

Directivity Control Part 2: A DIY Unidirectional Loudspeaker System

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✓ Following

In **Directivity Control Part 1**, ten (10) commercial loudspeaker systems were presented and their respective radiation characteristics were briefly discussed. Then based at least to some extent on that survey, primary system objectives were formulated.

I. THE OBJECTIVES

1. A 3-way active loudspeaker system.
2. Unidirectional radiation to below 100 Hz.
3. Plug and play USB streaming input from PC capability.

4. Reasonable system cost: < US\$4,000 / pair

II. THE PLAN

With respect to the above and to the author's preferences and prejudices, the following plan for a 3-way monitor system project was formulated.

1. Tweeter: 25 mm Al alloy dome mounted coaxial with the mid cone.
2. Midrange: No less than a 6 in. nominal Al alloy cone in an acoustic resistance enclosure.
3. Woofers: 2 x 10 in. with equalized sealed box enclosure.
4. Anti-woofers: 2 x 10 in. with equalized sealed box enclosure.
5. Fully active system (4-channel per side) with **DSP**.

III. THE LOUDSPEAKER

Rather than design a complete system to meet directional requirements from scratch, a finished coaxial loudspeaker (mid/tweeter) that is already unidirectional above the baffle frequency could be modified to meet the loudspeaker system requirements. A suitable choice for plan points 1 and 2 is a modified KEF Q350 loudspeaker. This approach offers good value and an element of simplicity to the project. Figure 1 below contains an exploded view of the KEF Q350 coaxial transducer array,

while figure 2 contains a picture of a black KEF Q350 loudspeaker.

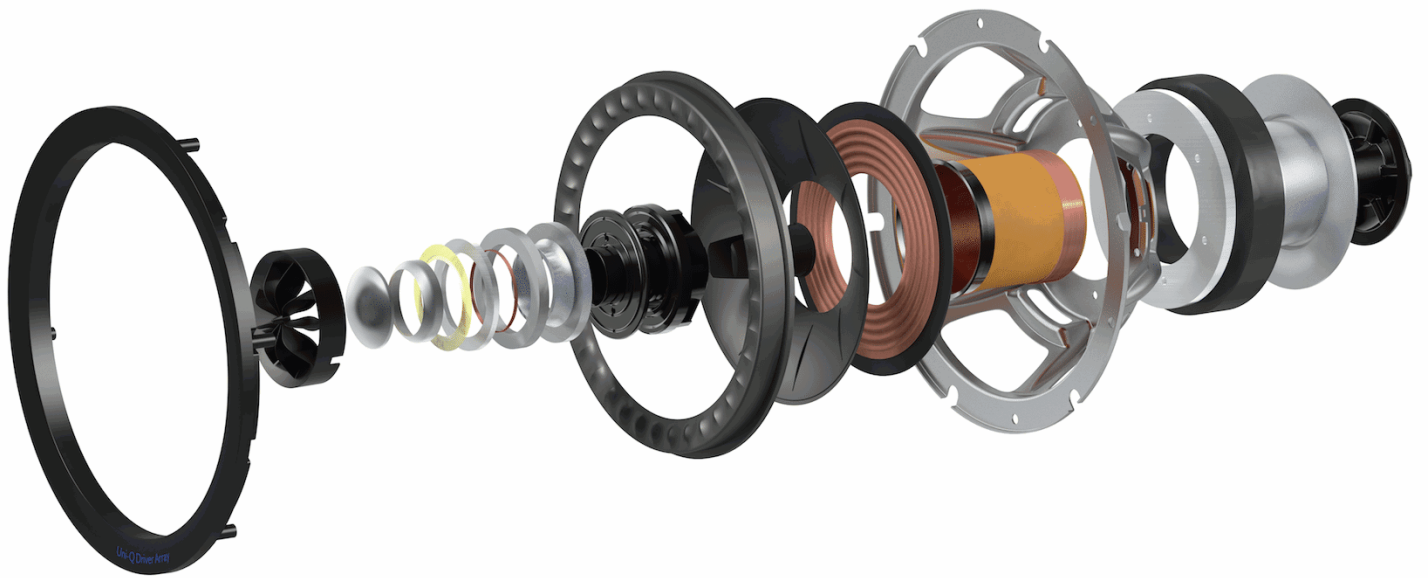


FIGURE 1. EXPLODED CAD VIEW OF THE KEF Q350 DRIVER ARRAY

The following US Patents relate to the Q350 transducer array.

