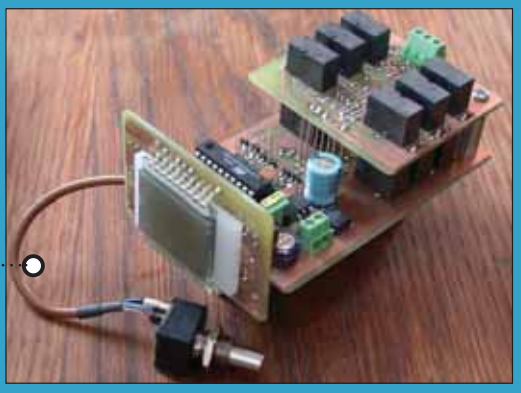
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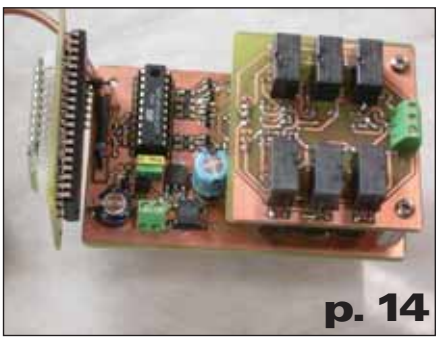


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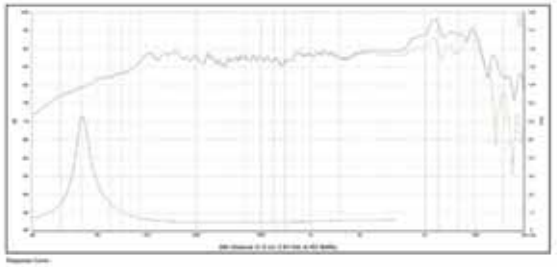


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WHATS NEW ?



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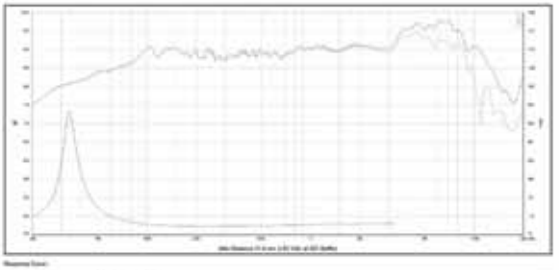


Specs :

Nominal Impedance	8 Ω	Free air resonance, Fs	41 Hz
DC resistance, Re	5.7 Ω	Sensitivity (2.83 V/1m)	87 dB
Voice coil inductance, Le	0.14 mH	Mechanical Q-factor, Qms	5.5
Effective piston area, Sd	88 cm²	Electrical Q-factor, Qes	0.4
Voice coil diameter	30.5 mm	Total Q-factor, Qts	0.37
Voice coil height	15 mm	Moving mass incl.air, md	9 g
Air gap height	5 mm	Force factor, Bl	5.7 Tm
Linear coil travel (p-p)	10 mm	Equivalent volume, Vas	18.7 liters
Magnetic flux density	1.0 T	Compliance, Cms	1.7 mm/N
Magnet weight	0.54 kg	Mechanical loss, Rm	0.4 kg/s
Net weight	1.47 kg	Rated power handling	50 watt

The parameter are measured on drive units that are broken in

THE SPECS



Specs :

Nominal Impedance	8 Ω	Free air resonance, Fs	34 Hz
DC resistance, Re	5.7 Ω	Sensitivity (2.83 V/1m)	88 dB
Voice coil inductance, Le	0.15 mH	Mechanical Q-factor, Qms	5.5
Effective piston area, Sd	118 cm²	Electrical Q-factor, Qes	0.4
Voice coil diameter	35.5 mm	Total Q-factor, Qts	0.35
Voice coil height	16 mm	Moving mass incl.air, md	11.8 g
Air gap height	5 mm	Force factor, Bl	6.2 Tm
Linear coil travel (p-p)	11 mm	Equivalent volume, Vas	37.5 liters
Magnetic flux density	1.0 T	Compliance, Cms	1.69 mm/N
Magnet weight	0.54 kg	Mechanical loss, Rm	0.5 kg/s
Net weight	1.58 kg	Rated power handling	60 watt

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Specs :

Nominal Impedance	6 Ω	Free air resonance, Fs	20 Hz
DC resistance, Re	4.9 Ω	Sensitivity (2.83 V/1m)	90 dB
Voice coil inductance, Le	3.0 mH	Mechanical Q-factor, Qms	4.5
Effective piston area, Sd	312 cm²	Electrical Q-factor, Qes	0.31
Voice coil diameter	75.6 mm	Total Q-factor, Qts	0.29
Voice coil height	28.5 mm	Moving mass incl.air, md	132 g
Air gap height	6 mm	Force factor, Bl	15.4 Tm
Linear coil travel (p-p)	22 mm	Equivalent volume, Vas	56 liters
Magnetic flux density	0.63 T	Compliance, Cms	0.48 mm/N
Magnet weight	2.1 kg	Mechanical loss, Rm	3.7 kg/s
Net weight	5.36 kg	Rated power handling	200 watt

The parameter are measured on drive units that are broken in

10" SB29SWNRX-S75-6

Drivers



Specs :

Nominal Impedance	8 Ω	Free air resonance, Fs	19 Hz
DC resistance, Re	4.8 Ω	Sensitivity (2.83 V/1m)	89 dB
Voice coil inductance, Le	3.0 mH	Mechanical Q-factor, Qms	5.0
Effective piston area, Sd	506 cm²	Electrical Q-factor, Qes	0.34
Voice coil diameter	75.8 mm	Total Q-factor, Qts	0.32
Voice coil height	28.5 mm	Moving mass incl.air, md	154 g
Air gap height	6 mm	Force factor, Bl	15.4 Tm
Linear coil travel (p-p)	22 mm	Equivalent volume, Vas	164 liters
Magnetic flux density	0.63 T	Compliance, Cms	0.48 mm/N
Magnet weight	2.1 kg	Mechanical loss, Rm	5.7 kg/s
Net weight	5.85 kg	Rated power handling	200 watt

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12" SB34SWNRX-S75-6

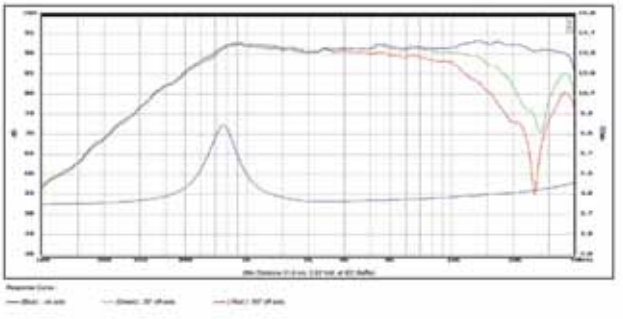
Drivers



SB26STAC-C000-4

Drivers

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- Flow optimized vented pole piece for optimum coupling to rear chamber
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- CCAW voice coil for low moving mass
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- Low resonance frequency



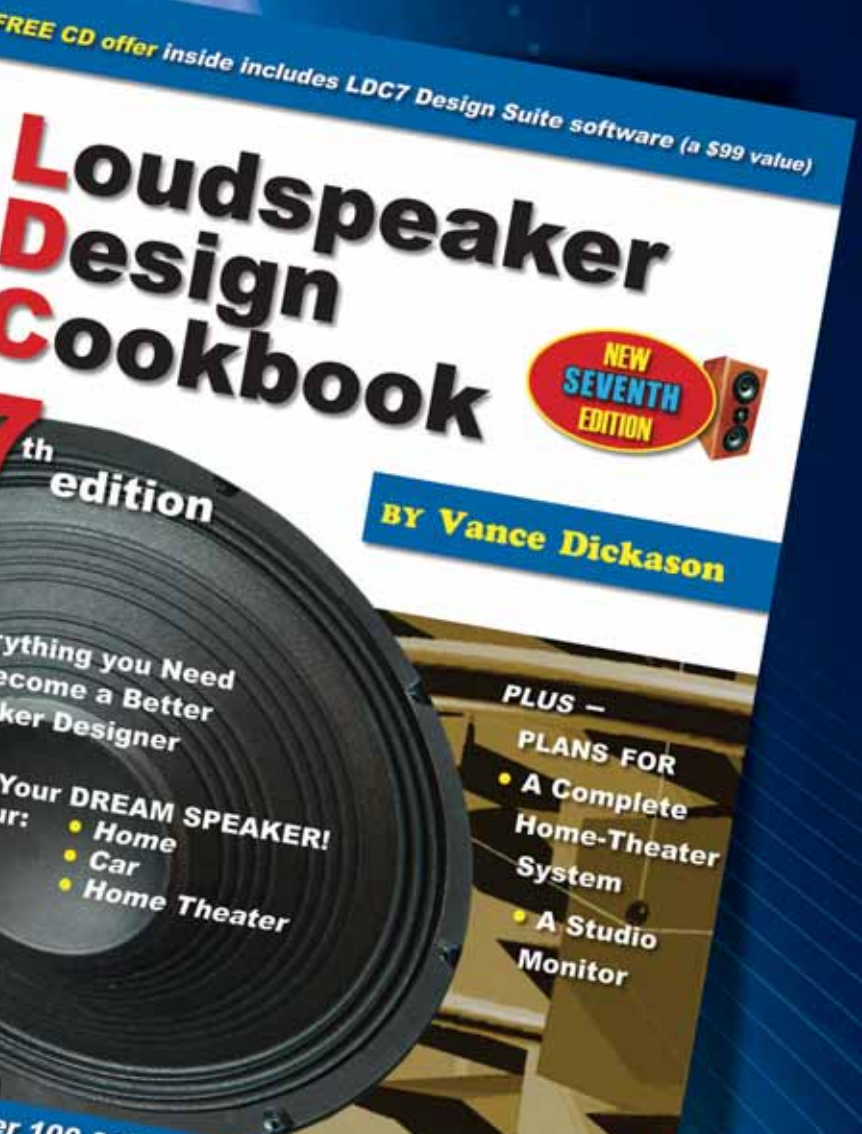
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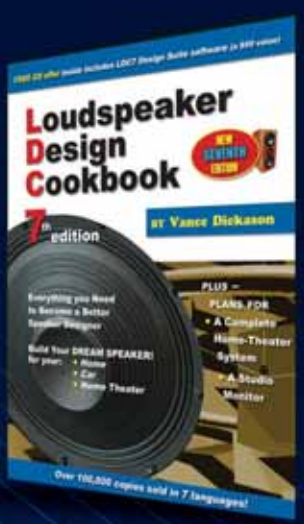
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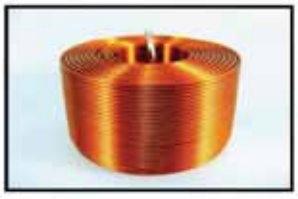
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By Ton Giesberts

Measurement Filter for Class D

Create a filter with less distortion while coping with higher voltage

This filter is an improved version of a filter published six years ago in *Elektor* ("Passive 9th Order Elliptical Filter, " *Elektor* 345, 2005). At the time, this filter was designed for carry out measurements on a Class T power amplifier ("ClariTy, 2 × 300 W," *Elektor*, 333, 2004). The accuracy of our measuring equipment was found to get worse when the frequency components above 200 kHz became too strong, hence the need to remove these with a very steep filter.

