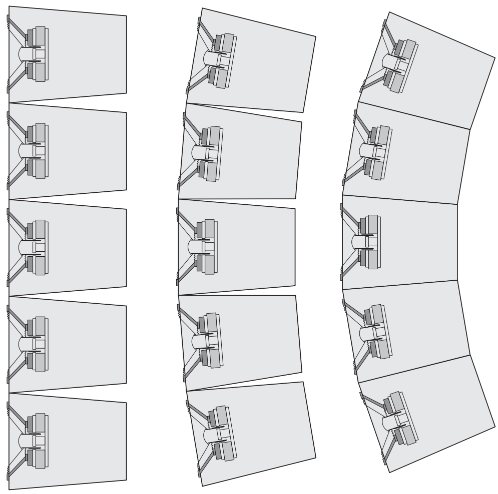
Application Note 2

Loudspeaker Arrays



■ **Highlights**

Sealed Highpass 2x15 Array
Custom Enclosure Model
Import 3D Enclosure Shell
Multi-Enclosure Analysis
Diffraction Analysis
Array Comparisons

■ **Objectives**

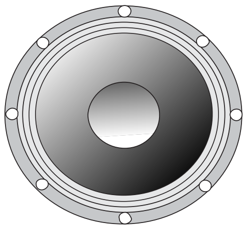
Design & simulate an array.
Evaluate Polar response.
Five 2x15 cabinets.
Compare array curvature.

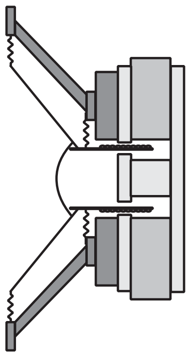
Loudspeaker arrays are commonly used in professional sound reinforcement where large theaters, arenas, and outdoor stadiums require substantial acoustic power. The revolutionary diffraction capabilities provided in *EnclosureShop* now enable the practical and detailed analysis of such arrays.

In this example we shall examine the response characteristics of an array of five enclosures, each consisting of two 15 Inch (380 mm) transducers. Since the focus here is not on the individual enclosure, but rather an array of them, a basic sealed highpass design will be used. A trapezoidal shape will be employed as is often the case with enclosures designed for array applications.

The analysis of arrays in *EnclosureShop* is provided through use of the *Custom Multipass* dialog. This dialog allows arbitrary enclosure structures to be defined. For the case of arrays, this is used to construct a multi cell enclosure with each cell representing an individual enclosure in the array. The result is a cluster of enclosures which can be continued within a single shell definition.

In most cases a custom 3D object will need to be created and imported in order to define the shell of the array. This is a panelization process required to decompose the shape of the array into a proper 3D polygon object. This process will be demonstrated here for three different array shells.

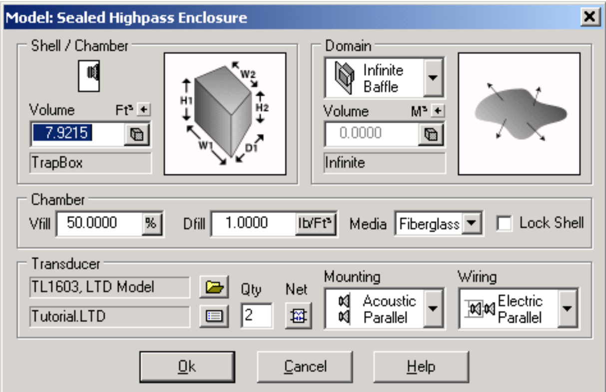




■ Transducer Parameters

A 15 Inch (380 mm) woofer will be used for this example. The TL1603A model was chosen. The driver is located in the *Tutorial.LTD* file of the *Transducers* folder. The driver LTD parameters are shown below.

```
* Loudspeaker Enclosure Analysis Program
* LEAP® EnclosureShop 5.0.0.317  Mar/07/2003
* ©1993-2003 LinearX Systems Inc
* Date: Mar  7, 2003   Fri  7:03 am
* LTD File=C:\Program Files\LEAP\Transducers\TUTORIAL.LTD
* Electro Mechanical Parameters
Name=   TL1603, LTD Model
Note=
Model=  LTD
Domain= FreeAir
Shape=  Round
Profile=       Cone
Fmd=       2.0000 KA
Qmd=       2.8280
Flp=       4.0000 KA
Qlp=       1.0000
Znom=      8.0000      Ohm      Txm=     558.4540E-6   Delta/°C
Revc=      6.8800      Ohm      Krs=     140.2228      N·S/M
Sd=       88.8000E-3   M²       Xrs=       6.8819E-3   M
Mmd=     103.8400E-3   Kg       Drs=     753.9800E-3
Pmax=    500.0000      W        Ers=     743.4800E-3
Rtvc=    500.0000E-3   °C/W     Grs=       4.7285
Xgap=      8.0000E-3   M        Trs=     -41.5820E-3   Delta/°C
Xcoil=    28.0000E-3   M        Kcs=     244.9552E-6   M/N
Xmax=     10.0000E-3   M        Xcs=       4.7352E-3   M
Xfrg=      7.8330E-3   M        Dcs=     399.0400E-3
Efrg=     14.8630               Ecs=      16.3400E-3
BLo=      18.7098      T·M      Gcs=     974.4900E-3
Ta=       25.0000      °C       Tcs=       9.5780E-3   Delta/°C
Vs=        2.8284      V        Rms=       2.9988      N·S/M
Krm=       5.8735      Ohm      Mms=     119.0130E-3   Kg
Frm=       1.3616E3    Hz       Cms=     246.2094E-6   M/N
Drm=     707.7300E-3            Vas=     277.3001E-3   M³
Erm=     725.8200E-3            Fo=       29.4159      Hz
Vrm=      14.2800E-3            Qms=       7.3317
Trm=    -192.2520E-6   Delta/°C Qes=       0.4336
Kxm=      10.2214      H        Qts=       0.4094
Fxm=       1.0644E3    Hz       BL=       18.6967      T·M
Dxm=     695.3300E-3            Levc=      1.6031E-3   H
Exm=     679.6300E-3            SPLo=     93.9452      dB
Vxm=      32.4200E-3            No=        1.5585      %
```

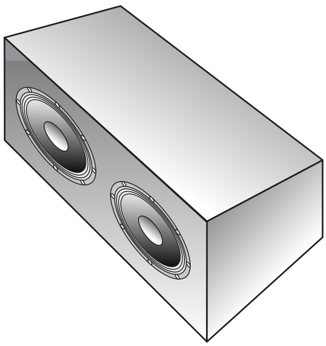


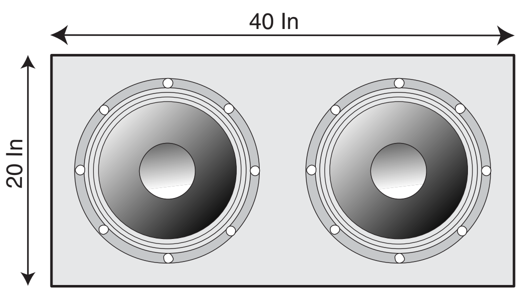
■ Sealed Highpass 2 x 15 Enclosure

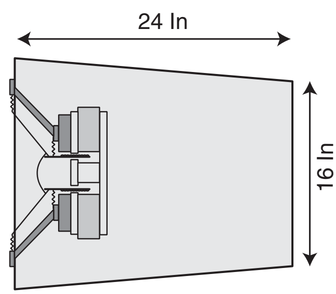
The basic design of the single 2 x 15 enclosure is shown below. A volume of about 4 Ft³ per speaker was employed, for a total volume of 8 Ft³ for the enclosure.

The enclosure has a trapezoidal taper on the height dimension from front to back, with a slope of 1 Inch per Foot.

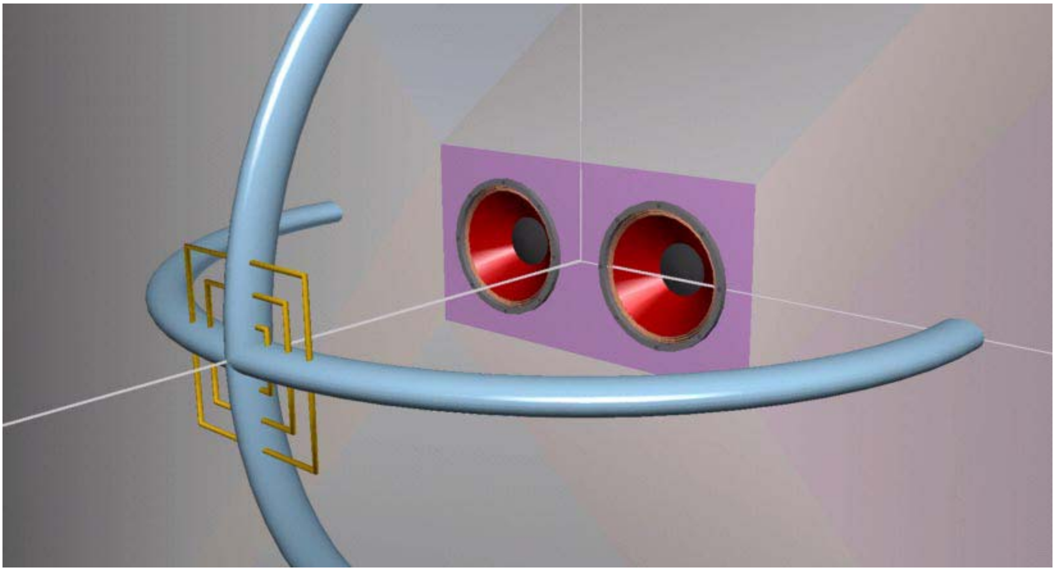
The single enclosure was simulated both in Infinite Baffle and Full Space domains. The 3D layouts and response curves for both domains are shown on the following pages.