1. US5548657: Filed 16 August 1994
(Expired), *COMPOUND LOUDSPEAKER DRIVE UNIT*, Assignee: KEF Audio LTD, Inventor: Lawrence R. Fincham.
2. US6792127: Filed 9 March 2000 (Expired), *ELLIPTICAL DOME FOR HIGH FREQUENCY TRANSDUCER*, Assignee: KEF Audio LTD, Inventors: Philip Jeffrey Anthony and Julian Roger Wright.
3. US8121330: Filed 13 April 2007, *PHASE PLUG FOR COMPRESSION DRIVER*, Assignee: GP Acoustics LTD,

Inventors: Mark Dodd and Jack Oclea – Brown.

4. US8804996: Filed 19 May 2010, *CONE LOUDSPEAKER*, Assignee: GP Acoustics LTD, Inventor: Jack Oclea – Brown.

5. US9271082: Filed 16 July 2010, *SURROUNDS FOR AUDIO DRIVERS*, Assignee: GP Acoustics LTD, Inventor: Jack Oclea – Brown.



FIGURE 2. PICTURE OF THE KEF Q350 LOUDSPEAKER

The proposed DIY mod includes the following.

1. Bypass the passive first order crossover network and bi-amp the coaxial transducers such that **DSP** can be utilized.
2. Close the rear port with a binding post assembly.

3. Add resistive side ports to the enclosure, similar to the **FULCRUM CCX / D&D**

8ctopology.

Martijn Mensink from Dutch & Dutch provides information on implementing the resistive material within the enclosure at the diyAudio forum. He appears to utilize Rockwool over side vents. However on 16 July 2011 at the diyAUDIO forum, he wrote, "I intended to use glasswool, my favorite, but I didn't have it at the time."

As Martijn Mensink implied, a suitable material for implementing Acoustic Resistance is OWENS CORNING 703 fiberglass. A plot of the Acoustic Resistance, R , of a 2.0 in. thick OWENS CORNING 703 fiberglass slab at various Sound Pressure Levels is contained in figure 3 below.

