct Radiating with 15” drivers	19%	Direct Radiating with 15” drivers	14%
Horn Loaded with 15” drivers	2%	Horn Loaded with 15” drivers	19%
Horn Loaded with 18” drivers	30%	Horn Loaded with 18” drivers	16%
Cardioid based systems	17%	Cardioid based systems	18%
Steered LF arrays	0%	Steered LF arrays	28%

REFERENCES

1. **v4 VerTec Preset Development**, Paul Bauman, JBL Professional
2. **Technical Notes Volume 1, Number 28: Forward Steered Arrays in Precision Directivity™ Speaker Systems.** JBL Professional 28/08/2001