The aim of the present design is to create a filter that has less distortion at 20 kHz and which can cope with higher voltages, so that it also becomes suitable for more powerful Class D power amplifiers (**Photo 1** and **Figure 1**). The theoretical values have remained the same as those in the original circuit, and the circuit itself has hardly changed. The biggest improvement is in the way the inductors are made. These are now substantially larger and have an air-gap, which reduces the distortion.



Photo 1: Prototype of the measurement filter as assembled at Elektor Labs. All inductors are home made to obtain the exact inductance values required for an almost ideal frequency response.

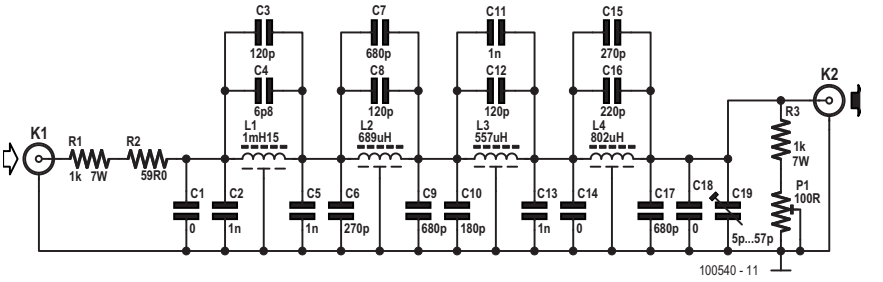


Figure 1: Schematic of the improved measurement filter for Class D amplifiers. Capacitors showing a value of 0 are not used.

The number of turns for each coil was derived using the stated value of the inductivity factor of the core material (A_L). If you have an accurate inductance meter, you could measure the coil before soldering it onto the PCB. It won't always be possible to obtain the exact values for the coils because the smallest change in the winding is half a turn. Measure the wound coil and calculate the real A_L value using the formula:

$$A_L = L/N^2$$

where L is the measured inductance and N is the number of windings. You can then recalculate the number of turns using the new A_L value, which should give you a more accurate number. Should fewer turns be required, you can simply remove them from the coil. Should you need more, you can add a new winding to a connection and connect the end to a third pin. Look carefully at the PCB layout (can be downloaded freely from www.elektor.com) to find out between which pins the coils have to be connected (**Figure 2**).

On either side of the coil former is a row of six connection pins. Three

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pins on one side are always connected to three pins on the other side. The most practical approach is to connect the ends of the coil to the two pins at the front, pin 1 and pin 12. When the inductance value has to be corrected and some turns have to be added, the extra winding can be connected to the first and second (or eleventh and twelfth) pins. The first (twelfth) pin, to which the coil was originally connected should then be cut back to the former, so that it can no longer make any contact with the PCB.

With the coils that we made for our prototype we had to adjust three of the four in this way. The measured values for L1 through L4 in our case were: 1.16 mH, 689 µH, 555 µH, and 816 µH.

The frequency response of the pass band can be seen in (**Figure 3**). The amplitude at 20 kHz is attenuated by only 0.17 dB (compared with 1 kHz) and 39 dB at 204 kHz. When we compare the response with frequency response B from the July/August 2005 article, you can see that there is less ripple up to 180 kHz. The reason for this can be found in the lower *Q* factor of the coils now used, which makes the graph deviate slightly from the theoretical ripple that is common to elliptical filters.

The frequency response of the pass band and the stop band can be seen in (**Figure 4**). The frequencies in the stop band are, apart from a little bump around 800 kHz, attenuated by more than 60 dB. The bump is caused by the various component tolerances, including those of the 1% capacitors.

We tested the filter with the maximum output voltage of our analyzer, which is 13 V. The distortion caused by the filter at this voltage can be seen in (**Figure 5**). The graph is just about the same as the bottom measurement limit of our analyzer.

At some point in the future we'd like to develop a separate amplifier that is able to output 70 V RMS at 20 kHz with an extremely low distortion figure. We'll then be back with a graph that shows the input voltage against distortion. The distortion at 1 kHz and a bandwidth of 22 kHz is less than 0.00018%. With a bandwidth of 80 kHz the distortion plus noise (THD+N) increases slightly to about 0.00028%. The

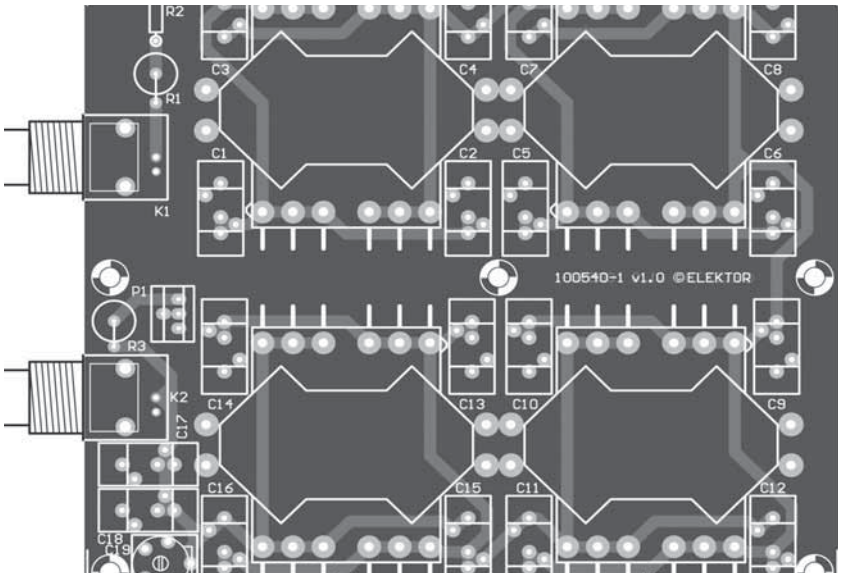


Figure 2: Component overlay of the circuit board designed for the filter. To make your own board, start by downloading the complete artwork files at www.elektor.com.

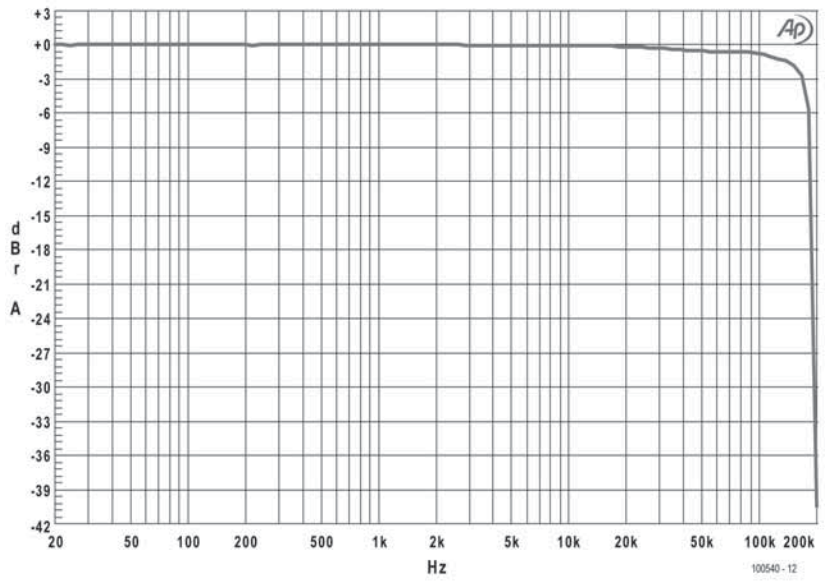
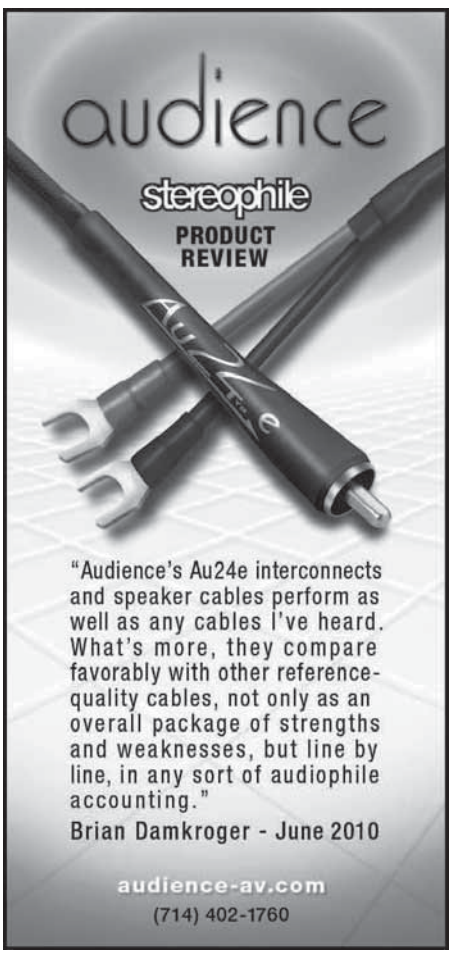