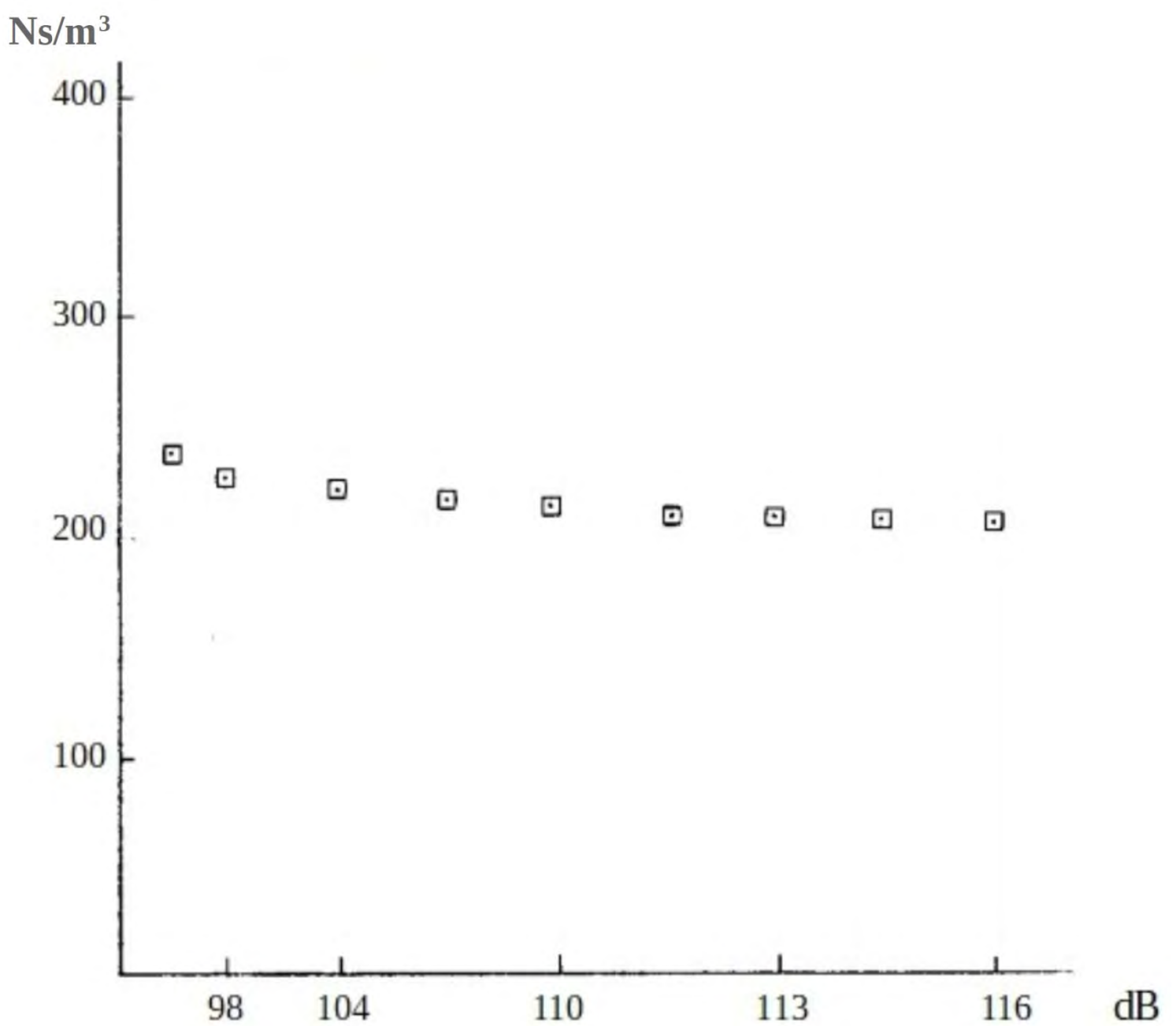


FIGURE 3. PLOT OF THE ACOUSTIC RESISTANCE OF A 2.0 in SLAB OF OWENS CORNING 703 FIBERGLASS AT VARIOUS SOUND PRESSURE LEVELS

The fiberglass will also increase the box damping and attenuate the anti-sound pressure from the rear of the mid diaphragm exiting through the ports. Le Bot's report contains simulations at various gain ratios with $\underline{D/\lambda} = 0.25$ and 0.125 in section F beginning on page 159.

OC 703 is not available in Thailand. The equivalent product is SCG UB-G 4850. The primary difference is that SCG UB-G 4850 is made solely from recycled glass, whereas OC 703 is made from sand. Otherwise, the densities and thicknesses are equivalent but the SCG UB-G 4850 is a symbolic green

rather than the typical Owens Corning yellow. Figure 4 below contains a picture of 2.0 in. OC 703 and SCG UB-G 48 boards in 25 and 50 mm thickness.

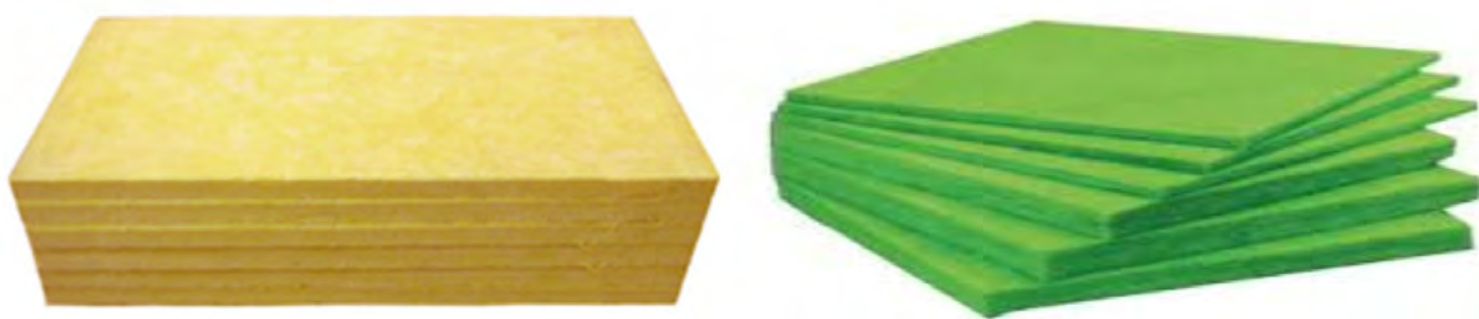


FIGURE 4. PICTURES OF OC 703 AND SCG UB-G 48 RESPECTIVELY

By utilizing a coaxial array with an acoustic resistance enclosure, the directivity control is then passive with no signal processing other than the crossover and EQ down to ~ 271 Hz for the Q350 mod. In addition, the Q350 mod addresses the primary issues that limit the performance of the Q350 that are related to the less than robust 15 mm MDF enclosure and a progressive suspension with DC offset and asymmetric reaction force. The modest effective free length of the suspension components, spider and/or surround along with a surround with asymmetric geometry are at the roots of the issues.