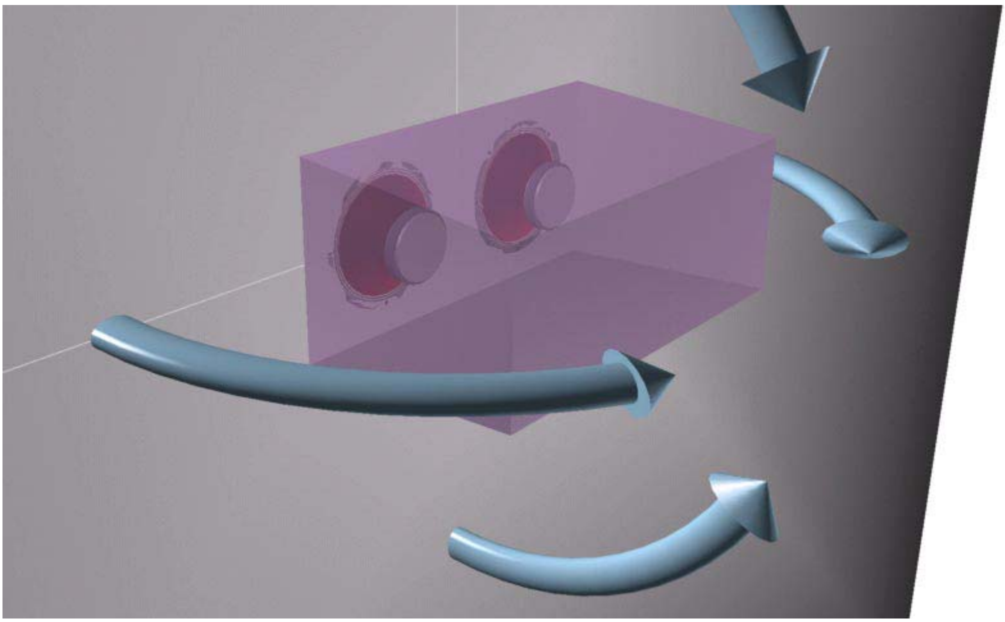




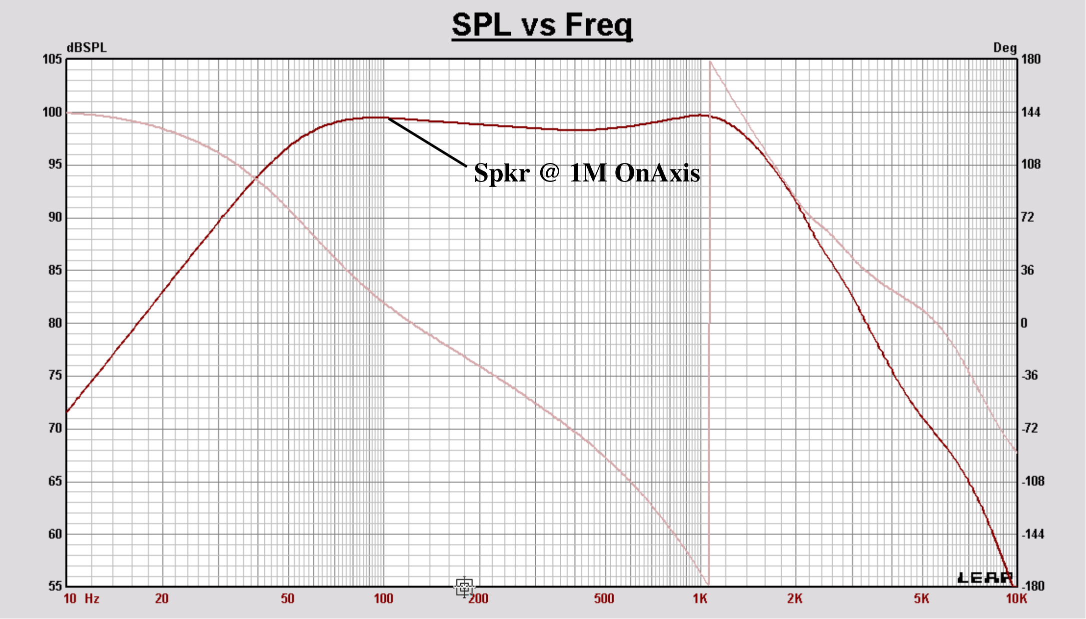
Single Enclosure, Infinite Baffle, Front View