Figure 3: Passband frequency response of the reworked filter



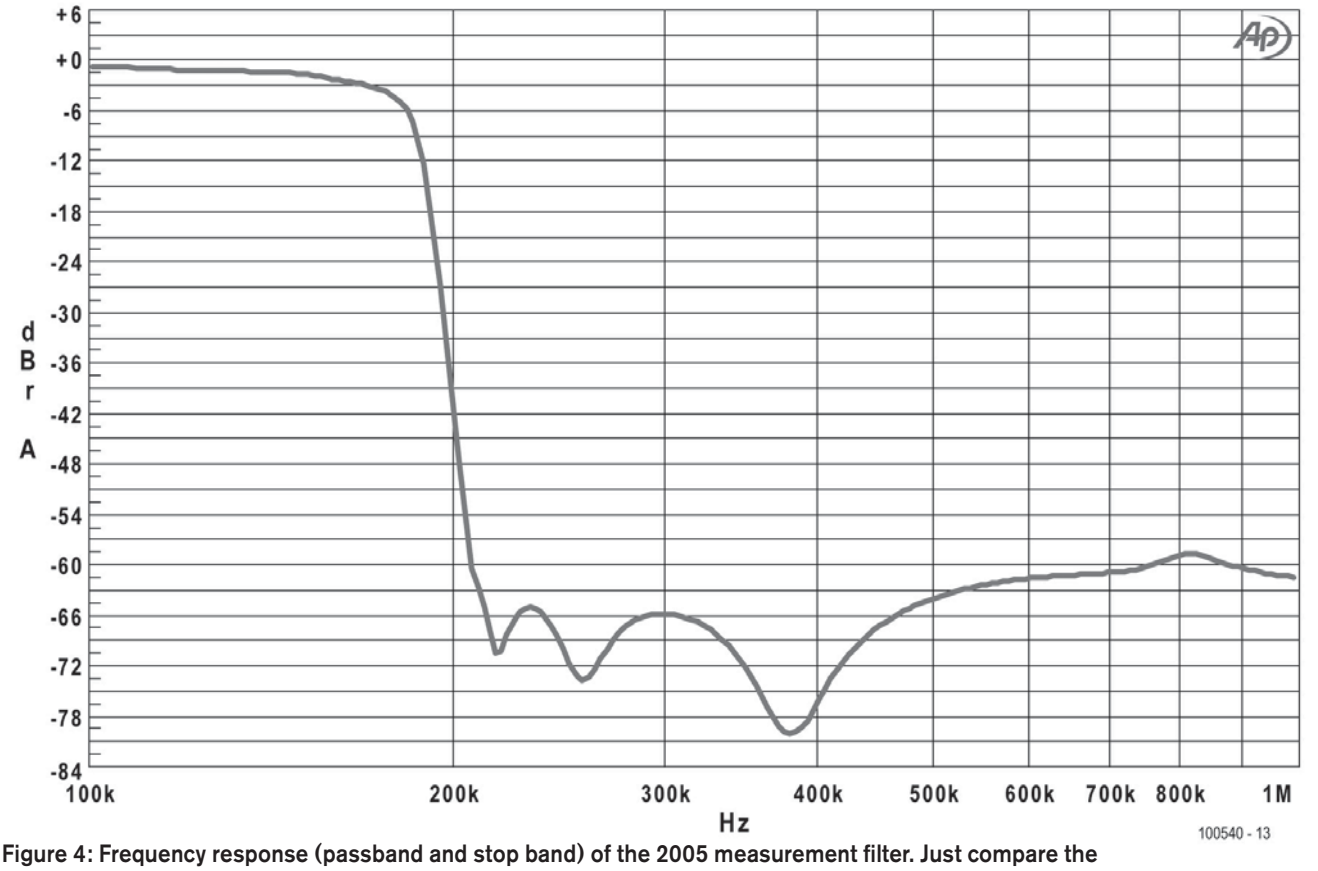


Figure 4: Frequency response (passband and stop band) of the 2005 measurement filter. Just compare the roll-off at 200 kHz with that of the new design (Figure 3).

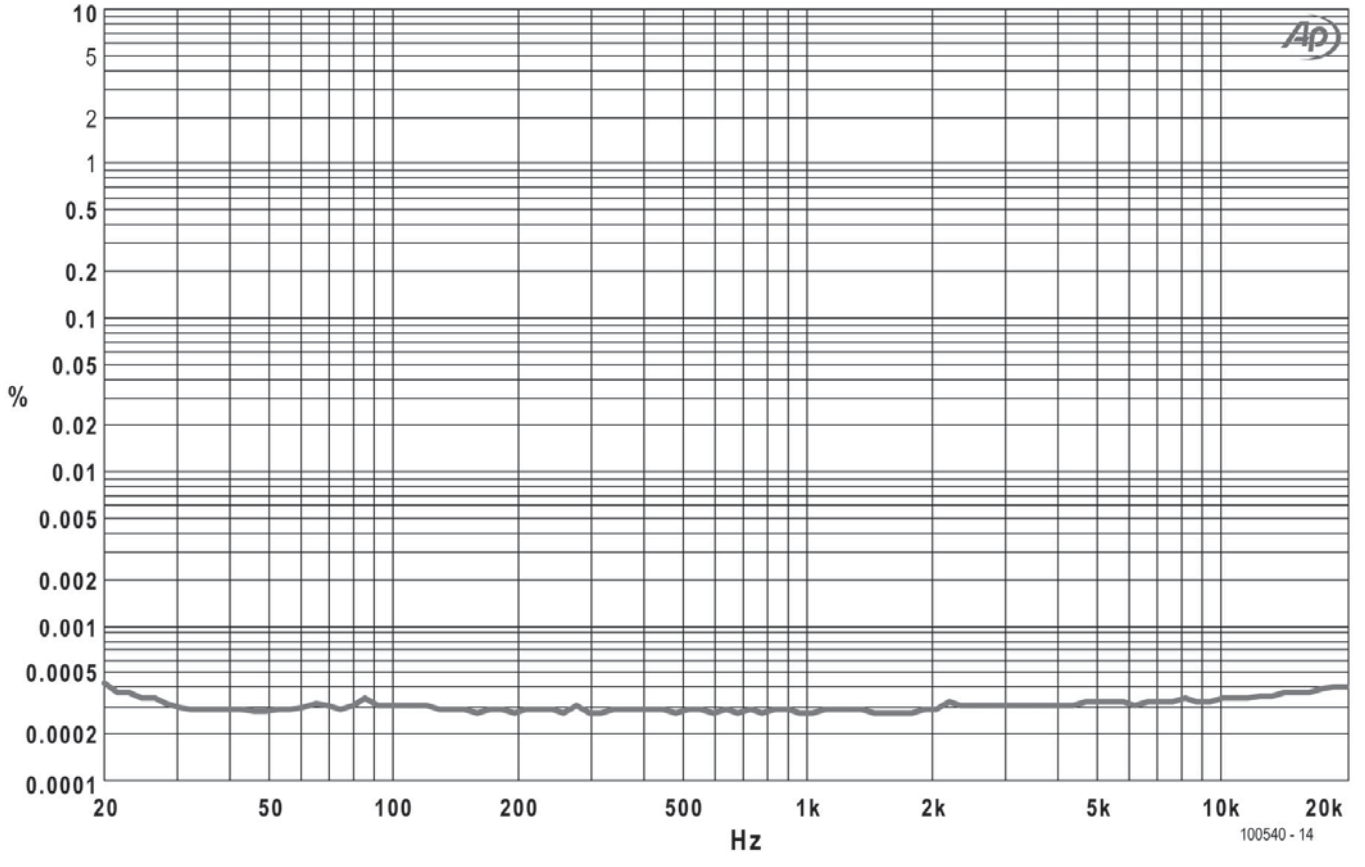


Figure 5: The distortion of the redesigned filter approaches the noise floor of the Elektor Labs's Audio Precision System 2 analyzer.

distortion at 20 kHz and a bandwidth of 80 kHz is about 0.0004%.

Since the filter was designed to cope with higher voltages we had to use power resistors. With a voltage of 70 V RMS across 1 kΩ the power is about 5 watts; the recommended resistors in the parts list are rated at 7 W. The input resistor is a combination of a power resistor and a smaller resistor. We suggest that you measure the value of R1 and then calculate the value for R2. The sum of their values should be 1060 Ω. In our prototype we had to replace R2 with a resistor of 73.2 Ω, to compensate for the tolerance of R1.

At the output of the circuit, multiturn trimpot P1 can be used to set an attenuation of 2 at 1 kHz. Capacitor C19 can be used to compensate for the parasitic capacitance of the cable and the input of the analyzer, although this has more of a theoretical benefit than a practical one.

When you build this filter you have to make sure that you buy the correct set of cores (see the part numbers in the parts list.) There are other cores with different sizes of the air gap and there some without an air gap at all. We have chosen the biggest air gap (smallest A_L value). This means that more turns have to be wound, with the result that the coil can be wound closer to the required theoretical inductance. Another advantage of the air gap is that the tolerance in the inductivity factor (A_L) is only ±3%. Without the air gap it's stated as +30/–20% ! *aX*

Editor's note: This article was originally published in Elektor, *July/August 2011, page 36. Go to www.elektor.com for more information.*

PARTS & COMPONENTS

Capacitors
- C1,C14,C18 = not used
- C2,C5,C11,C13 = 1nF, 1%, 500V, silver mica (Cornell Dubilier CD19FD102FO3F)
- C3,C8,C12 = 120pF, 1%, 500V, silver mica (Cornell Dubilier CD15FD121FO3F)
- C4 = 6.8pF, 1%, 500V, silver mica (Cornell Dubilier CD15CD(6.8)DO3F)
- C6,C15 = 270pF, 1%, 500V, silver mica (Cornell Dubilier CD15FD271FO3F)
- C7,C9,C17 = 680pF, 1%, 500V, silver mica (Cornell Dubilier CD19FD681FO3F)
- C10 = 180pF, 1%, 500V, silver mica (Cornell Dubilier CD15FD181FO3F)
- C16 = 220pF, 1%, 500V, silver mica (Cornell Dubilier CD15FD221FO3F)
- C19 = 5-57pF PTFE trimmer, 250V, (Vishay BCcomponents BFC2 809 08003)

Inductors (incl. materials)
- L1 = 1.15mH, 85 turns 20 AWG mm enameled copper wire*
- L2 = 689µH, 65.5 turns 20 AWG enameled copper wire*
- L3 = 557µH, 59 turns 20 AWG enameled copper wire*
- L4 = 802µH, 71 turns 20 AWG enameled copper wire*
- L1-L4 core = RM14 core set, 160nH (A_L) N41 (Epcos B65887E160A41), e.g. RS Components #212-6772
- RM14 12-pin coil former (Epcos B65888C1512T1), e.g. RS #212-6839
- RM 14 clamp, stainless steel spring (Epcos B65888A2002X, 2 per coil), e.g. RS Components #647-9323
- RM 14 isolation washer. base (Epcos B65888B2005X), e.g. RS Components #180-121
- 20 AWG enameled copper wire (Pro Power ECW0.80). Nearest US equivalent: AWG20