The acoustic resistance enclosure is pressure release in practice relative to a sealed or ported enclosure. The acoustic resistance enclosure has more in common with open baffle topology. The mod should reduce excitation of the enclosure baffles. Note that the front baffle is 34 mm thick MDF in part to facilitate the transducer

mounting recess; however, the larger side 15 mm baffles have only a single brace.

John Atkinson's review of the Q350 for Stereophile magazine includes accelerometer facilitated enclosure baffle natural frequency measurements.

Then in addition, by limiting the bandwidth of the midbass and using woofers, displacement requirements of the mid will be reduced such that the progressive suspension in effect becomes more linear.

The Q350 Large Signal Parameters are not available to the author at this time; however, an independent LS50 LSI Klippel acquisition is available and is contained below in figure 5.

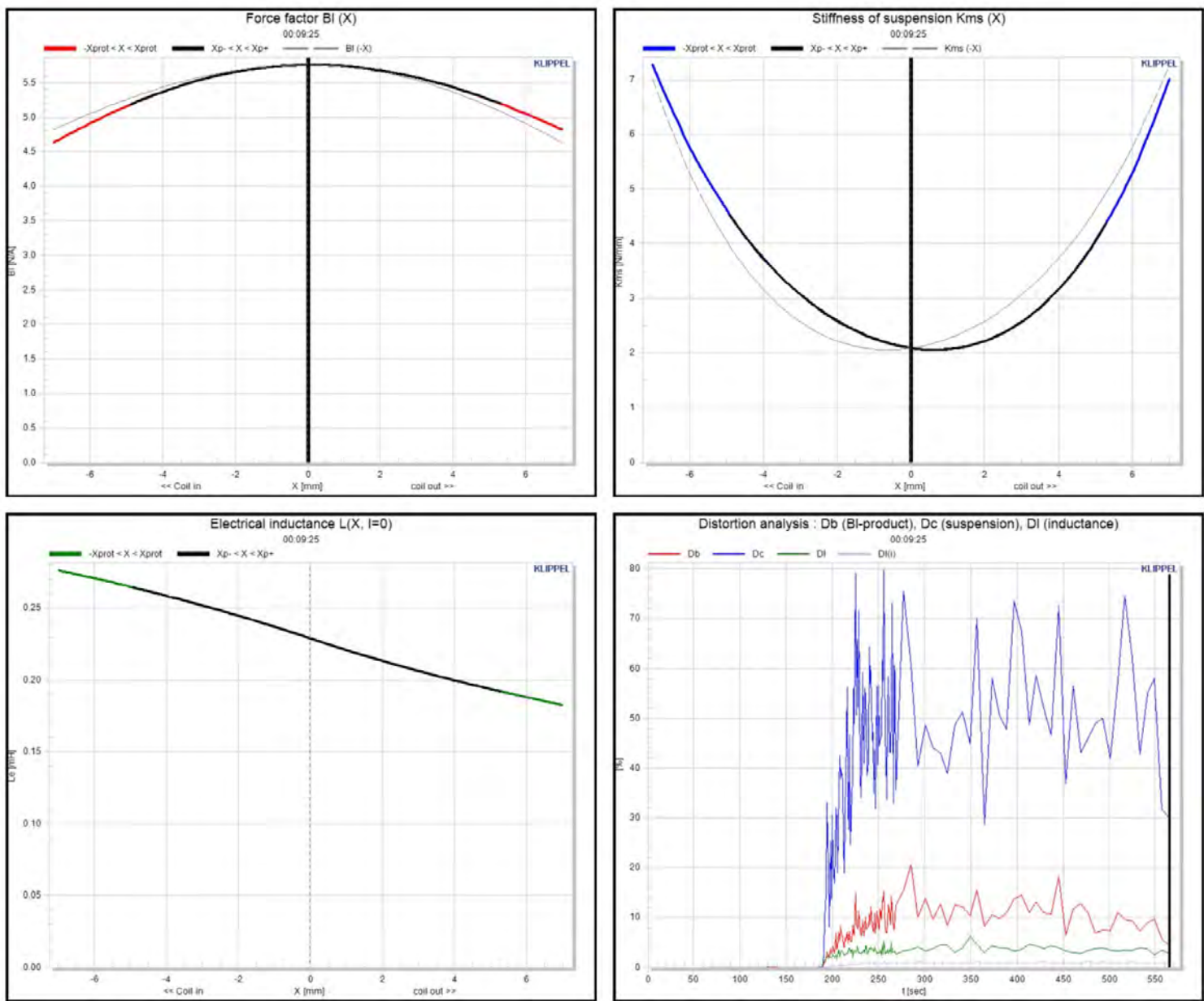


FIGURE 5. KLIPPEL D/A LSI ACQUISITION OF A KEF LS50 NONLINEAR PARAMETERS, $Bl(x)$, $Kms(x)$, $L(x)$ AND RELATED DISTORTION @ X_{max}

It can be observed within the last plot that dynamically at x_{max} , most of the distortion is suspension related. KEF claims that this is not audible, OUCH.

Below are the design equations for the Q350 enclosure mod.

$T_M = R V_{BOX} / B / S_p$ (s) The midrange passive time delay
 $f_{baffle} = c / w_{baffle}$ (s^{-1} or Hz) The front baffle frequency

Let:

$D_M = l_M + T_M c = 2l_M$ (m) Cardoid condition*

$c = 343$ (m/s) The speed of sound in air

$D_M f_{baffle} / c = 0.60$

$V_{BOX} = 14.5$ (l) The box volume

$B = 142,000$ (N/m²) The bulk modulus of air

$S_d = 100$ (cm²) The net piston area of the midrange diaphragm

$w_{baffle} = 0.210$ (m) The width of the front baffle

Then:

$f_{baffle} = 1.633$ (kHz)

$D_M = 0.126$ (m)

$l_M = 0.063$ (m) The normal distance from port center to front baffle

$R = 200$ (Ns/m³) Acoustic resistance approximation

$T_M = 0.18$ (ms)

$S_d < S_p = 113$ (cm²) The net open area of the ports

Let:

$f_{cutoff} = 271$ (Hz) The midrange low cutoff frequency

Then:

$D_M f_{cutoff} / c = 0.10$

Port Dimensions:

4 x $\phi 60$ mm

Plan numbers 3 and 4 can be realized with a DIY woofer/anti-woofer system implementation similar

to one half of the Kii BXT woofer topology. Figure 6 below contains a picture of the BXT woofer array.



FIGURE 6. PICTURE OF A Kii BXT WOOFER ARRAY

In a sense the Dayton Audio LS10-44 woofers are robust 10 in. versions of the Kii Three 6 in. woofers. Figure 7 below contains pictures of the Dayton Audio LS10-44. The LS10-44 can be recessed mounted in which case the transducer geometric discontinuities and thus baffle inconsistencies are mitigated and less than typical. The front primary woofers can be mounted in a complementary array (push-pull). The woofers can then be vertically aligned with the mid with a small signal processing delay. The low stack-up profile and flat diaphragm facilitate this topology. In this way any DC offset and/or asymmetric forces will be mitigated, while the side anti-woofers will be mounted

conventionally. β of the LS10-44 is 60 N²/W but for a 2 x LS10-44 system, $\beta = 120$ N²/W. Where $\beta = (Bl)^2/R_e$. There are two 60 liter enclosures separated by a non-parallel baffle that forms two parallelogram sections. The proposed MDF enclosure thickness is 30 mm with several 30 mm diameter cross braces.



FIGURE 7. PICTURES OF THE DAYTON AUDIO LS10-44 WOOFER

Below are the design equations for the DIY ANC woofer system.