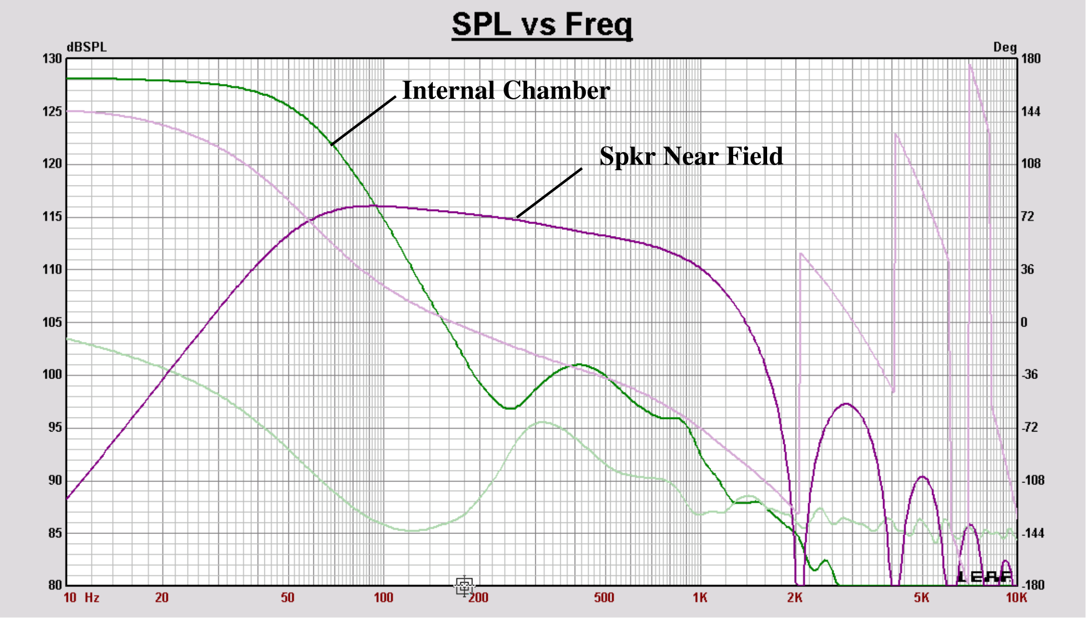


Single Enclosure, Infinite Baffle, Rear View

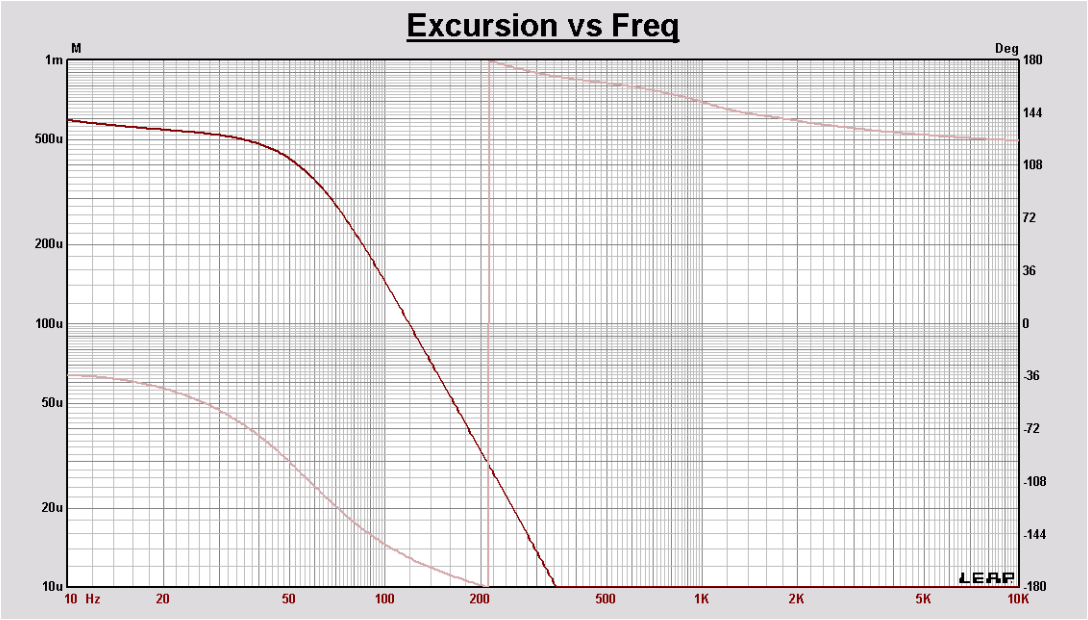


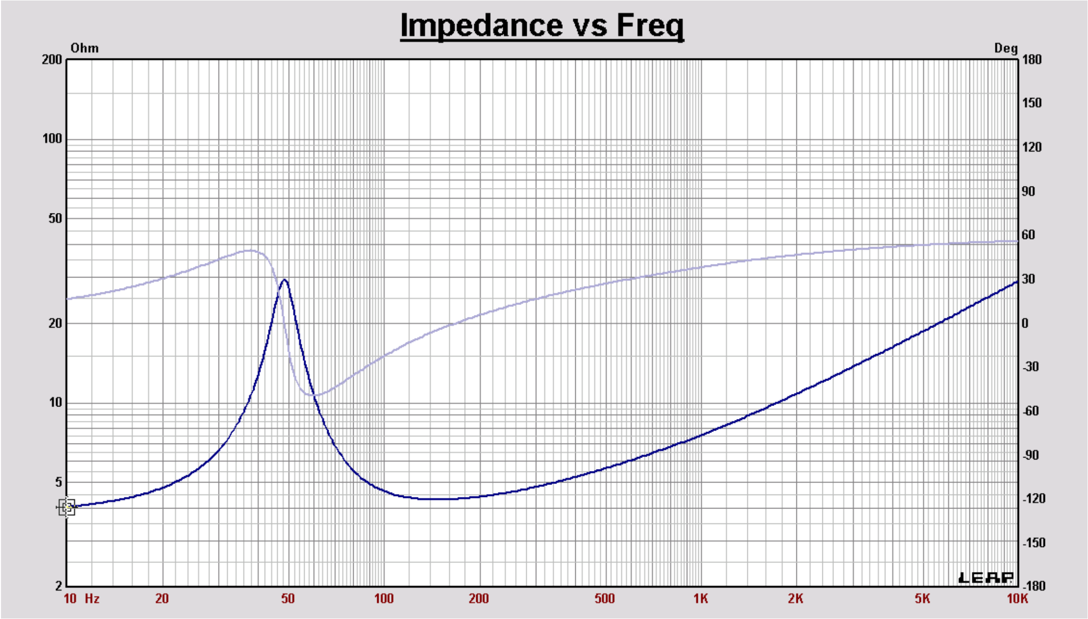
Single Enclosure, Infinite Baffle



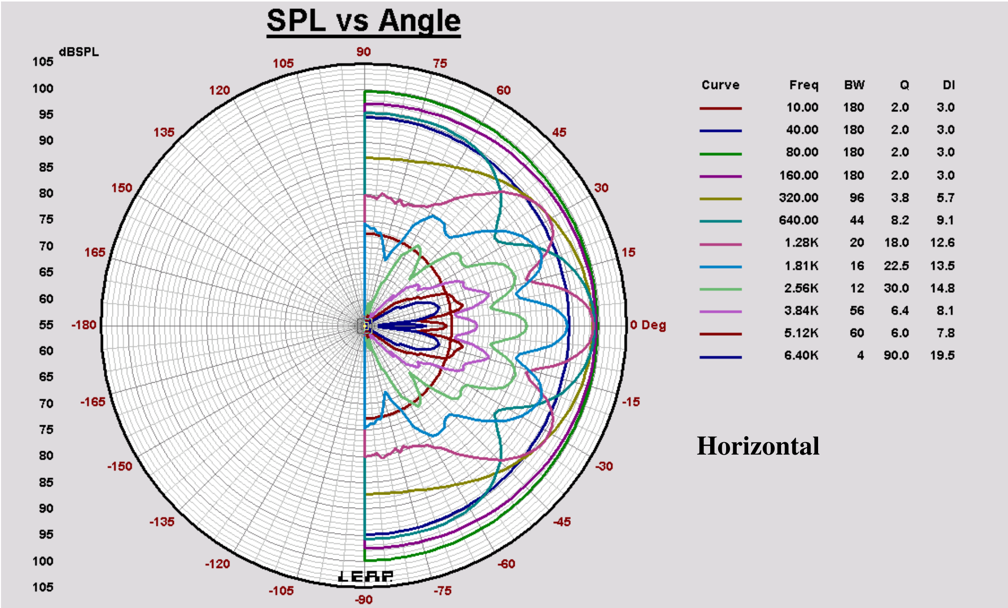


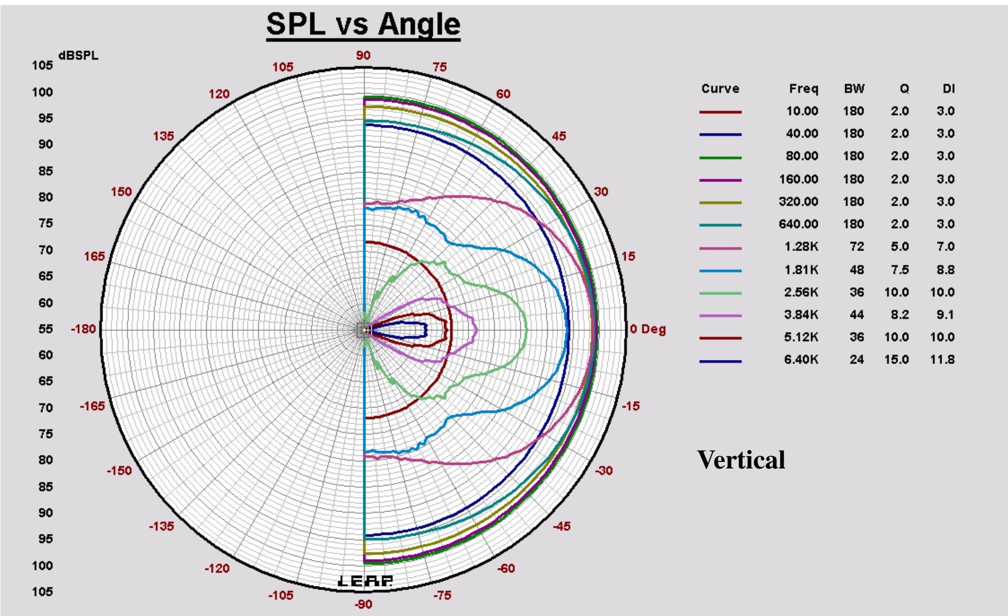
Single Enclosure, Infinite Baffle



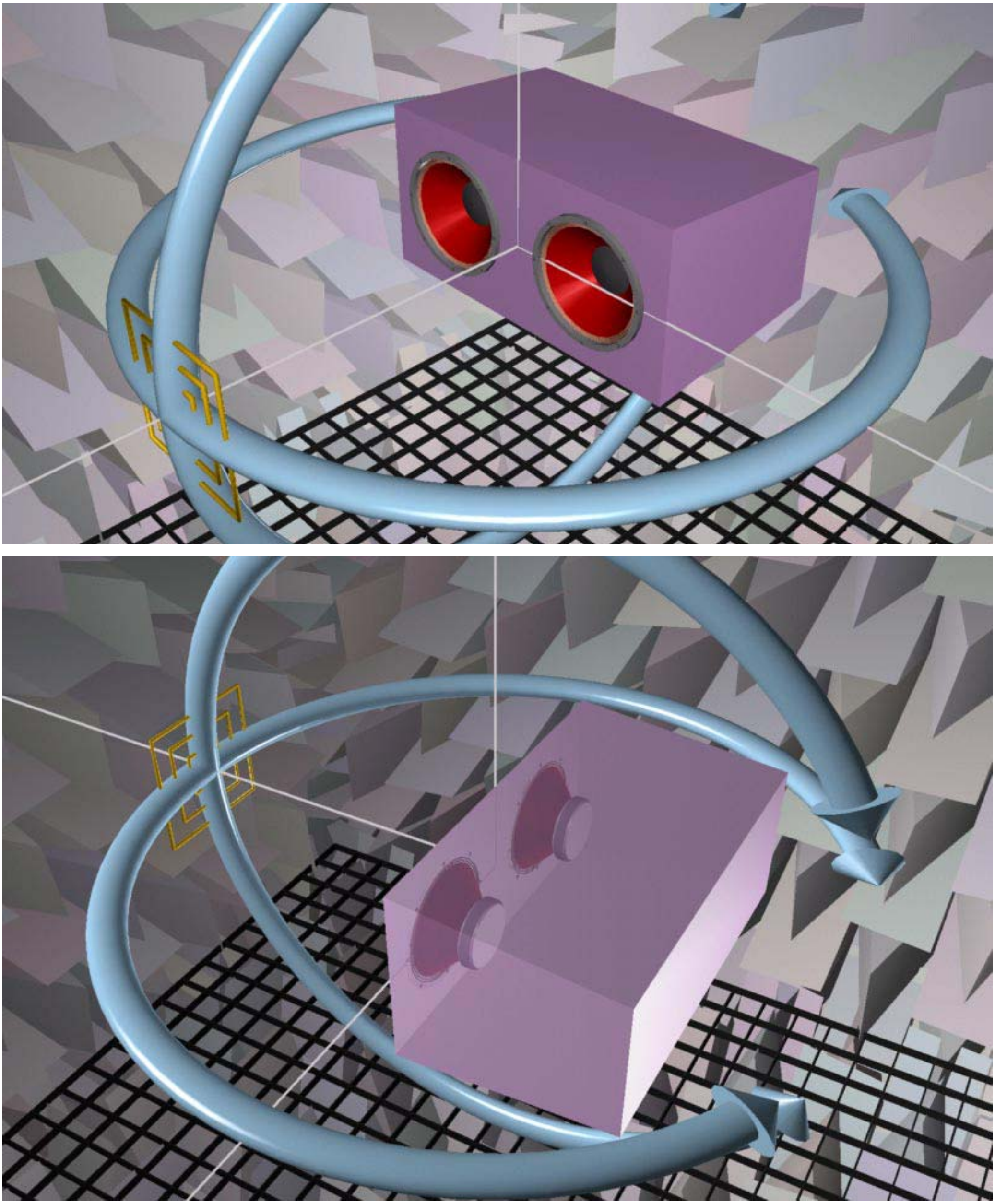


Single Enclosure, Infinite Baffle





Single Enclosure, Full Space, Front & Rear Views



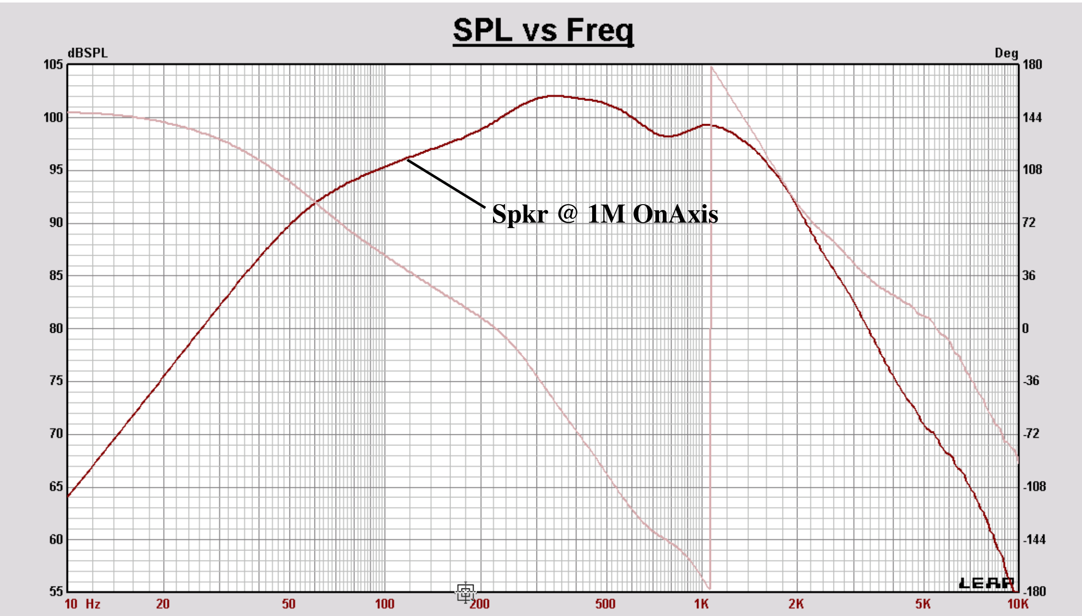
The acoustic response of the single enclosure in the anechoic domain is shown below. The response is quite different from that of the Infinite Baffle domain. Note that the response rises above 300 Hz. This is due to the directivity of the enclosure relative to those frequencies. At lower frequencies the enclosure has no directivity and radiates into full 4π space, thus producing a lower On-Axis level.

The polar plots on the following page give the same information. At low frequencies the enclosure behaves omnidirectional as indicated by the circular response curves. At higher frequencies the enclosure, and then the transducers, become directional.

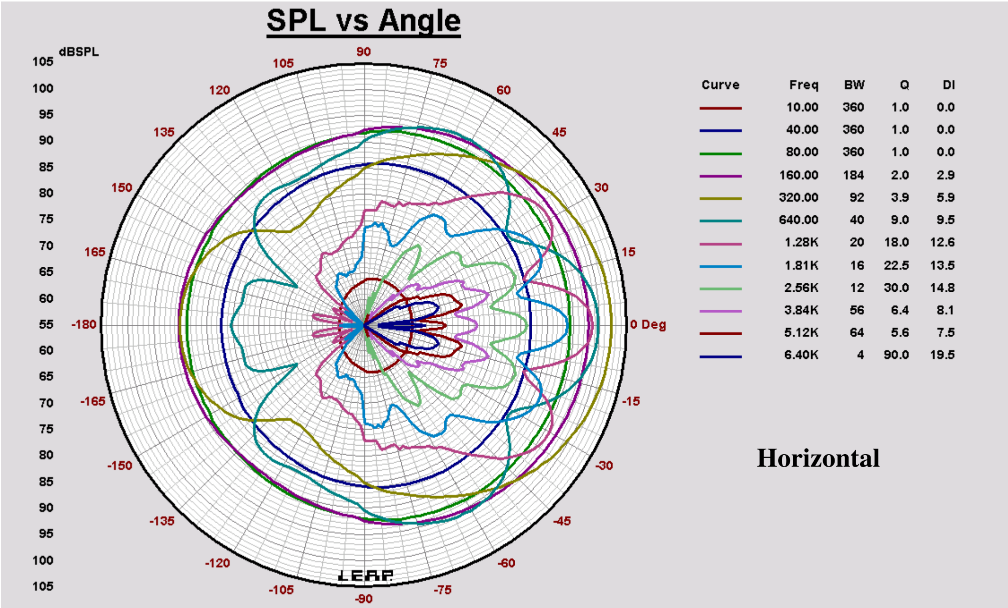
The horizontal curves show the typical lobing patterns that arise from multiple sources. The vertical curves show only the behavior of a single transducer, since the two transducers are located in-line horizontally.

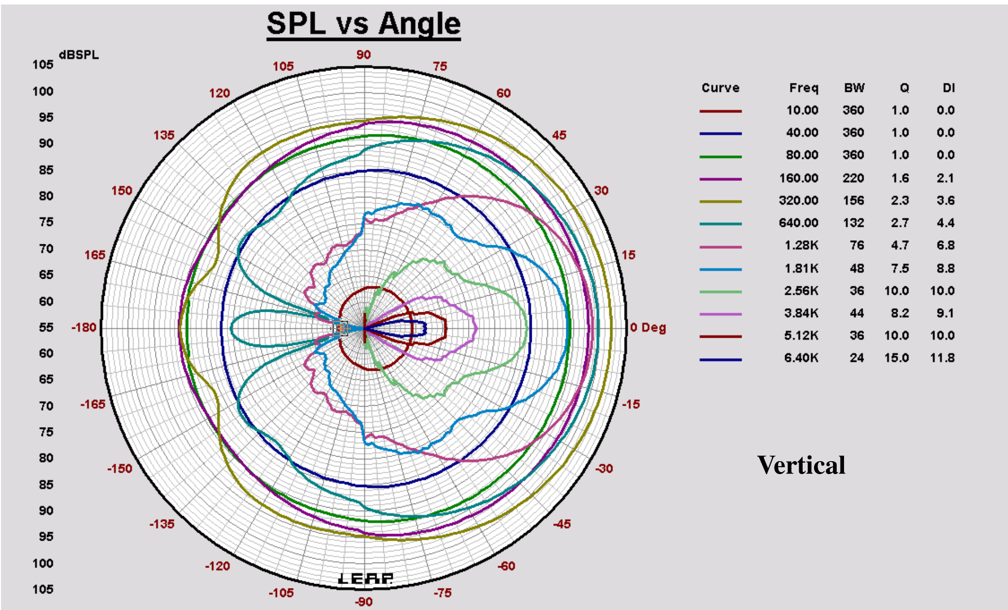
We can expect that an array of these enclosures will increase the directivity dramatically at low frequencies due to the larger baffling effect of their combination.