Miscellaneous
- K1,K2 = BNC socket, PSB mount, angled, 75Ω (Tyco Electronics 1-1478032-0)
- Locking washer, BNC/TNC (Tyco Electronics 1-1634817-0)
- Nut, BNC/TNC (Tyco Electronics 1-1634816-0)

Resistors
- R1,R3 = 1kΩ, 5%, 7 W (Tyco Electronics ER581K0JT)
- R2 = 59Ω, 1%, 0.6W*
- P1 = 100Ω, 10%, 0.5W, 24 turn trimpot (Vishay Spectrol M64W101KB40)

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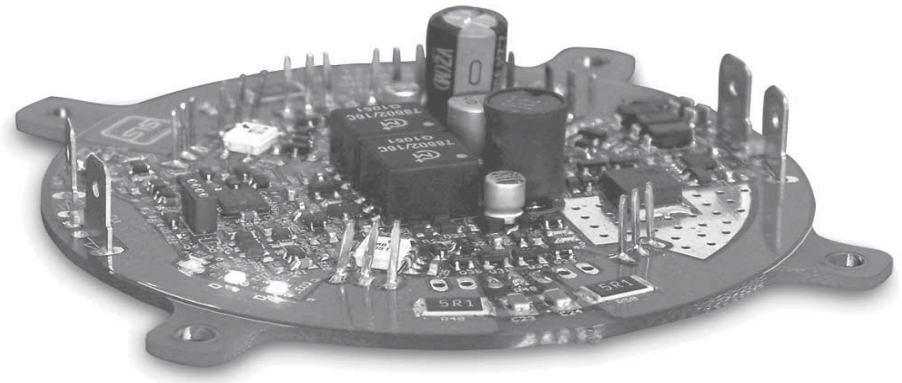
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NEUMANN SUBWOOFER

Neumann has followed its recent announcement of the KH 120 two-way active nearfield monitor with the launch of a matching subwoofer, the KH 810. According to Neumann, the KH 810 is far more than a simple subwoofer; it serves as the heart of a modern monitoring system. The comprehensive 7.1 High Definition Bass Management system can be used either as a subwoofer dedicated to reproducing the LFE channel, or as a means of providing low-frequency extension with an increased maximum SPL. With the KH 810, it is now possible to assemble flexible monitoring systems for studios of different sizes, with a response that ranges from below 20 Hz to above 20 kHz.

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The KH 120/810 combo can be used for tracking, mixing, and mastering in music, broadcasting, project, and post-



Neumann KH 810 subwoofer



State-of-the-art amplifier technology

production studios. For more information, contact Pr-Info@neumann.com.

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Powersoft_M Series DSP+ETH

The high-performance DSP card offers FIR/IIR filters for accurate crossover control for bi-amped loudspeakers.

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The two four-channel models provide up to 1250 W/channel on 4 Ω loads, while the three two-channel models offer a maximum output of 1500 W/channel on 4-Ω loads, while full range can reach up to 360 W/channel on 8-Ω loads. For more information, visit www.powersoft-audio.com.

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 By Robert Nance Dee

Build a BCD-Digital Potentiometer

A pot design that brings accuracy and flexibility to audio controls

My goal with this design was to control the level of a circuit with as little intervention as possible. I could have traveled traditional routes and built expensive potentiometers with gold contacts, numerous resistors, multiple gangs and switches, and so on, but I have always seen this as a flawed, albeit brute force, method lacking elegance. It's basically a poor way to address potentiometer design.

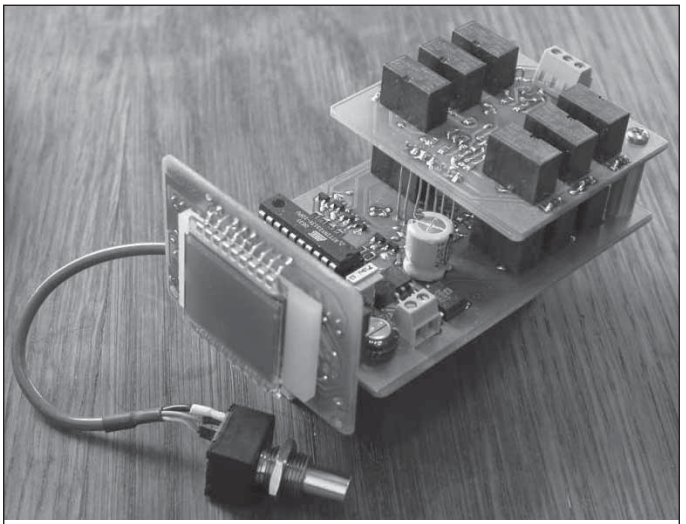


Photo 1: The completed circuit board

I played with digital pots, but they introduce semiconductors and add impedances into the circuit. They are also limited by how much voltage—both positive and negative —they will accept.

I decided to take out a clean sheet of paper and start from scratch to see whether I could make a pot that rivaled present designs while maintaining a reasonable cost. This, then, is the result of that inquiry (**Photo 1**).

I wanted flexibility—that is, I wanted to be able to use it in audio or any design and I wanted to be able to manipulate the value of the pot with just a few components to simplify other applications. Also, it must have a high degree of accuracy along with its flexibility. Next I wanted it to have as few—if any—moving parts and a long life that didn't require any maintenance or lubrication. I wanted it to work as well in 10 or more years as it did the day I built it. I also wanted to know what level the pot was at all times so I could return to a specific point or listening level at any time.

THE DESIGN

For this design, I used an Atmel ATtiny2313V, 8-bit microcontroller programmed in assembly. It let me control the LCD and the output to the relays and also enabled me to use a small capacitor 0.33 F to save my settings with the power off so my circuit would not draw—nor require—any external power in the off condition.

The design uses binary-coded decimal (BCD) to select any level from 0 to 63 by manipulating six double-pole relays (**Table 1**). This has the advantage of requiring only 12 resistors (although I will be using 18, but more about this later). Of the 18 resistors, only nine are ever in the circuit at any one level, so for stereo I employ 18 resistors total for 64 levels and two channels. BCD is reflected in the program as hexadecimal, so no manipulation of the data is required for the outputs from the registers. Again, you can see this in (**Table 1**).

I chose the relays carefully because current draw, contact isolation, and relay life needed to be examined for the design to work well. The relays draw 6 mA each. For stereo, there are 12 relays, six per channel. You can add channels and have four or more channels simply by building more auxiliary boards. In the same respect, you can have only one channel for monaural or to control a three-terminal regulator in an entirely different application if you desire.

These relays are hermetically sealed, washable, and have gold-plated contacts; their cost is also low—12 relays cost under $40. The engineers at Tyco who make the relay told me that the mean time between failures (MTBF) is in the millions at the low current and voltages that audio circuits require. Using relays and not MOSFETs or other electronic devices means that you have no positive or negative voltage limitations and the controlled circuit only sees the combinations of resistors. It is also important to realize that nowhere in this circuit is any switch exposed to outside air, thus oxidation is not a factor.

For the resistors, I used Panasonic SMD low-noise, 0.1%, 1/8-W metal film devices. With the pot at maximum —64K in my application—the total resistance error was 6 Ω. At the lowest value (1K), the measured resistance was 1000.13 Ω (four-wire method). To make up the values shown in (**Table 1**) only requires three resistor values: 1, 2, 16 Ω. This can be in any multiplication: 10, 20, 160, 10k, 20k, 160k, and so on. For example:

Resistor 1 = 2 Ω (parallel)
Resistor 2 = 2 Ω
Resistor 4 = 2 × 2 Ω (series)
Resistor 8 = 2 × 16 Ω (parallel)
Resistor 16 = 16 Ω
Resistor 32 = 2 × 16 Ω (series)

TABLE 1

Resistor values						
	32	16	8	4	2	1
binary	1	0	1	0	1	0
BCD			42			
Hexadecimal		2		a		

You can also start the progression with 2: 2, 4, 8, 16, 32, 64, to give you 128 Ω total for 10 resistors using the original two values.

For trouble-free operation, I used a low-cost 64-step optical encoder to switch the relays through the microcontroller. Operating as a stereo volume control, there is no sense of "stepping" as the volume is increased over its 64 steps. The complete process is smooth and detent-free.

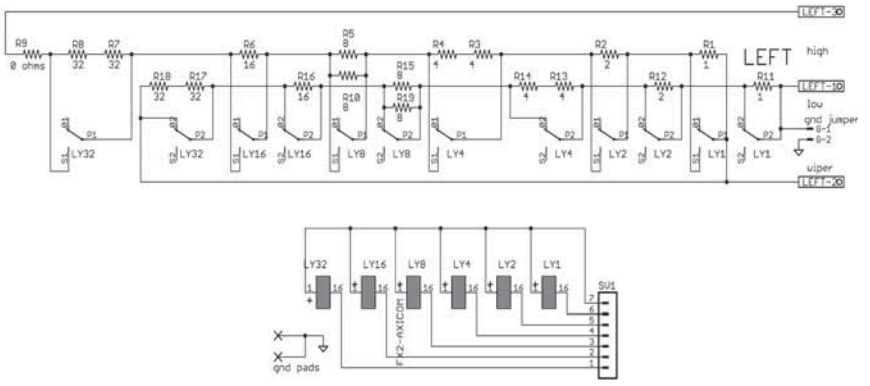
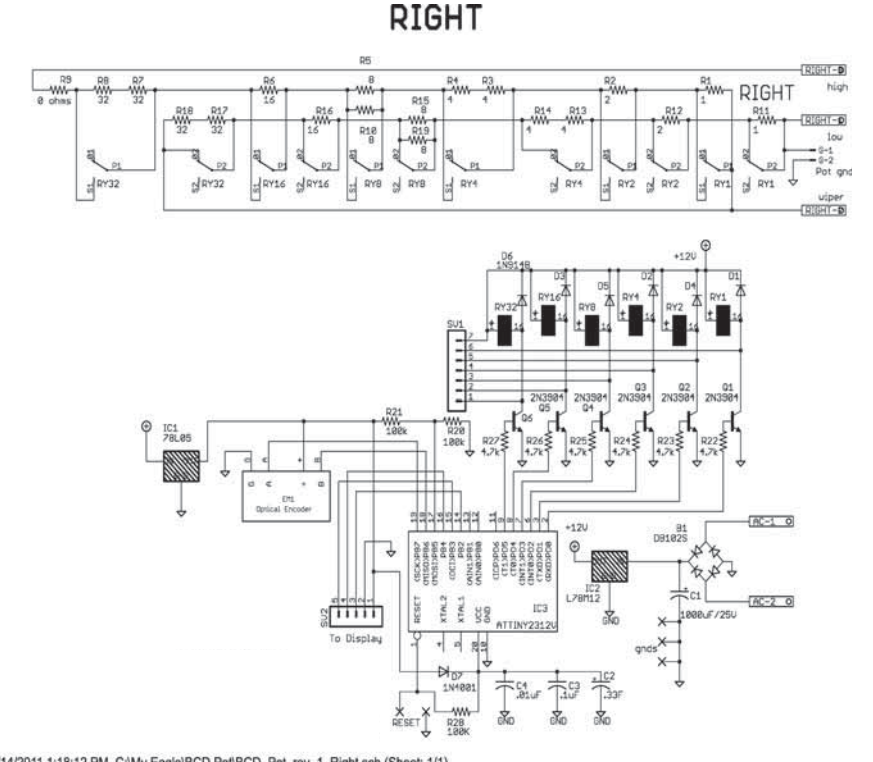