Let:

$D_W f_{\text{cutoff}} / c = 0.60$

$D_W = \ell_W + T_W c = 2\ell_W \text{ (m) Cardoid condition*}$

$D_W f_{\text{anticutoff}} / c = 0.13$

Then:

$D_W = 0.760 \text{ (m)}$

$\ell_W = 0.380 \text{ (m)}$ The normal distance from anti-woofer center to front baffle

$T_W = 1.11 \text{ (ms)}$ The anti-woofers electronic time delay

$f_{\text{anticutoff}} = 60 \text{ (Hz)}$ The low cutoff of the anti-woofers

$f_{\text{primcutoff}} = 30 \text{ (Hz)}$ The low cutoff of the primary woofers

*If:

$T_M < \ell_M / c \text{ (s)}$ Supercardiod condition

$T_M \ll \ell_M / c \text{ (s)}$ Hypercardiod condition

$T_M = 0.0$ Dipole condition

$T_M > \ell_M / c \text{ (s)}$ Subcardiod condition

$T_M \gg \ell_M / c \text{ (s)}$ Omni

Enclosure:

width = 346 mm (13.6 in)

depth = 560 mm (22.0 in)

height = 906 mm (35.7 in)

Note: Golden Ratio (1.618) related outside dimensions

Net Volume = 2 x ~60 (l)

Figure 8 below contains a 2D wire frame drawing of the proposed diy and modified Q350 loudspeaker enclosures.