Single Enclosure, Full Space



Single Enclosure, Full Space





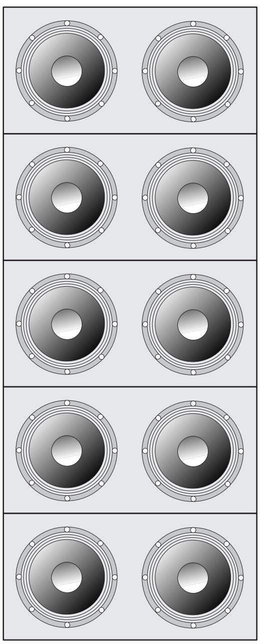
■ Loudspeaker Array - No Curvature

We will now combine five of the dual woofer enclosures into a vertical array as shown in the pictorial below. For this first array simulation the enclosures will be aligned vertically without curvature.

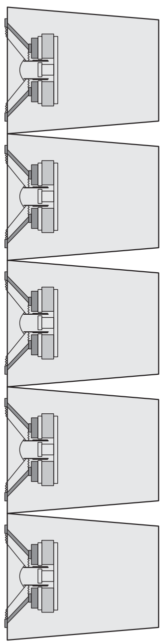
The array is now viewed as a single multi-enclosure, with five isolated chambers and ten transducers, two in each chamber. To construct this enclosure the *Custom Multipass* model dialog is used as shown below. Virtually any arbitrary enclosure structure with any combination of chambers, transducers, and ports can be defined using this dialog. Here we configure five chambers with two transducers each.

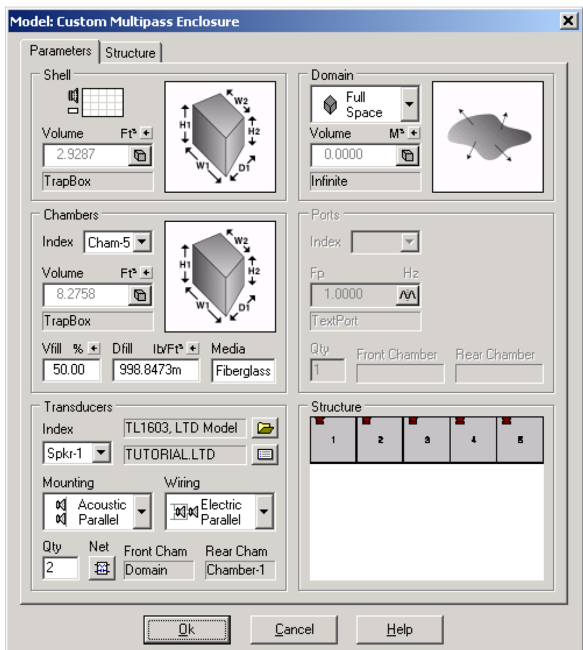
For this straight array a standard shell could be chosen from the dialog. However, since we will need to use an imported 3D shell for the next arrays, we shall introduce the process now. A polygon version of the array must now be defined with the proper *vertex* and *face* information. This information can then be used to create an *OBJ* text file defining the shell for import into *EnclosureShop*. The panelization of the array shell is shown on the following page.

FRONT VIEW



SIDE VIEW

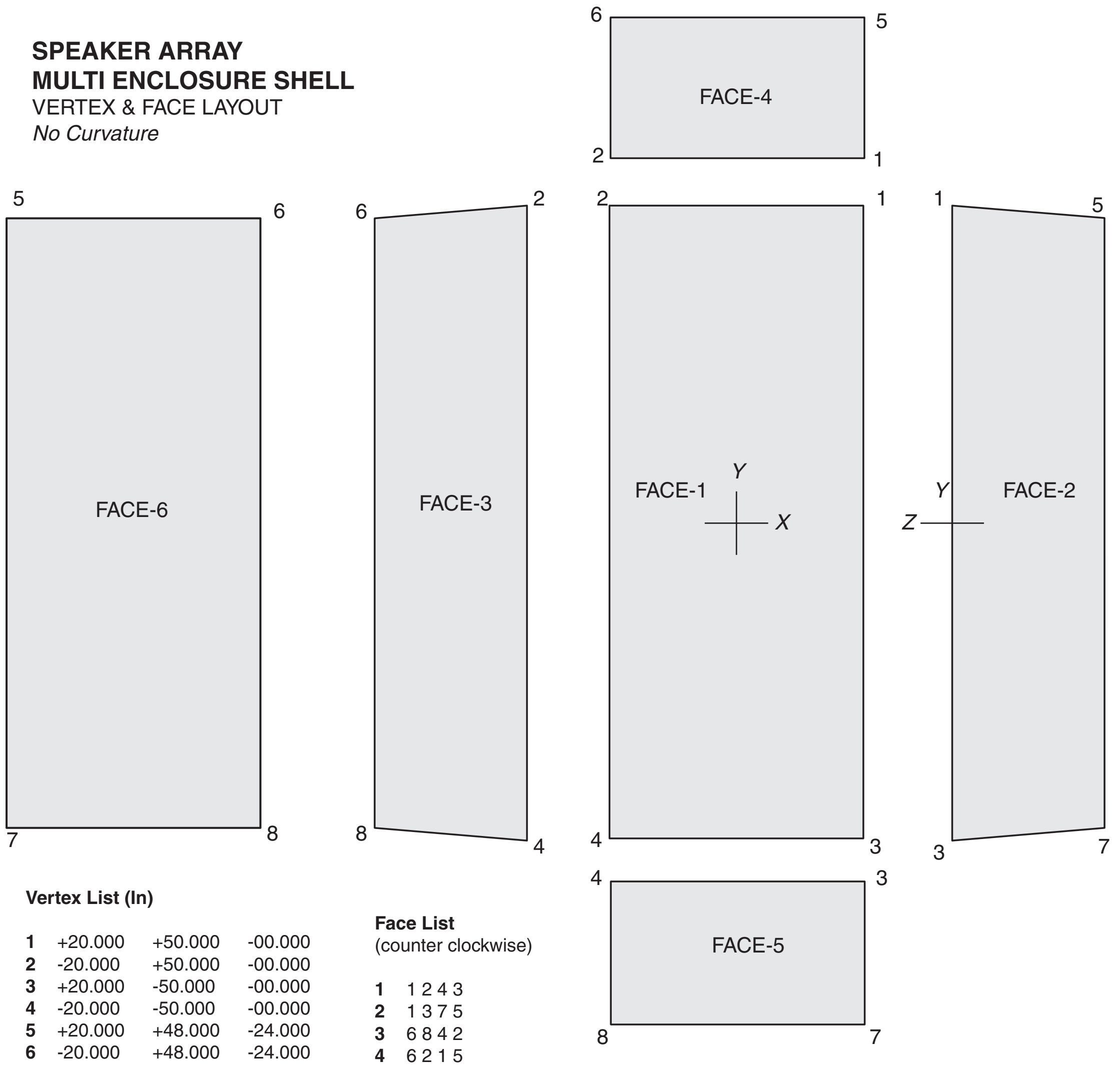




SPEAKER ARRAY
MULTI ENCLOSURE SHELL

VERTEX & FACE LAYOUT

No Curvature



Vertex List (In)

1	+20.000	+50.000	-00.000
2	-20.000	+50.000	-00.000
3	+20.000	-50.000	-00.000
4	-20.000	-50.000	-00.000
5	+20.000	+48.000	-24.000
6	-20.000	+48.000	-24.000
7	+20.000	-48.000	-24.000
8	-20.000	-48.000	-24.000

Face List
(counter clockwise)

1	1 2 4 3
2	1 3 7 5
3	6 8 4 2
4	6 2 1 5
5	4 8 7 3
6	5 7 8 6

The array panelization contains a simplified version of the rear surfaces. The back of the array is represented as a flat surface, while in reality there might be small angular voids between the individual enclosures for a trapezoidal shape.

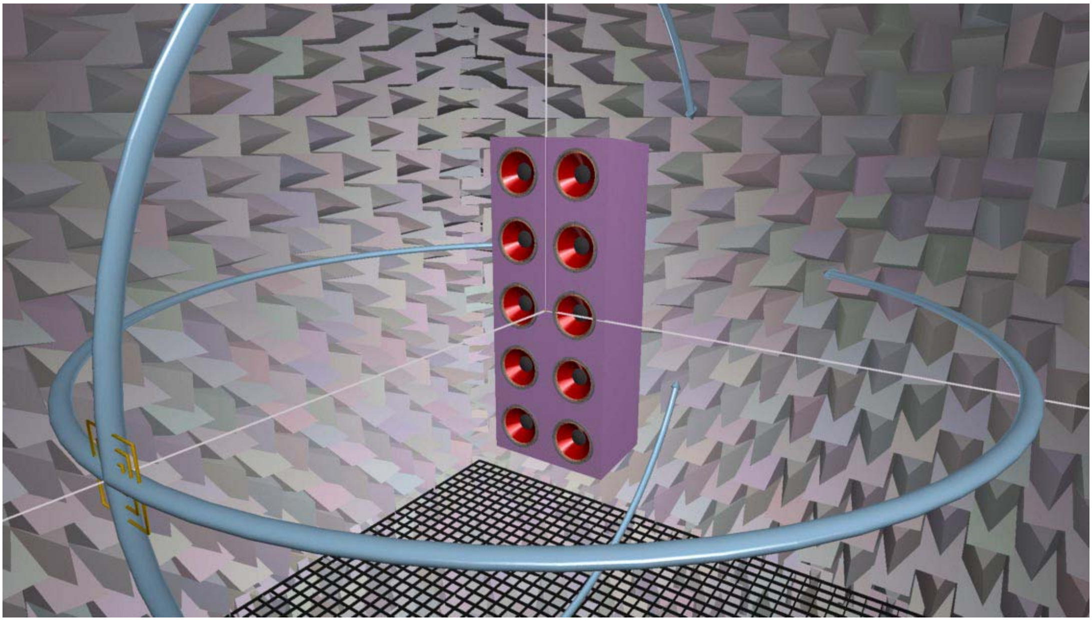
Simplification of real physical shells is often needed and desirable for diffraction analysis. The inclusion of small details, especially on the back of the enclosure, does not greatly benefit the results. Yet these small details can dramatically increase the computational requirements and produce a model which requires unreasonable resources.