Figure 1: Schematic left



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Figure 2: Schematic right

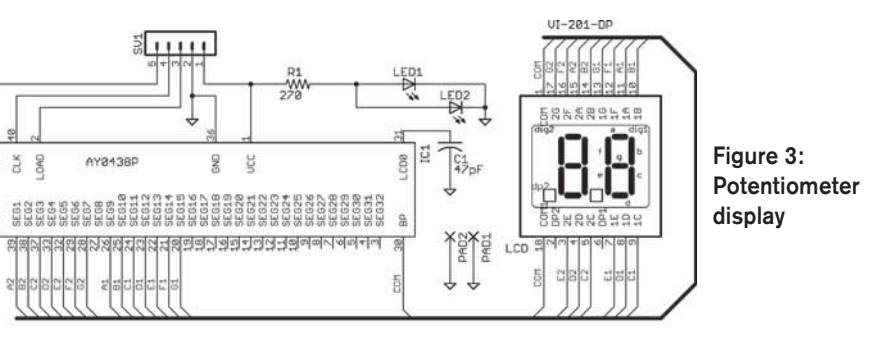


Figure 3: Potentiometer display

It is possible to isolate the relay low-clicking noise completely, but it is not overbearing, and I personally enjoy the positive sound as I run up and down with the control. Most times I just change the volume to a new level, and the fact that I'm using a sophisticated control is not an issue. It's kind of neat, actually! This control, however, is especially suited for the most sophisticated hi-end audio products. I did not add remote control to this design, but the design, by nature, lends itself well to this addition.

For this project, the ATtiny2313V, along with an AY0438 driver for the display, does all the work. The display mounts on the main board with the power supply. I did not isolate the supply from the resistor boards because noise measurements are below what my instruments can sense. The resistors are not tied into any part of the circuit, only the sealed relay contacts. In my stereo control, I used a jumper to tie the low leg of the pot to ground, but in all respects the resistors are autonomous.

When the power to the BCD pot is off, current draw from the circuit is less than 200 nA, and the 0.33 F capacitor will run for weeks holding the last level before going below 1.8 V—at which level this chip is capable of running.

Last, I included the LCD for a relative level: 31 can be 31 Ω or 310 k Ω, I did not see any need to set dB output indications. My thinking is that volume is set to a specific level and what is paramount is knowing and returning to that level. This applies to instrumentation as well.

SOFTWARE AND OPERATION

The software was written in Atmel's Studio 4 in assembly. It starts up with an initialization of the registers driving PortD, the relay port; the initial output is "00," which is the lowest setting. From there it goes to the LCD and loads the same value as the outputs and sets the load lead hi to lock the value. If no other input pulses come in from the encoder, the microcontroller goes to "wait" for a change in the encoder state and pro-

ceeds to update the outputs on PortD and the LCD.

When the circuit is powered down, pin 17 (PortB,5) low sends the program to sleep (power down mode). In this mode, the internal 4-MHz oscillator turns off and the last output values are saved. Wakeup is from a pin change (PortB,5 again) going high, which sends the program to wait for a change from the encoder (pin 19, PortB,7) and the cycles repeat. The output (PortD) drives the six 2N3904 NPN transistors through the six 4.7k resistors, and the transistors in turn drive the 12-V relays by grounding the negative side (pin 16).

When the power to the circuit is turned off, the 1N4001 diode on pin 20 of the microcontroller isolates the microcontroller and the 0.33-F capacitor from the LCD and the relays. In this configuration, the only power the capacitor sees is that of the microcontroller in sleep mode; on wakeup it is recharged to 4.3 V (5 V minus the 0.7 V loss from the 1N4001 diode). Do not change this diode to a Schottky diode because it has too much leakage, and the voltage drop benefit will not make up for the extra load on the 0.33-F capacitor.

CONSTRUCTION

Building the circuit is straightforward with a mix of SMD and through-hole components (**Photo 2**). The only components not on the board are the LCD, which attaches with a single five-pin 90° connector, and the encoder. You can connect the LCD with a wire harness extended to a front panel if desired, as you can with the encoder. In my case, I attached the display to the main board and the encoder with wires (there are four).

Build the main board first and test the voltages before inserting the encoder or the microcontroller. Pin 20 of the IC socket should have about 4.3 V and the encoder should be just about 5 V. The positive side of the relay (pin 1) should have 12 V. These are polarized relays, which won't operate with B+ attached to pin 16. The LCD should also be attached after the initial testing and have 5 V on pin 1. Power for the circuit can be from a 12-V transformer at 300 mA or 15 V DC. This is handy to allow tapping off audio power when used as a stereo pot.

I placed auxiliary relay boards for additional channels on 19-mm (¾") standoffs and ran wires through the connector to the main circuit. Place the AY0438 driver chip on the underside of the LCD board and the LCD on top. The two SMD LEDs (I used amber) light the display in low light conditions. I also inserted a piece of milky white Lexan between the LEDs and the bottom of the display to diffuse the light hitting its underside before I soldered it in place. While this is not required, it does add a nice touch.

I did not build a dedicated case for this pot because it's going into my latest audio design. This device will also work nicely in an active audio control along with an input switching circuit plugged into a preamp.

I have placed an adjusting resistor (R9) on the relay boards to help when using the circuit for different applications. With my audio circuit, I simply shorted across R9 to remove it from the circuit, which must either have the resistor or a short in its place.

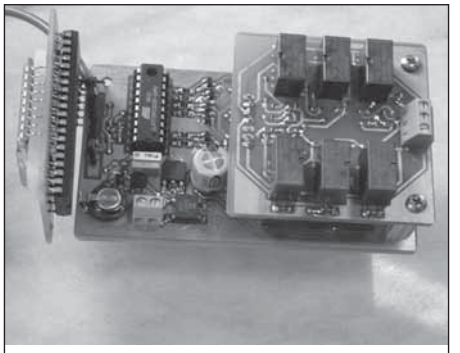


Photo 2: Top view of circuit board

SPECIFICATIONS

- Noise: Less than 5 mV
- Linearity better than 0.1%
- Maximum error less than 0.1%
- Current 110 mA peak, two channels
- Main board dimensions: ~5.7 cm W, 9 cm L, 3.8 cm H (two channels)
- Auxiliary boards ~5.7 cm W, 5.7 cm L

CONCLUSION

This design turned out exceptionally well; it works with no glitches and its accuracy is far better than an audio circuit could ever need. I like the fact that it acts as a smooth transition when passing from one level to the next.

I have never understood why detents were ever put into audio pots, especially with many having only 24 specific levels. I always seem to be listening somewhere between two detents, and multiple switch pots are no better. This pot with 64 levels and precision metal film resistors is hard to beat for sound or facility. I hope you enjoy building and utilizing it as much as I enjoyed designing it! aX



Castle Tower Omni Speakers

Build a pair of Castle Tower speakers for your kingdom.

By Ken Bird

While attending a recent concert of the Sedalia Missouri Symphony orchestra (the second oldest in Missouri now celebrating 75 years of good music), my intermission thoughts turned to the sound I was hearing in the concert hall. It was all omnidirectional and there was no such thing as a "sweet spot." Since the advent of stereo in the late 1950s, speaker builders—both professional and amateur—have espoused the mantra of the sweet spot and sharp imaging. We strive to create that point between the speakers where the orchestra or the soloists appear to be centered. The only problem is when you change your position or even move your head a bit and the audio illusion disappears. That does not happen in the concert hall; no matter where you sit, you are surrounded by music.



Photo 1: The hex-shaped Castle omnidirectional speakers with grille screens

Speaker designers have done little to replicate the phenomena of reflected sound. In the 1950s, Stewart Hegeman designed many omnidirectional speakers for Harman-Kardon. The Bose 901 system, introduced in the 1960s, was another commercial attempt, and while it is still produced and helped make Mr. Bose a very rich man, it has not been widely accepted by the "serious" audiophile community. In the engineering department of a well-known Chicago-area audio manufacturer, where I once worked, there was a sign on the wall—"BOSE, No Highs–No Lows." That may have been an indication why the 901 System did not sell well to audio purists.

In searching online and in my library, I could not find much on omnidirectional loudspeakers. There are a few that used an upward-facing speaker playing into a reflector, and there are commercial models used for paging and background sound. Other examples include a few do-it-yourself models designed by David B. Weems and published in a now out-of-print *21 Custom Speaker Enclosures Projects You Can Build* (TAB Books, 1980). One was a 30" tower with two 8" woofers, four 3" tweeters, and a single piezo super tweeter. Another project in the same book was called the Omni Hex, which used six 6" × 9" drivers in a hexagon-shaped cabinet that doubled as an end table. Mr. Weems earlier designed an omni speaker called the "Plus 4" in the March 1975 issue of *Popular Electronics*. The system used a single 8" upward-firing woofer with 5" whizzer cone-equipped mid-tweeters in a unique triangular-shaped enclosure.

All of these efforts by others inspired my design of the "Castle System," or, as some of my chess-playing friends have called it, the "Rook" (**Photo 1**). I'll just go with the Castle, even though my bride commented when she say it: "Are you going to build a drawbridge and moat to go with them?" followed by "If it fails as a speaker, we are going to have two of the best-looking bird feeders in the neighborhood."

THE MOCK-UP

This system is not for the faint-of-heart woodworker. Producing a large hexagon-shaped enclosure was a challenge with my limited equipment and woodworking skills, and, if not for the table saw skills of a friend, Mr. Earl Meyer, who once managed a commercial woodworking shop, the project may not have been built.