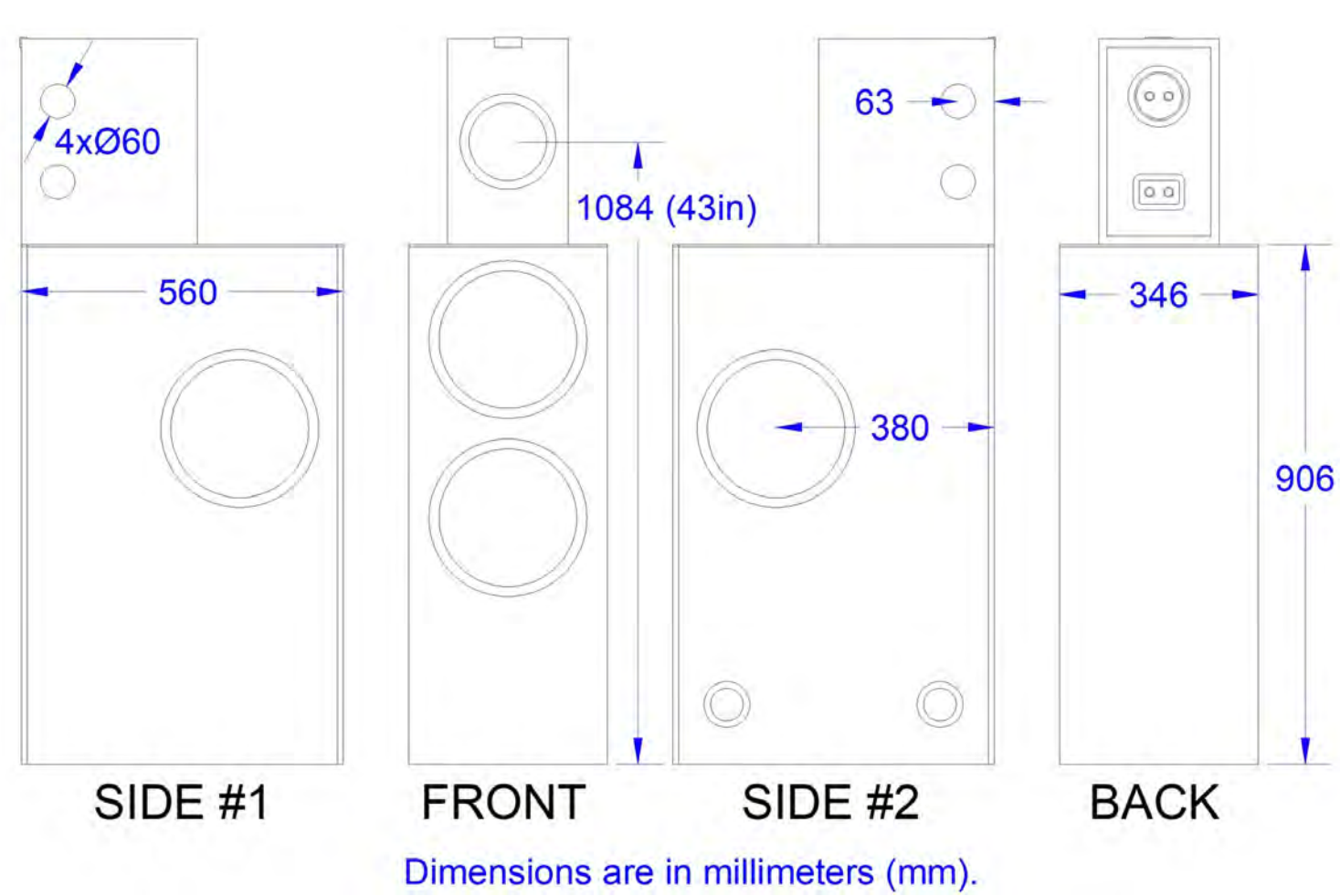


FIGURE 8. WIRE FRAME DRAWING OF THE PROPOSED ENCLOSURES

IV. THE SYSTEM

The loudspeaker needs electronic components to implement a plug and play audio system that assumes the input is *.FLAC files located on a PC.

1. USB Streamer
2. Digital Signal Processor
3. Power Amplifier

Figure 9 below contains pictures of the **miniDSP USB Streamer**, USB in from a PC and optical out to DSP unit.



FIGURE 9. PICTURES OF THE miniDSP USB STREAMER

Then a **miniDSP 4x10 HD** processor with an 8-channel amplifier will realize plan number 5. Pictures of the processor are contained in figure 10 below.



FIGURE 10. PICTURES OF A miniDSP 4x10 HD DIGITAL SIGNAL PROCESSOR

The user friendly graphic interface allows the user to design the system electronic with a computer mouse. Figure 11 below contains an illustration of the 4x10 HD dashboard.



FIGURE 11. miniDSP 4x10 HD VIRTUAL OUTPUT CONTROL DASHBOARD

The 4x10 HD also functions as the system preamp, in addition to the eight (8) analog outputs there are several input options and digital outputs are also available along with the master volume control. Note that there is only one D/A conversion just before the power amplifier inputs.

With the addition of UMIK-1 USB calibrated microphone and REW software, sound pressure can be acquired and graphically displayed on the computer monitor. These acquisitions facilitate the system setup including crossovers, EQ, and delays. Figure 12 below contains a picture of a miniDSP UMIK-1 microphone.



FIGURE 12. A PICTURE OF THE miniDSP UMIK-1 MEASUREMENT MICROPHONE

Figure 13 below contains the REW software overlay acquisition screen.



FIGURE 13. REW SPL PLOT OVERLAY SCREEN EXAMPLE