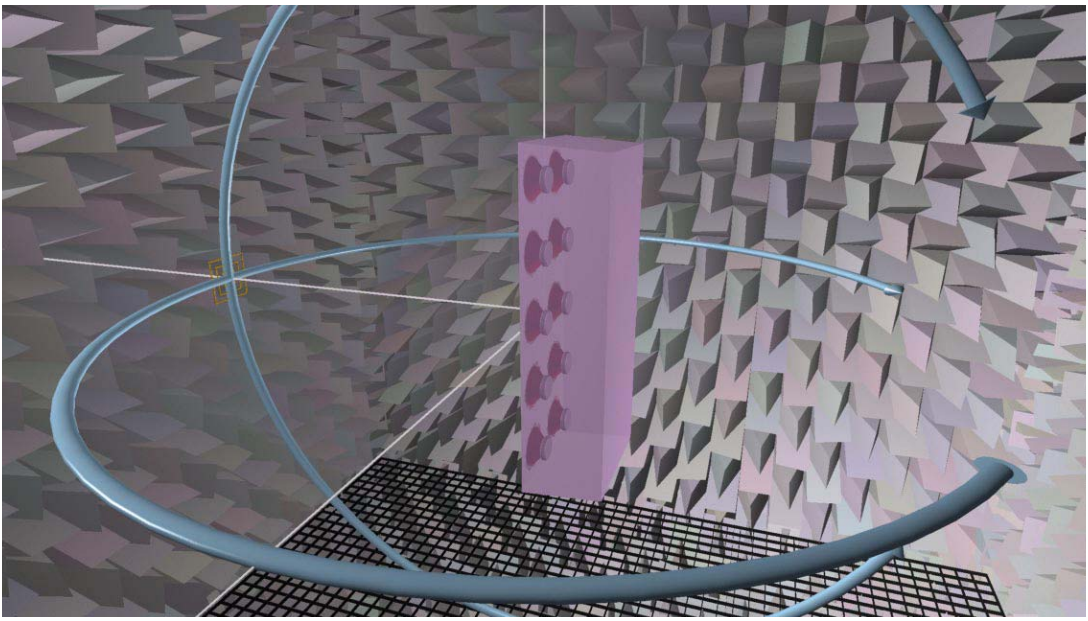
All of the vertex (or nodes) of the enclosure faces are first calculated and listed. The faces are then labeled and listed using their appropriate vertex numbers. The faces must be have their vertex numbers listed in *counter clockwise* direction when the face is viewed from the outside of the enclosure. This is the *winding* order. This is important so that *EnclosureShop* can understand which side of each face belongs on the inside and outside of the enclosure. The vertex list for any face can begin at any vertex around the face.

The *OBJ* file can then be created using any text editor as shown below. The vertex are listed first beginning with the letter *v,* followed with the *x,y,z* coordinates on each line. The faces follow beginning with the letter *f*.

```
# OBJ Import file for EncShop
# Date: Mar/05/2003,  Author: C. Strahm
# AppNote02 Speaker Array Multi-Enclosure, No Arc
# Units are Inches.

v       +20.000 +50.000 +00.000
v       -20.000 +50.000 +00.000
v       +20.000 -50.000 +00.000
v       -20.000 -50.000 +00.000
v       +20.000 +48.000 -24.000
v       -20.000 +48.000 -24.000
v       +20.000 -48.000 -24.000
v       -20.000 -48.000 -24.000

f       1 2 4 3
f       1 3 7 5
f       6 8 4 2
f       6 2 1 5
f       4 8 7 3
f       5 7 8 6
```

Loudspeaker Array, No Curvature





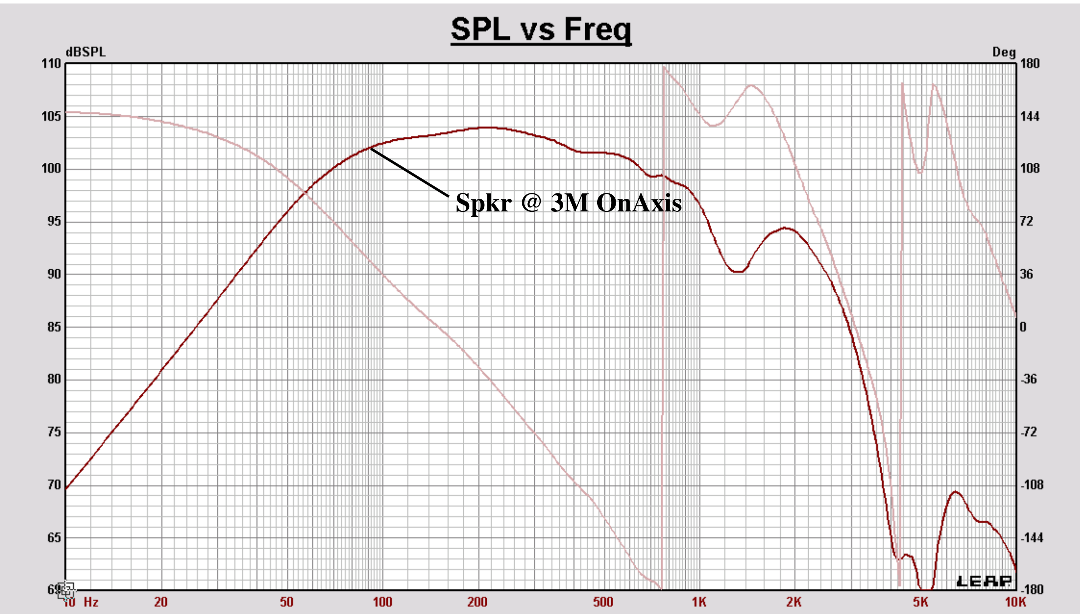
The 3D shell definition *OBJ* file is then imported. The transducers are arranged on the multi-enclosure as shown in the view of the 3D scene on the preceding page. The single enclosure was simulated at a distance of 1 Meter. However, a larger distance is appropriate when simulating the response of the array. A distance of 3 Meters was chosen for the analysis of these arrays.

The acoustic On-Axis response is now shown in the graph below for this straight array (no curvature). As expected there is a remarkable increase in the low frequency amplitude. Indeed, the level at 100Hz now exceeds that of 1kHz.

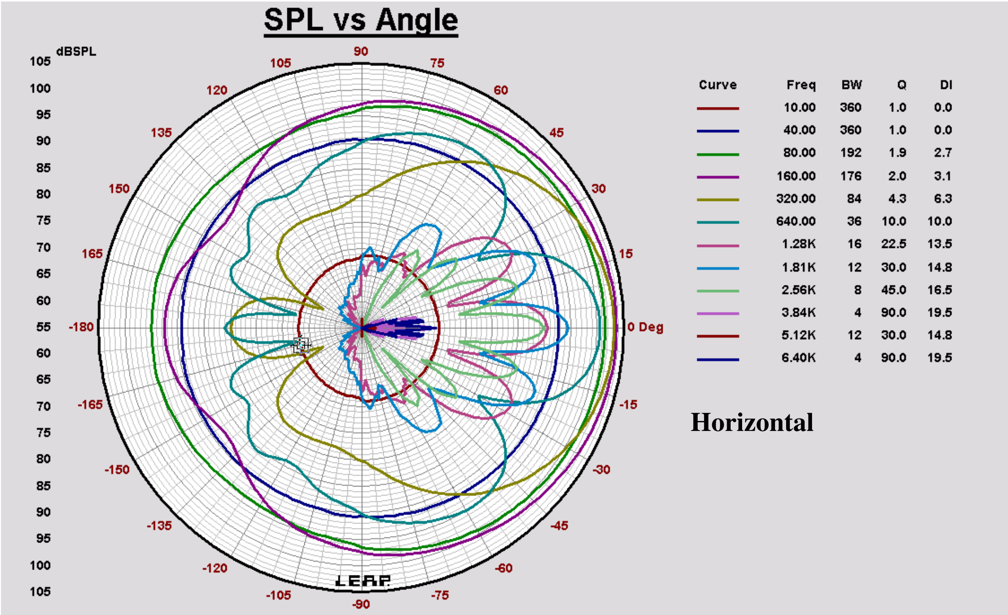
The response also shows a null which occurs at 1300Hz. This is due to the cancellation between the multiple drivers spread across the vertical distance. The array is over 8 Feet in height.

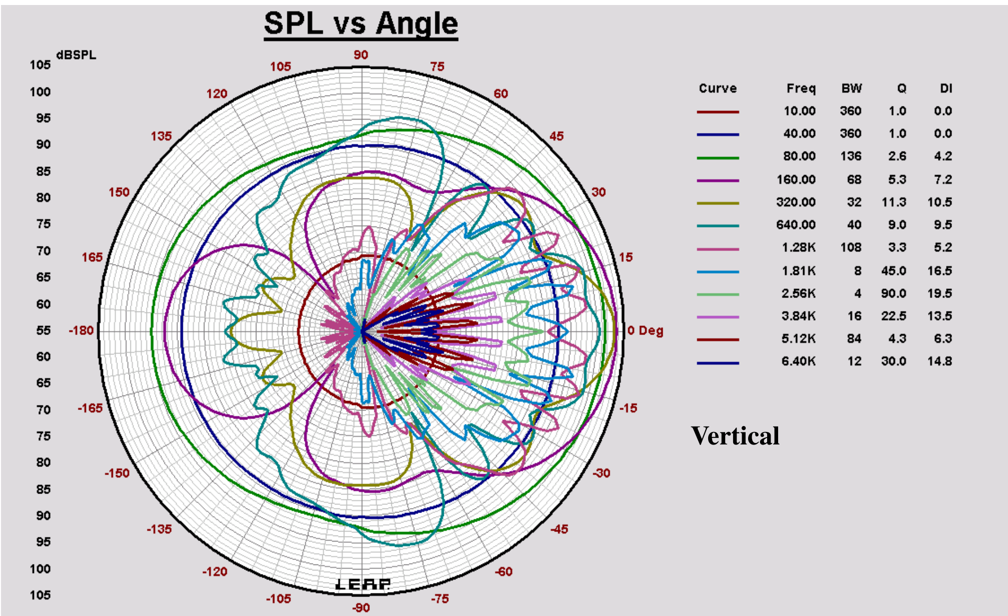
The horizontal and vertical polar response curves are now shown on the following page. Note that the Directivity Index (*DI*) for the vertical profile is now over 4dB even at 80Hz. At 160Hz the level behind the array is only about 10dB below that in front of the array.

Loudspeaker Array, No Curvature



Loudspeaker Array, No Curvature



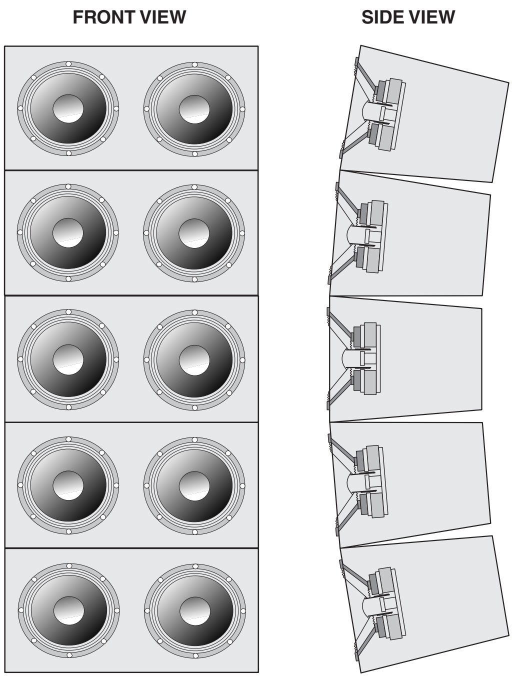


■ Loudspeaker Array - Small Curvature

The design of the array is now altered to utilize half of the possible curvature provided by the trapezoidal enclosure. The array configuration is shown below.