Before any wood was cut, I assembled a full-size non-working mock-up (**Photo 2**) using 0.5" *21 Custom Speaker Enclosures Projects You Can Build* foam insulation board, which was easy to cut with a carton knife. It was held together with tacky craft glue and 2" nails with the seams covered in duct tape. It made a sturdy structure, which I recommend for replicating other odd-looking enclosure designs before you commit them to wood. The tower turret is an optional decoration and is designed to just sit on the top. You can eliminate it from the project if you want a less medieval look.

DRIVERS

My collection of drivers included some very nice 6" surplus Delco Automotive speakers that measured reasonably flat in response from 80 to about 8 kHz. Because they are no longer available, I have chosen close substitutes in the parts list.

The tweeters are piezo types available from MCM and the woofers are Parts Express 10" Dayton models that work well in a ported enclosure. This is the first system I have ever built using a downward-firing woofer, a discussion of which you can find in the reference section. I did not experience any sub-



Photo 2: Foam board mock-up

jective changes in woofer performance in the downward position. The crossover points are 400 and 5000 Hz with a simple 6 dB per octave circuit (**Photo 3**).

CONSTRUCTION

The system is a hexagon-shaped tower using six piezo tweeters, six 6" mid-range speakers, and a 10" downward-firing woofer in the base (**Figure 1**). The side panels are 1 × 8" dimensional pine, and the internal partitions are 0.75" plywood. The 1.8 ft^3 woofer chamber is ported, while the 1.1 ft^3 mid-range chamber is sealed.

As in my past projects, I used dimensional lumber for the enclosure side panels and cut 0.75" plywood for the hex-shaped top, partition, and woofer baffle. I selected the number 2 grade 1" × 8" pine, because it has fewer knot holes or other defects. However, there can be variations in the face width of dimensional lumber which can make forming an accurate hex enclosure difficult. In checking the lumber, I discovered that some of the face widths were 1/8 smaller than the nominal 7.25" of a 1" × 8" board. I corrected this defect by running all the boards through the table saw to achieve a consistent 7.125" (7 1/8") face width.

The most tedious aspect of building this enclosure is the correct cutting of the 30° bevels on the side panels. I achieved this by running each side of the 12-panel boards through the table



Photo 3: The drivers

saw and checked them with an accurate miter gauge set to 30° (**Photo 4**). Changing the face width of the speaker panel also changes the rear face width, which determines the length of the hexagon sides.

To lay out the proper-size hexagon pieces for the top, partition, and woofer baffle, go to www.hstutorials.net/math/geometry/constructions/hexagon.htm. You will need to know the width of the rear face of the beveled panels—that is, the base length of the six triangles that will form your hexagon. Use the same criteria for the enclosure base and the turret top. The tutorial will take you through the layout procedure. Produce the hexagon pattern on stiff drawing paper or draw the hexagon directly on the plywood. You will need a 12" compass for this task.

Once you have beveled the boards, cut out the tweeter and mid-range mounting holes along with the port,

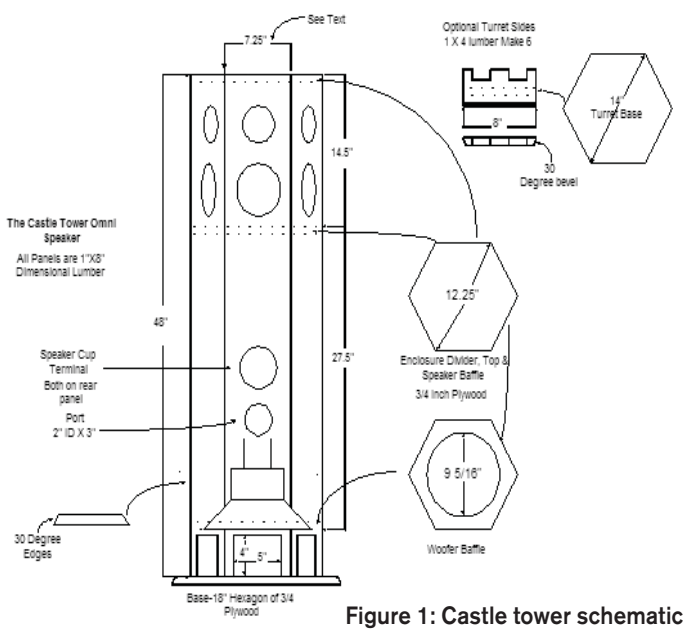


Figure 1: Castle tower schematic



Photo 4: Cutting panels at 30°

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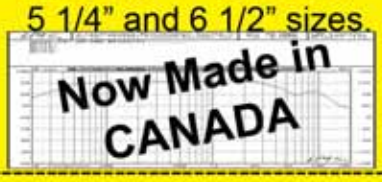
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terminal cup, and the 4" × 5" woofer vents in the bottom of each panel. I used a router with a Jason Model 200 circle jig for each round hole and a jigsaw for the woofer vents. The diameter of the speaker cutouts will vary with the drivers you use. Mine required the tweeter holes to be 2.25" and the mid-range 5 5/8" hole with 0.25" countersink of 6 1/16". The 10" Dayton woofer required a 9 5/16" hole.

I cut the hex-shaped top, internal partition, woofer baffle, turret top, and base from 0.25" plywood using a Skil saw. Cut the hole for the woofer first, then cut the hexagon sides. **Photo 5** shows a complete set of parts for one system, less the hexagon base.

ASSEMBLY

Begin with the back panel—the one with the speaker terminal and portholes. Carefully position the top and woofer baffle applying wood glue to each piece. The woofer baffle is positioned 0.5" above the lower 4" × 5" woofer vents (**Photo 6**). Use furniture clamps to hold it in place. To mount panels, I used 1 5/8" drywall screws, two per side, and countersunk 0.25". I first drilled a guide hole in the panel using a 1/8" bit. Go only about 0.5" into the panel. I countersunk each screw 0.25". This prevents the panel from splitting and will enable you to fill the screw hole with plastic wood later.

Once the top and woofer panel are in place, mount the internal partition 14" from the top of the panel and repeat the screw mounting. Drill a 0.25" hole in the internal partition to carry the wiring for the mid-range and tweeters. Once the back piece is in place, add a second panel, carefully matching the top and bottom ends. Use a liberal amount of wood glue on the bevel ends and the hex forms. When you've assembled three panels, apply caulking to the interior joints, and continue caulking as you mount each panel (**Photo 7**). The last panel will require you to apply caulking through the woofer opening and the mid-range openings; apply some by hand, because there is limited space for the caulking gun.



Photo 5: Castle system parts

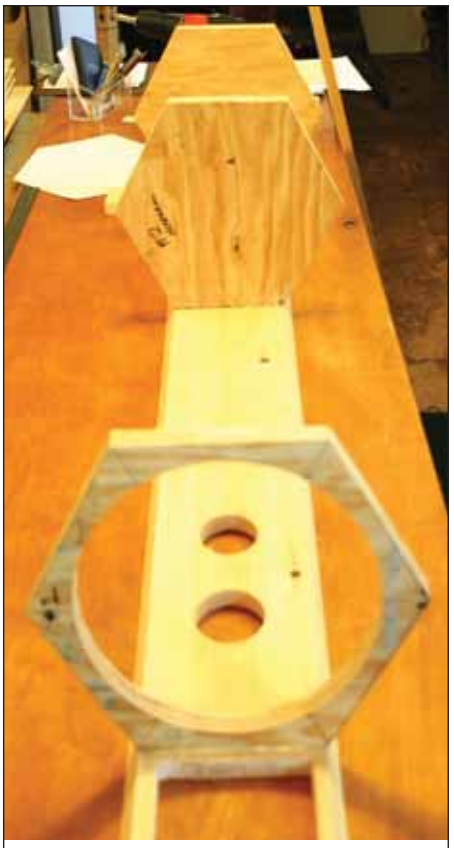


Photo 6: The start of the assembly



Photo 7: Gluing and caulking the panels

I built the optional turret as a separate assembly. The sides are 1" × 4" pine with a routered ogee pattern on the bottom edge. I cut the top crenellations with a jigsaw. I made the 30° edge miter cuts with a compound miter saw. The turret floor hexagon sides are 7 1/8" wide.

The base is a piece of 0.75" plywood and the hexagon sides are 9" long. I also decorated the base edge using an Ogee bit and router. Once you've cut the base, set the enclosure on the base, spacing the legs an equal distance from the edges. Mark the letter "B" near the base edge on which the back of the enclosure sets. Trace each leg position with a pencil, remove the base, and drill 0.125" pilot holes for the mounting screws within the center of each leg. Mark the letter "B" on the bottom of the base referencing the original "B" mark you placed on the top of the base near the back edge. This will allow you to match the base to the proper screw holes. Make sure you don't drill into the leg joint between panels. Sand and finish the base to match the enclosure.

The woofer port is a 3" piece of 2"-inside-diameter PVC plastic pipe. Paint the ends and internal walls of the port pipe with flat black spray paint. Coat one end of the pipe with clear caulking and install it flush with the enclosure wall.

Once you have fully caulked the enclosures and filled in the screw holes, let them set for 12 hours before sanding the external surfaces (**Photo 8**).

The choice of finish is yours. The

non-turret versions look very modern painted with a high-gloss enamel. I thoroughly sanded my version, wiped it down with mineral spirits, and stained it with a mixture of two-parts walnut and one-part mahogany Minwax stain, followed by two coats of high-gloss polyurethane. The optional turrets are held in place with two screws countersunk in the top and hidden by wood plugs, which are not glued in, to allow removal of the turrets. Let the polyurethane dry for at least one day before further work on the enclosures.

CROSSOVER

I constructed the three-way, 400-5000 Hz, first-order crossover from hand-wound coils, and in the case of the woofer coil, unwound coils. I had some surplus iron core 9.9-mH coils, which I unwound until I achieved the 3.2 mH value needed for the woofer section. I wound the midrange coil on a blank hookup wire spool using #18 gauge magnet wire. I have included part numbers for commercial coils in the parts list.

I discovered that my local motor rewinding shop has end spools of wire that are too short for motor use. They give me the end runs at no charge, and there is usually enough wire for winding four or five sets of coils. Speaker builders who want to wind their own coils should consider investing in a good RCL meter. The instrument makes determining coil values easy. And it is wise to check capacitor values. I have found some non-polarized capacitors to be off 25 to 30% in value.