A UMIK-1 and REW software are used to help select crossovers, perform correction EQ, and apply appropriate gains and delays.

The only reasonably priced 8-channel power amplifier that could be identified was the PYLE PRO PT8000CH. The manufacturer's power rating is overstated; however, power should not be an issue for this application. Woofers ($8\ \Omega \parallel 8\ \Omega$), anti-woofers ($8\ \Omega \parallel 8\ \Omega$), mid, and tweeter are all $4\ \Omega$ nominal loads. Figure 14 below contains pictures of the PT8000CH.



FIGURE 14. PICTURES OF A PYLE PRO PT8000CH 8-CHANNEL POWER AMPLIFIER

Table 1 below contains a simple Bill Of Materials for the diy unidirectional loudspeaker system.

ITEM	QANTITY	COST	SUPPLIER
KEF Q350 Louspeakers	One Pair	\$700	amazon.com
miniDSP 4x10 HD	One	\$499	minidsp.com
miniDSP USB Streamer	One	\$105	minidsp.com
miniDSP UMIK-1 Mic	One	\$75	minidsp.com
REW Software	One	Freeware	roomeqwizard.com
Dayton Audio LS10-44 Woofers	Eight	\$782	parts-express.com
Pyle Pro PT8000CH 8-Ch Amp	One	\$332	parts-express.com
Misc.	N/A	\$500	TBD
SUBTOTAL		\$2,993	
Epoxy Coated MDF Enclosures	One Pair	≤\$1,000	TBD
TOTAL		≤\$3,993	

TABLE 1. THE BILL OF MATERIALS FOR THE DIY LOUDSPEAKER SYSTEM

V. COMMENTS

The proposed system offers very high setup flexibility thanks to the `miniDSP 4x10 HD`. Just a few years ago, one would need to design the signal processing filters and the circuits to implement those filters. Anyone who followed the work of `Siegfried Linkwitz` witnessed this. Implementing filters with software using a mouse is effectively 'A Dream Come True'. Having said that, being able to conveniently acquire response measurements 'in room' with just a microphone and a freeware software application enhances that dream.