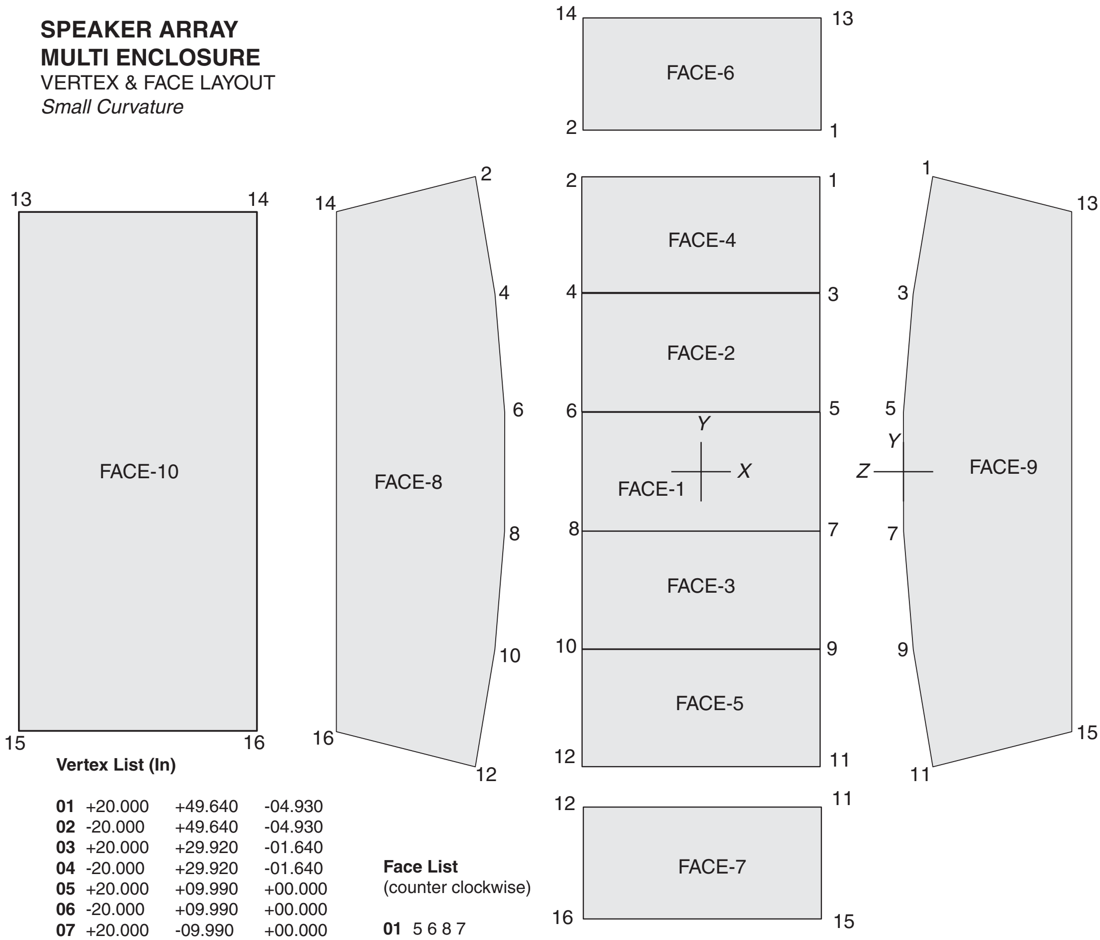
The array panelization for this configuration is shown on the following page. As before the back of the array is simplified and merely represented as a flat surface. The vertex and face lists are given in the pictorial on the following page, and in the associated *OBJ* file shown below.

The transducers are arranged on the multi-enclosure shown in the view of the 3D scene on the next following page. Again a simulation distance of 3 Meters is used. The front of the array now contains five distinct panels, representing the baffle boards for each of the single enclosures.




```
# OBJ Import file for EncShop
# Date: Mar/05/2003,  Author: C. Strahm
# AppNote02 Multi-Enclosure, Small Arc

v       +20.000 +49.640 -04.930
v       -20.000 +49.640 -04.930
v       +20.000 +29.920 -01.640
v       -20.000 +29.920 -01.640
v       +20.000 +09.990 +00.000
v       -20.000 +09.990 +00.000
v       +20.000 -09.990 +00.000
v       -20.000 -09.990 +00.000
v       +20.000 -29.920 -01.640
v       -20.000 -29.920 -01.640
v       +20.000 -49.640 -04.930
v       -20.000 -49.640 -04.930
v       +20.000 +43.730 -28.270
v       -20.000 +43.730 -28.270
v       +20.000 -43.730 -28.270
v       -20.000 -43.730 -28.270

f       5 6 8 7
f       3 4 6 5
f       7 8 10 9
f       1 2 4 3
f       9 10 12 11
f       13 14 2 1
f       11 12 16 15
f       14 16 12 10 8 6 4 2
f       1 3 5 7 9 11 15 13
f       13 15 16 14
```

SPEAKER ARRAY
MULTI ENCLOSURE
VERTEX & FACE LAYOUT
Small Curvature



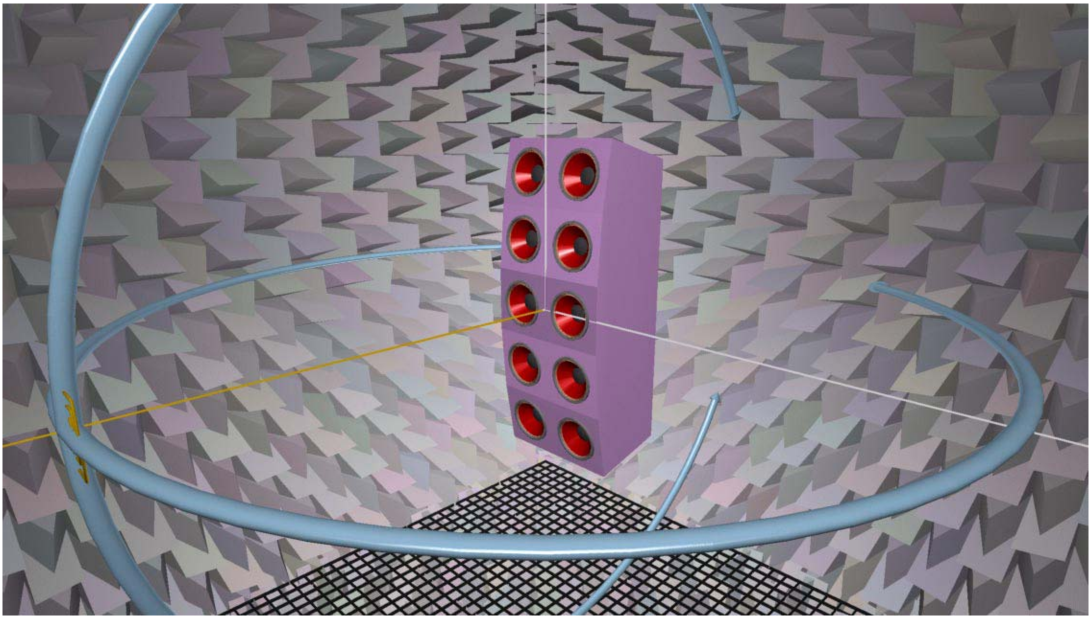
Vertex List (In)

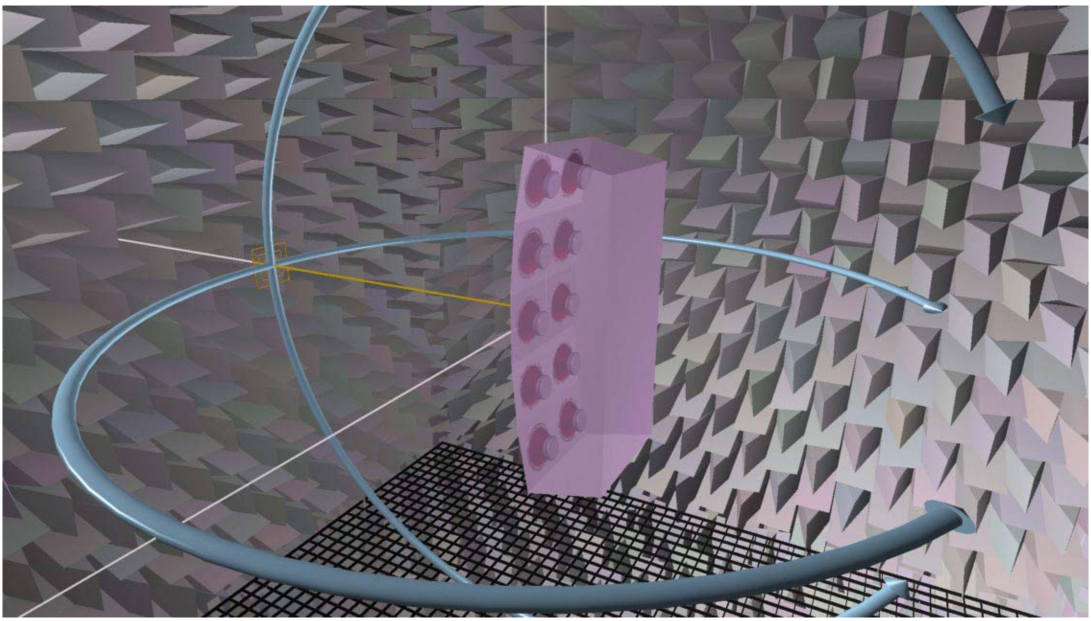
01	+20.000	+49.640	-04.930
02	-20.000	+49.640	-04.930
03	+20.000	+29.920	-01.640
04	-20.000	+29.920	-01.640
05	+20.000	+09.990	+00.000
06	-20.000	+09.990	+00.000
07	+20.000	-09.990	+00.000
08	-20.000	-09.990	+00.000
09	+20.000	-29.920	-01.640
10	-20.000	-29.920	-01.640
11	+20.000	-49.640	-04.930
12	-20.000	-49.640	-04.930
13	+20.000	+43.730	-28.270
14	-20.000	+43.730	-28.270
15	+20.000	-43.730	-28.270
16	-20.000	-43.730	-28.270

Face List
(counter clockwise)

01 5 6 8 7
02 3 4 6 5
03 7 8 10 9
04 1 2 4 3
05 9 10 12 11
06 13 14 2 1
07 11 12 16 15
08 14 16 12 10 8 6 4 2
09 1 3 5 7 9 11 15 13
10 13 15 16 14

Loudspeaker Array, Small Curvature





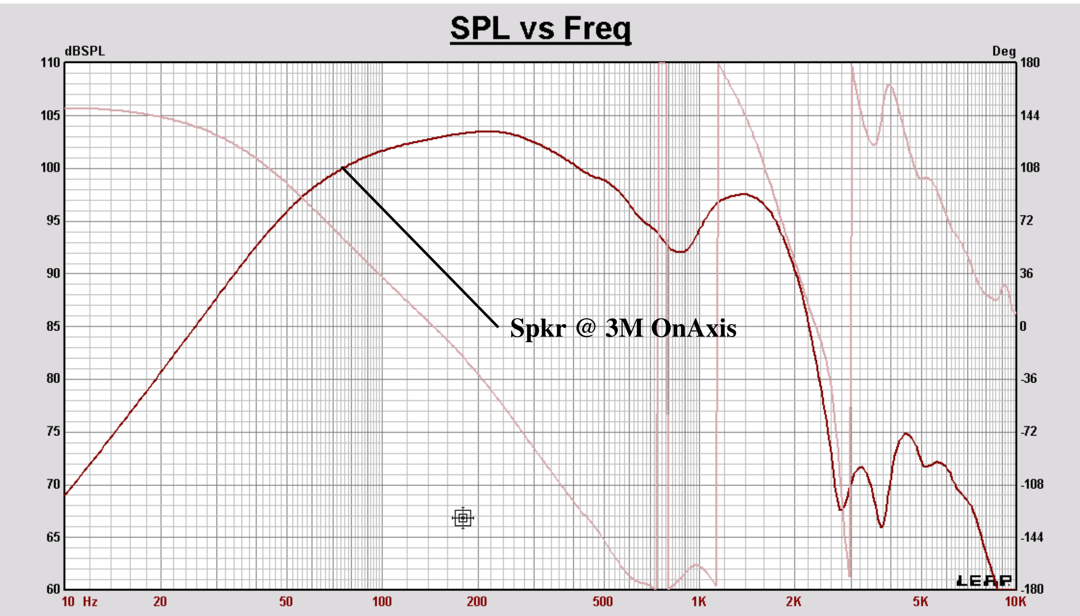
The acoustic On-Axis response is shown in the graph below for this slightly curved array (small curvature). Again we see the low frequency increase, but the null has moved from 1300Hz down to 900Hz. Arcing the array pushes the outer transducers further away from center and more off-axis, thus causing more path delay and lower frequency cancellation.