I mounted the woofer coil on the wall of the woofer chamber and the midrange and tweeter components on a terminal strip in the floor of the upper chamber. I bench-tested all the speaker and crossover components before final assembly using an audio oscillator and vacuum tube voltmeter to measure the crossover functions.



Photo 8: A castle ready to finish

WIRING THE SPEAKERS

Refer to the speaker schematic when wiring the system. The piezo tweeters require a 50˚ 1-W resistor be wired in series with each tweeter. I used two 100˚ 1-W resistors in parallel mounted on each driver (**Figure 2**).



Photo 9: Making midrange grilles

Turn the enclosures upside down, less the turrets, resting them on a section of scrap carpet or other non-marring surface. Wire the terminal cups with two wire leads soldered to the cup terminals. Use solder for all the speaker connections to ensure a permanent connection. I used 18-gauge zip cord molded with one lead black and the other red. You can find this type of wire at auto parts stores, and the obvious color-coding makes installation easier.

Make one lead 36" and the other 15". Feed the longer lead through the 0.25" hole into the upper chamber and use the shorter lead for the woofer. Mount the woofer coil on the wall of the enclosure near the woofer and wire the positive lead (red) in series with the coil.

Don't wire the woofer until the next step is complete. Line the walls of the woofer chamber with 1" of polyester

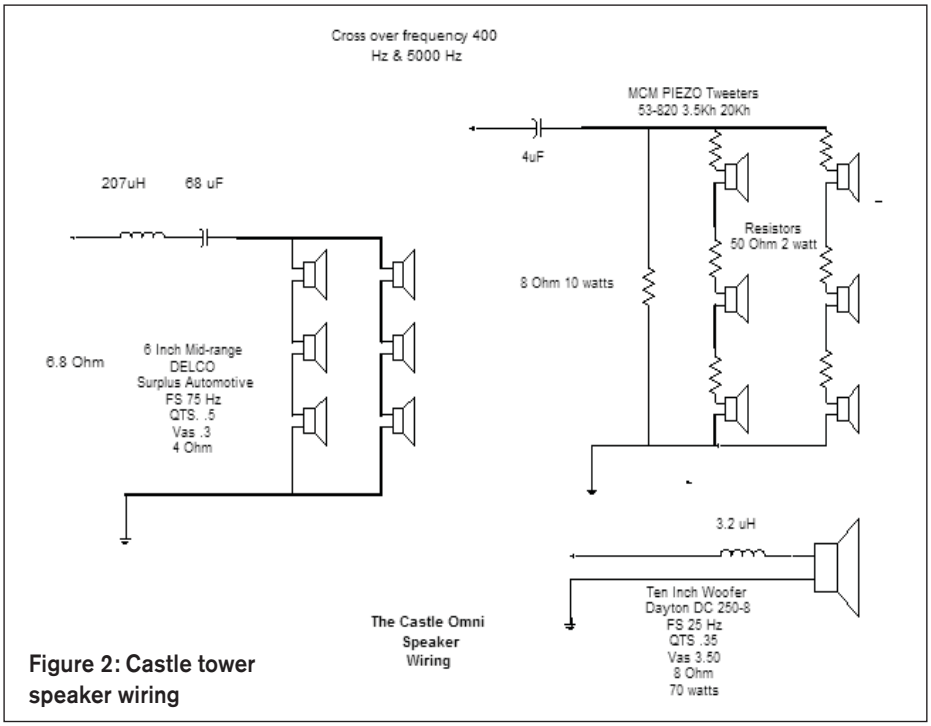


Figure 2: Castle tower speaker wiring

blanket batting available from craft stores or your local WalMart. Staple the batting, being careful not to staple the speaker wires. Keep the port pipe clear of the batting. Once you've installed the batting, attach the woofer wires and mount the woofer, first coating the mounting ring with the clear silicone caulking. Use 1" drywall screws to hold the woofer in place.

Before proceeding, test the woofer by connecting your amplifier to the terminal cup. Play some music with low-frequency content or use an audio oscillator and run it up and down at a moderate volume level. Listen for any vibration or other non-speaker sounds.

Attach the base after you finish the enclosures and install the woofer. Orient the letter "B" you placed on the bottom of the base with the back of the enclosure. Carefully match predrilled screw holes with the legs. Use 1/14 screws and no glue, so you can remove the base for servicing the woofer. Once the base is installed, set the enclosures right side up for installation of the mid-range and tweeters.

I wired the crossover components for the mid-range and tweeters to a terminal strip mounted on the floor of the upper speaker chamber. This makes it easier to attach the respective speakers to the proper terminal by working through the speaker holes.

With so many drivers to install, it is best that you pre-wire each speaker with a 12" lead. I started with a red lead to the positive terminal of the first speaker in the group of three that are wired in parallel. Then I attached a black wire to the negative terminal of the other speakers in the group. You will wire each black wire to the positive terminal of the next.

Begin with the tweeters, using a bead of silicone caulk on the back of each unit. I drilled starter holes with a 1/16" bit and then used 1" drywood screws to mount the tweeters.

Once the tweeter wiring is complete, connect the black wires to the common on the terminal strip, and the red leads to the tweeter capacitor mounted on the terminal strip. Test the tweeters with a signal applied to the speaker terminal cup, making sure you have sound from each driver.

Prewire and install the mid-range

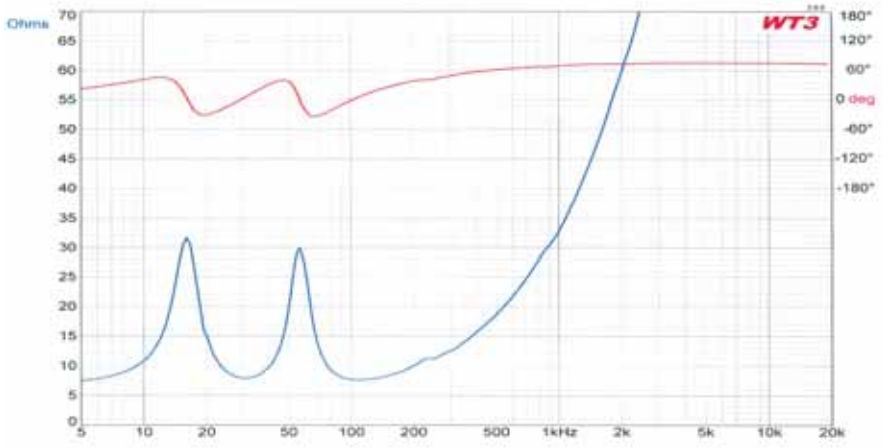


Table 1: Castle speaker impedance.

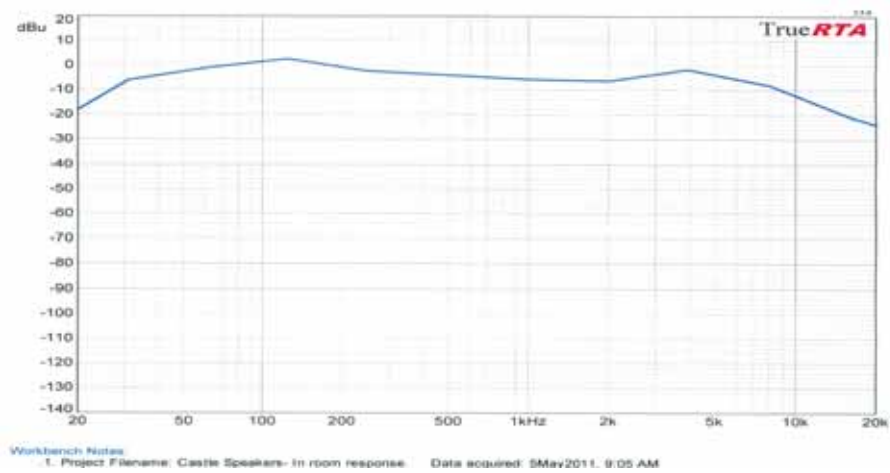


Table 2: In-room response

PARTS LIST FOR TWO ENCLOSURES

- 12 each 1′ × 8′ × 4′ clear pine or hardwood of choice for side panels
- 3 each 2′ x 4′ ¾" plywood panels
- 1 each 1 x 4 × 8 pine or hardwood (for optional tower turrets)
- 100 each 1¼" drywall screws
- 120 each 1″ drywall screws for speaker mounting
- 2 each 3" long sections of 2" ID PVC for ports
- 2 tubes window caulking—white or brown
- 1 tube clear silicone caulk
- Additional items: sandpaper, carpenter's glue, wood stain, polyethylene varnish, or paint of choice.

Drivers

- 12 piezo tweeters; MCM part number 53–820
- 12 each 50° 2W resistors for tweeter circuit (or use two 100° in parallel)
- 2 each 8° 20W resistor
- 12 each 6" mid-range speakers; MCM 55-2970 or Parts Express 299-030
- 2 each 10" woofer; Parts Express DC250-8
- 2 each speaker terminals; Parts Express 260-285
- 25′ 18–gauge zip cord for speaker wiring

Crossover Components

- 2 each 3.2 mH inductor; Part Express 266–840
- 2 each 0.22 mH inductor; Parts Express 266–808
- 2 each 68 mF capacitors; Parts Express 037–356

2 each 027-330 capacitors; Parts Express 027–330

speakers the same way as the tweeters. The difference is that you must attach the wires to the last speaker, then wire the black leads to the common on the terminal and the red leads to the mid-range capacitor before installing the speaker. Attach the wires and run a bead of clear silicone caulking on the rim of each speaker as you install them. Before installing the last speaker, I stuffed the upper chamber with 8 oz. of polyester pillow stuffing, taking care not to disturb the speaker wiring. Once you've installed the speakers, perform a live sound test at low volume. If all the speakers seem to work, don't do any further testing for at least four hours, giving the silicone caulk time to cure.

You can leave the mid-range drivers bare, but I preferred to cover them with a protective grille made from fiberglass screen door material. Commercial grilles are available from both the MCM and Parts Express catalogs. I used a router to cut out 7"circles from 3/16 plywood, painted them black, and then stapled the screen to the rear (**Photo 9**). They are held in place with small pieces of Velcro sticky pads.

I ran an impedance curve using the WT3 Woofer Tester, which showed an fB of 30 Hz (**Table 1**), somewhat lower than the 35 Hz the Thiele/Small calculations. I also ran an in-room response test using the RTA program (**Table 2**).