The horizontal and vertical polar response curves are now shown on the following page. Compare these polar curves to those of the previous straight array. The DI values are slightly reduced. Clearly the result of arcing the array.

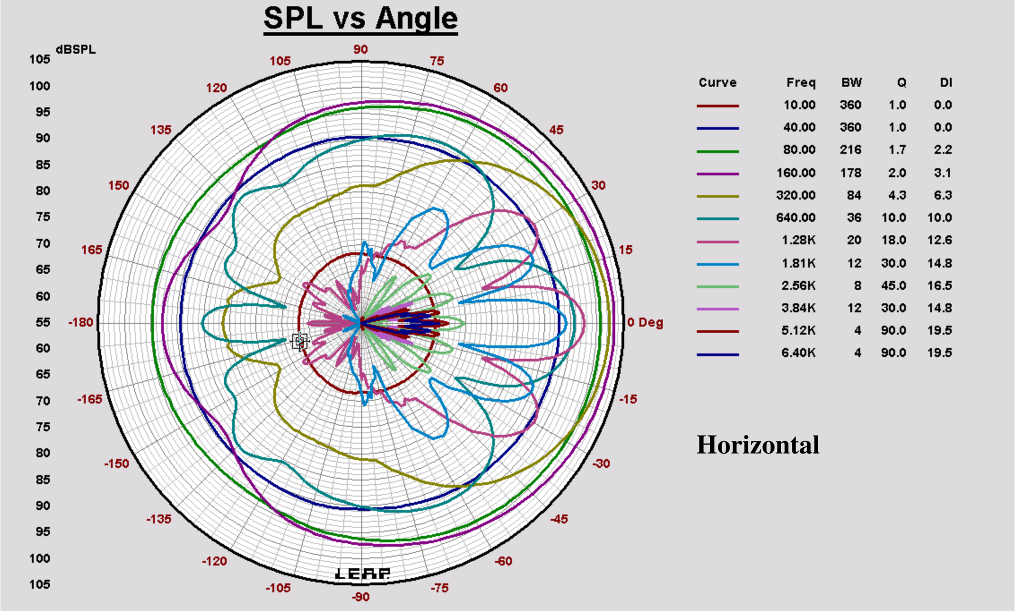
The amplitude of the higher frequency lobes in the vertical direction has slightly increased. Arcing the array points the outer transducers more off-axis and increases the higher frequency coverage to more distant vertical angles.

However, the curvature of this array was small. We will now arc the array to the maximum allowed by the enclosures and observe those changes.

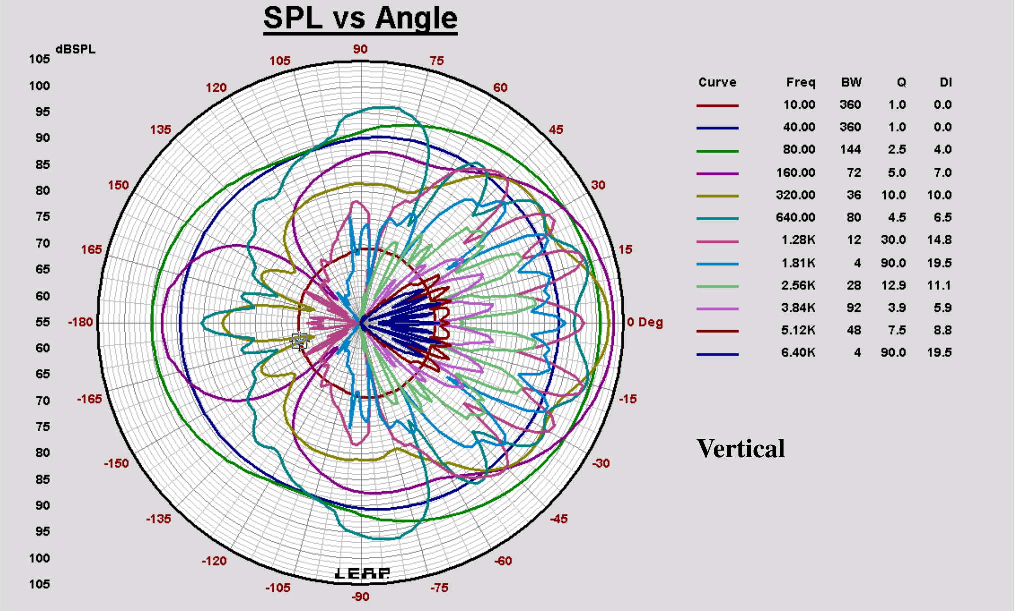
Loudspeaker Array, Small Curvature



Loudspeaker Array, Small Curvature



Horizontal



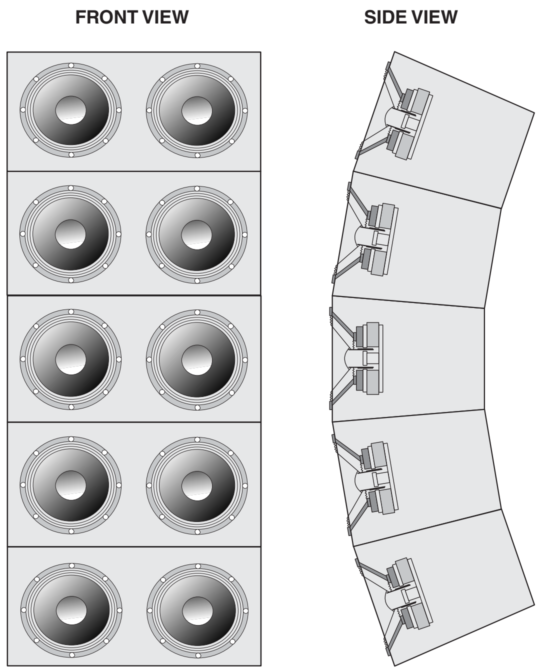
Vertical

■ Loudspeaker Array - Large Curvature

The design of the array is altered again to utilize the full amount of curvature provided by the trapezoidal enclosure. The new array configuration is shown below.

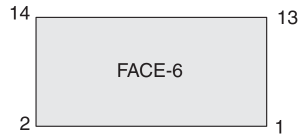
The array panelization for this configuration is shown on the following page. As before the back of the array is simplified and merely represented as a flat surface. The vertex and face lists are given in the pictorial on the following page, and in the associated *OBJ* file shown below.

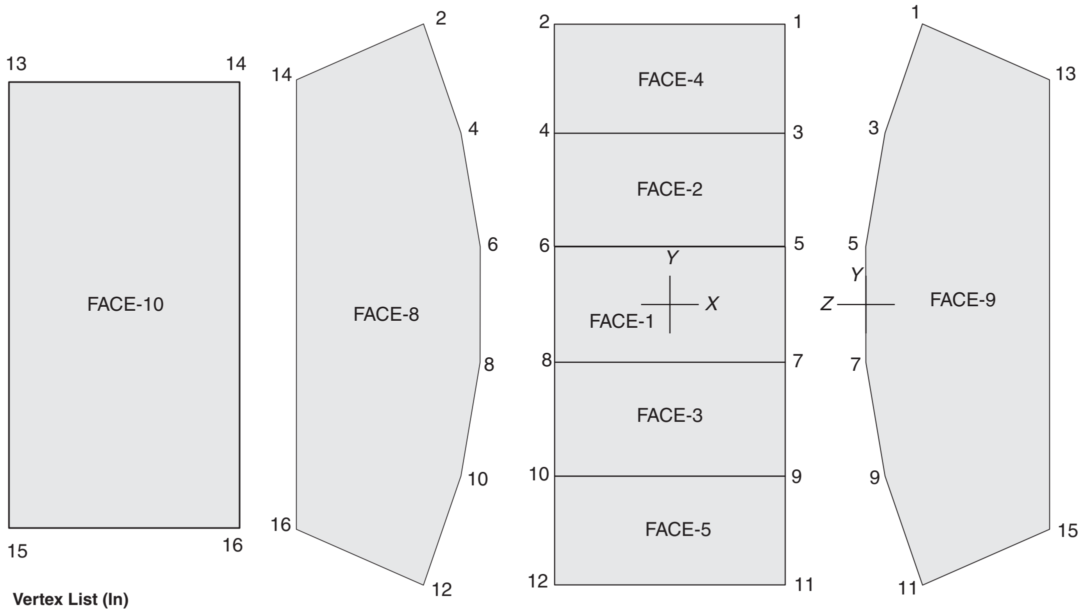
The transducers are arranged on the multi-enclosure shown in the view of the 3D scene on the next following page. A simulation distance of 3 Meters is once again used.

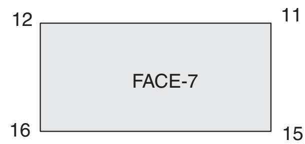



```
# OBJ Import file for EncShop
# Date: Mar/05/2003,  Author: C. Strahm
# AppNote02 Multi-Enclosure, Large Arc

v       +20.000 +48.600 -09.790
v       -20.000 +48.600 -09.790
v       +20.000 +29.720 -03.300
v       -20.000 +29.720 -03.300
v       +20.000 +10.000 +00.000
v       -20.000 +10.000 +00.000
v       +20.000 -10.000 +00.000
v       -20.000 -10.000 +00.000
v       +20.000 -29.720 -03.300
v       -20.000 -29.720 -03.300
v       +20.000 -48.600 -09.790
v       -20.000 -48.600 -09.790
v       +20.000 +38.920 -31.850
v       -20.000 +38.920 -31.850
v       +20.000 -38.920 -31.850
v       -20.000 -38.920 -31.850

f       5 6 8 7
f       3 4 6 5
f       7 8 10 9
f       1 2 4 3
f       9 10 12 11
f       13 14 2 1
f       11 12 16 15
f       14 16 12 10 8 6 4 2
f       1 3 5 7 9 11 15 13
f       13 15 16 14
```

SPEAKER ARRAY
MULTI ENCLOSURE
VERTEX & FACE LAYOUT
Large Curvature







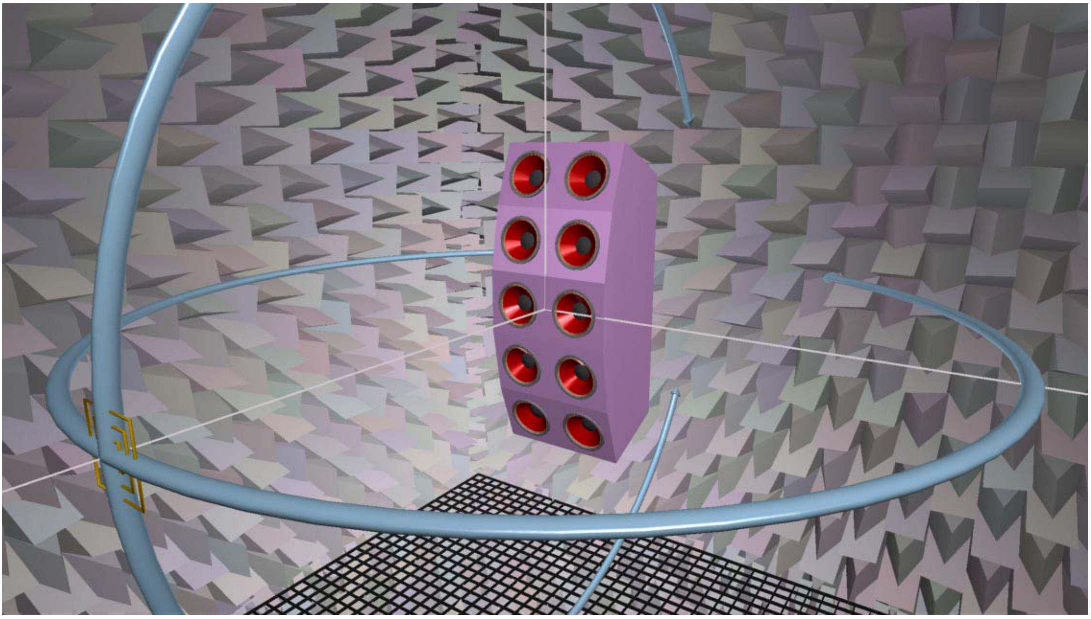
Vertex List (In)

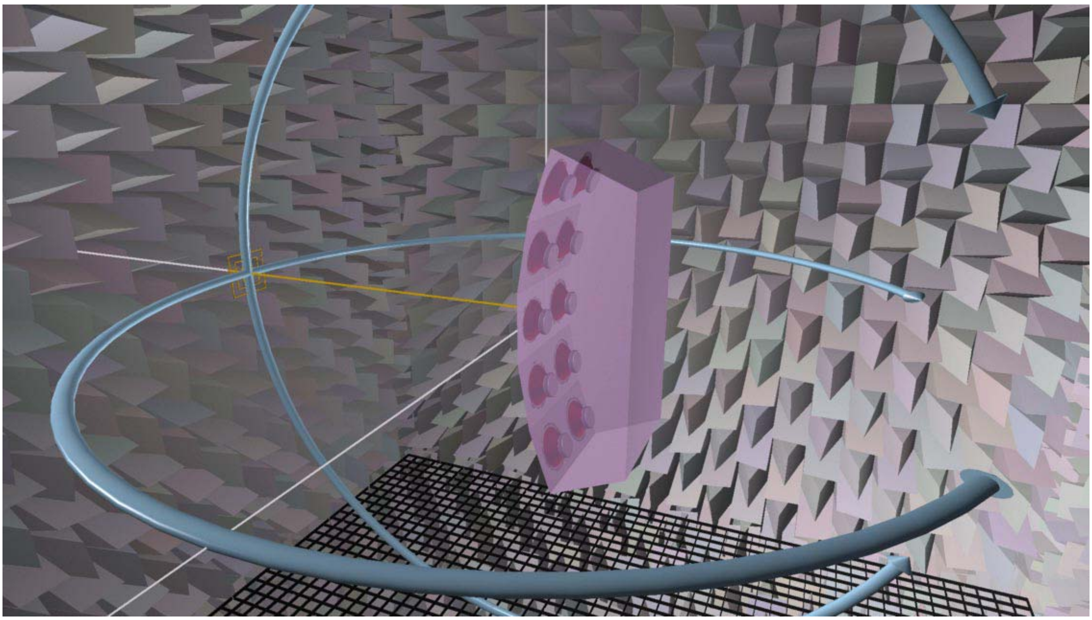
01	+20.000	+48.600	-09.790
02	-20.000	+48.600	-09.790
03	+20.000	+29.720	-03.300
04	-20.000	+29.720	-03.300
05	+20.000	+10.000	+00.000
06	-20.000	+10.000	+00.000
07	+20.000	-10.000	+00.000
08	-20.000	-10.000	+00.000
09	+20.000	-29.720	-03.300
10	-20.000	-29.720	-03.300
11	+20.000	-48.600	-09.790
12	-20.000	-48.600	-09.790
13	+20.000	+38.920	-31.850
14	-20.000	+38.920	-31.850
15	+20.000	-38.920	-31.850
16	-20.000	-38.920	-31.850

Face List
(counter clockwise)

01	5 6 8 7
02	3 4 6 5
03	7 8 10 9
04	1 2 4 3
05	9 10 12 11
06	13 14 2 1
07	11 12 16 15
08	14 16 12 10 8 6 4 2
09	1 3 5 7 9 11 15 13
10	13 15 16 14

Loudspeaker Array, Large Curvature





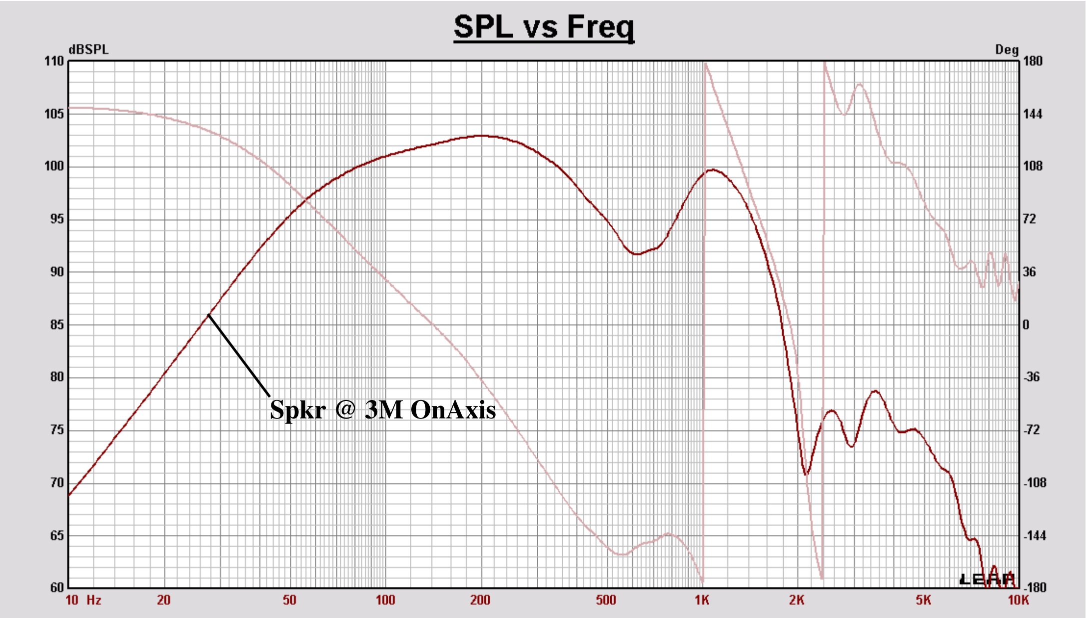
The acoustic On-Axis response is shown in the graph below for this maximum curved array (large curvature). Again we see the low frequency increase, but the null has moved further from 900Hz down to 600Hz. Arcing the array further has continued to push the outer transducers further away from center and more off-axis, thus causing more path delay and lower frequency cancellation.

The horizontal and vertical polar response curves are shown on the following page. Compare these polar curves to those of the previous straight array. The *DI* values are much more reduced. At 80Hz the *DI* has decreased from 4.3dB to 3.9dB.

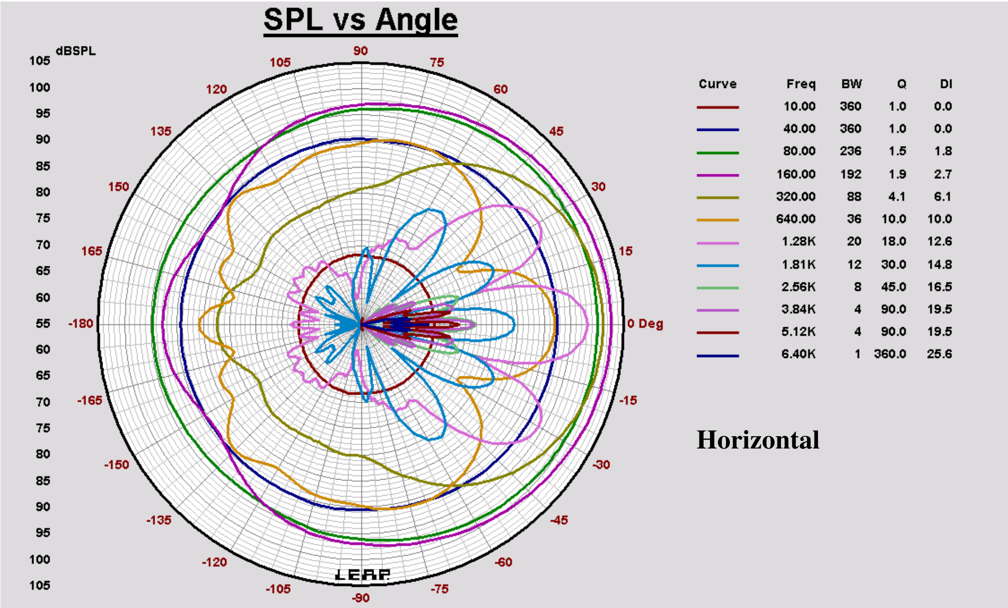
Note also that the *DI* values between 160Hz and 640Hz have generally fallen to one-half those of the straight array (5 vs. 10). This is a considerable broadening of the coverage pattern in the vertical direction.

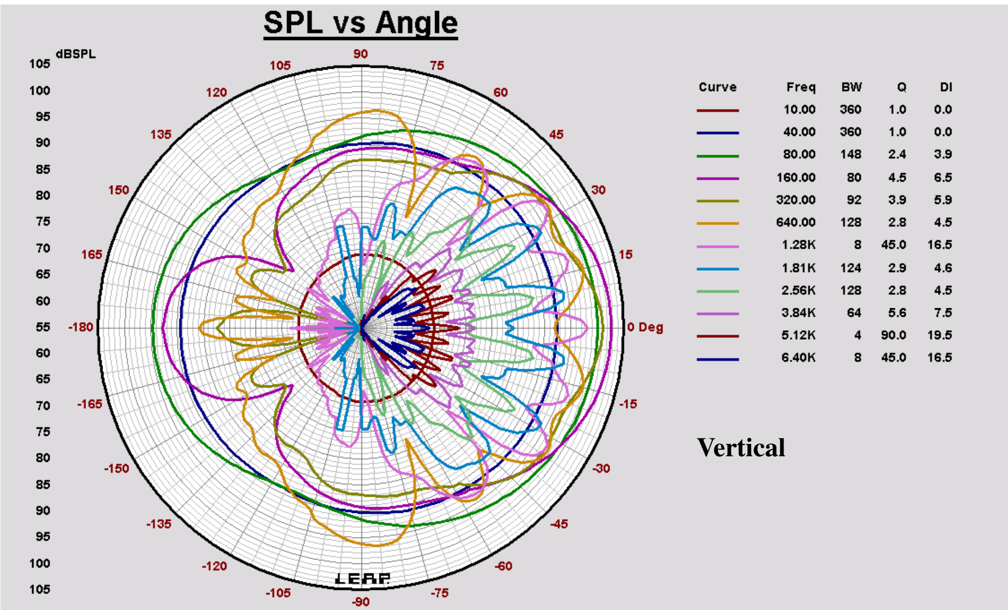
It should also be mentioned that the On-Axis null will decrease somewhat at larger simulation distances, and the response will generally become more uniform. The closer to the array, the larger the path length differences between the drivers.

Loudspeaker Array, Large Curvature



Loudspeaker Array, Large Curvature





■ Summary

Many different types of array characteristics can be explored. The examples given here are merely an introduction to array modeling. Different types and shapes of arrays can be investigated both for low and high frequency transducers.

The computational requirements of array analysis can be substantial. Diffraction analysis on large or complex shells will require the latest computer resources. These simulations were performed on a Pentium® 4 PC with 2GB of memory.

The simulations provided in this example utilized 3kHz diffraction resolution, and 4th order diffraction analysis. Simulation of the single 2 x 15 enclosure only required 5 minutes of computation time and 75MB of memory. However, simulation of each array required 3 hours of CPU time and consumed over 500MB of memory. Large arrays can exhaust the entire 2GB address space of the Win32® operating system.

It is therefore wise to plan the design carefully and eliminate any unnecessary small surfaces from the shell. Their contribution to the overall result is typically minimal, but can greatly increase the computational burden. Proper choice of the diffraction resolution and diffraction order also play a critical role in determining the computation requirements.

This completes the application note.