Subjective testing with a number of non-audiophile listeners produced positive comments all around. The sound was described as "airy," "transparent," "wide," "magical," "rich," and "crystal clear." I had to agree with most of them. Omnidirectional sound is definitely different, and it certainly does open up the sound stage. It seems as though you are sitting in the orchestra. The mid-range is well detailed, especially noticed on horns, woodwinds, and strings. The treble sparkles in the high-end, and on orchestral or organ recordings, the bass is both thunderous at times and tight as need be on other passages.

The system places the listener in the recoding venues, rather than the sound seeming to come from two left and right windows, as in a traditionally-focused stereo system. Solo instruments and voices are not as diffuse as expected, and there is still a semblance of positional sound in spite of the omni pattern of the drivers. The strings are still on the left, the brass is the middle, and the basses on the right. Depending on the placement and room acoustics, many sweet spots are apparent with an omni speaker system. The large number of drivers produced low distortion, and the downward-firing woofer spreads the lows evenly throughout the room.

This experimental system has convinced me that you don't always need a focused "sweet spot" system to experience realistic sound reproduction. *aX*

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D. Weems, *21 Custom Speaker Enclosures Project You Can Build*, TAB Books, 1980.

SOURCES

MCM Electronics
www.mcmelecctronics.com

Parts Express
www.parts-express.com



Legacy Audio Focus SE Speaker

By Robert W. Nehring

Legacy Audio Focus SE Speaker
Legacy Audio 3023 E. Sangamon Ave. Springfield, IL 62702 (217) 544-3178 www.legacyaudio.com info@legacyaudio.com service@legacyaudio.com
$8,750/pr in natural cherry, $9,250/pr in rosewood or black pearl



Photo 1: Legacy Audio's Focus Special Edition rosewood speakers

The Legacy Audio Focus has been a superb loudspeaker that has not only garnered excellent reviews over the years, but has also begun to be used more as a studio monitor for mastering purposes. Still, designer Bill Dudleston knows that the speaker could be made even better as better drivers emerge in the marketplace. Despite the success of the previous incarnation of the Focus design, the Focus 20/20, Dudleston rolled up his sleeves and went to work in his laboratory, to see whether the new generation of drivers could lead to evolutionary improvements to the already-solid Focus design package.

The first fruit of his labors was the Focus HD, a worthy successor to the 20/20. But Dudleston was not done. He envisioned a speaker that would take the design of the Focus HD and push it to new sonic and aesthetic heights. The end result of his quest is the new Focus Special Edition (SE), a speaker that has changed in more ways than Dudleston ever imagined when he first contemplated implementing those evolutionary improvements to the Focus design (**Photo 1**).

Taking the Focus HD as his starting point, Dudleston reshaped the cabinet, making it a bit narrower but deeper, plus stiffening and angling the sidewalls, front baffle, and top to avoid parallel surfaces and potential standing waves. The Focus HD looks much like the previous generations of Focus speakers, albeit with different drivers. The SE, however, with its beveled surfaces and beautiful finishes, makes an indelibly striking first impression of quality. To my eye, at least, the design of the SE is reminiscent of Cadillac's "Art and Science" design aesthetic, especially in its remarkable black pearl finish.

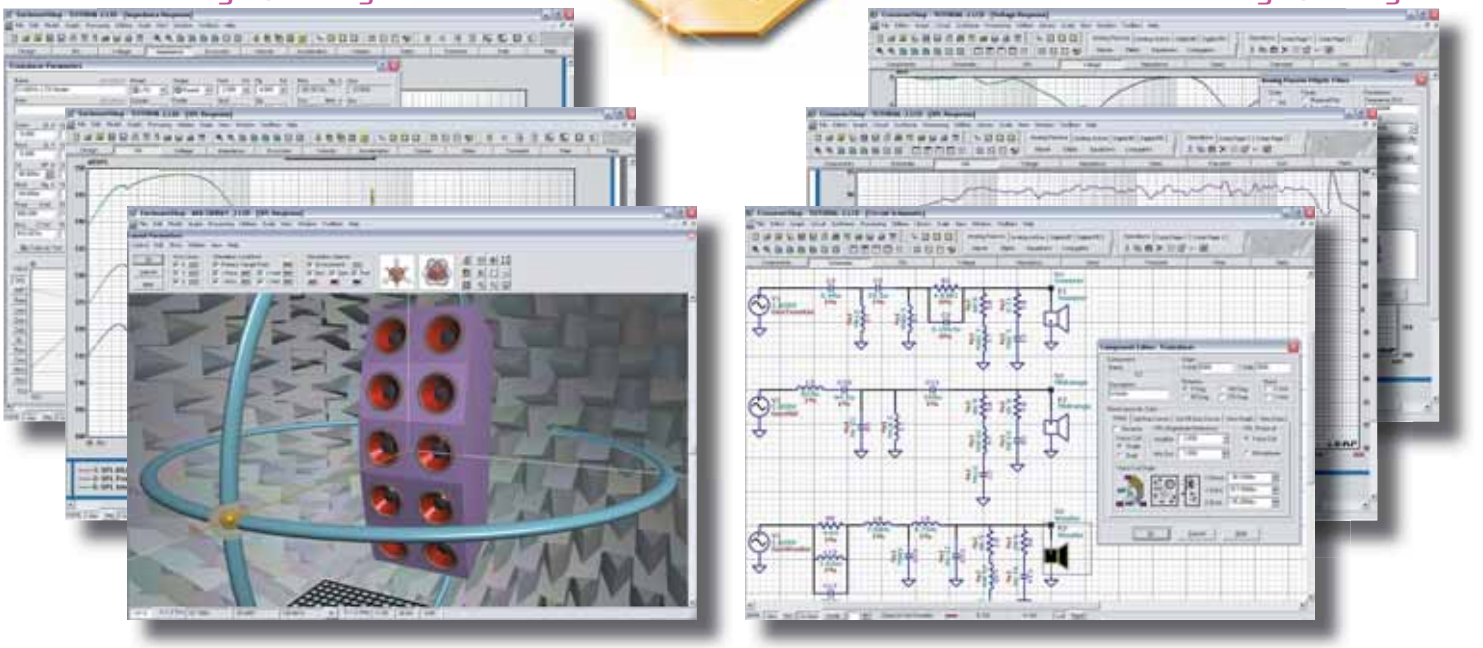
The SE uses the same drivers as the HD, but are more precisely tested and selected, being matched to ±0.25 dB. The SE crossover uses Solen metalized polypropylene capacitors imported from France as bypasses in the high-frequency network and braided silver cable by Ray Kimber to the upper ribbon (**Photo 2**). Dudleston then hand-tuned the final crossover network personally, before signing the Silver Edition owner's certificate.

As I mentioned, the drivers in the Focus SE (and HD) are of a newer vintage and design than those used in the previous-generation Focus 20/20. For the treble frequencies, the 20/20 employed a 1.25" upper midrange dome and a ribbon tweeter. The SE replaces

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these two units with two new neo-ribbon drivers. The very top end of the sonic spectrum is handled by a 1" Kapton pleated ribbon with a custom-machined acoustic chamber, a shaped lens to control dispersion, and a neodymium motor structure.

Dudleston noted that the development of this driver was essential to the new Focus design, since no other ribbon previously available could match the dynamic requirements of high sensitivity, high output, and transient performance needed to meet his design ideals and match well to the rest of the system. The 3" mid-ribbon features a push-pull neodymium magnetic structure with an ultra-low-mass vapor-deposited Kapton diaphragm. This driver operates below 8 kHz to provide a transition to the cone midrange drivers.

The two 7" midrange drivers are the same size as those in the 20/20, but are quite different in construction. The Kevlar units in the 20/20 have been superseded in the SE by drivers in which threads of silver are woven into a carbon fiber diaphragm to distribute bending modes across the spectrum, and then backed with a layer of ultra-light Rohacell. According to Dudleston, this new driver exhibits a smooth response over seven octaves, and a high sensitivity of 95 dB owing to the complex motor structure, which adds a secondary reversion magnet of neodymium under the front phase plug (**Figures 1-3**).

The two 12" bass drivers on the front panel are also different from those used in the 20/20 (which actually employed three 12" drivers, one of which provides some phase cancellation to flatten the overall response). The new 12" aluminum cone woofers employ the patented AURA motor technology, which fea-



Photo 2: The Focus SE's internal parts

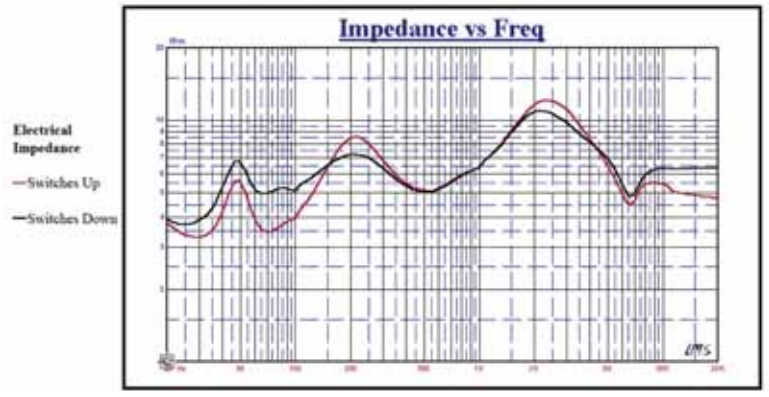


Figure 1: Electrical impedance (A = switches up; B = switches down) (All measurement data supplied by manufacturer)

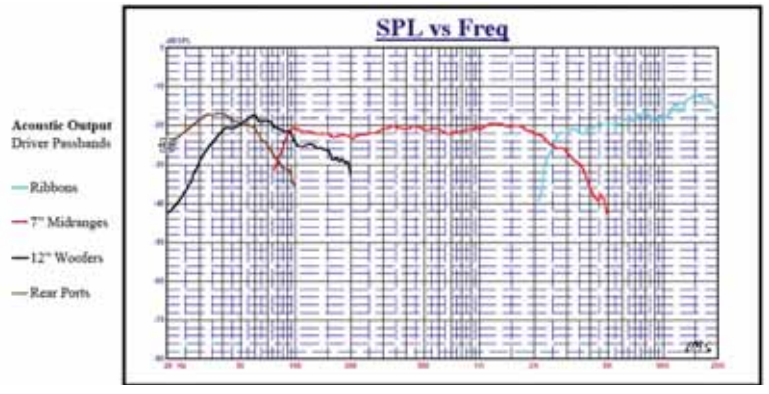


Figure 2: Acoustic output. Driver passbands (A = rear ports; B = 12" woofers; C = 7" midranges; D = ribbons)

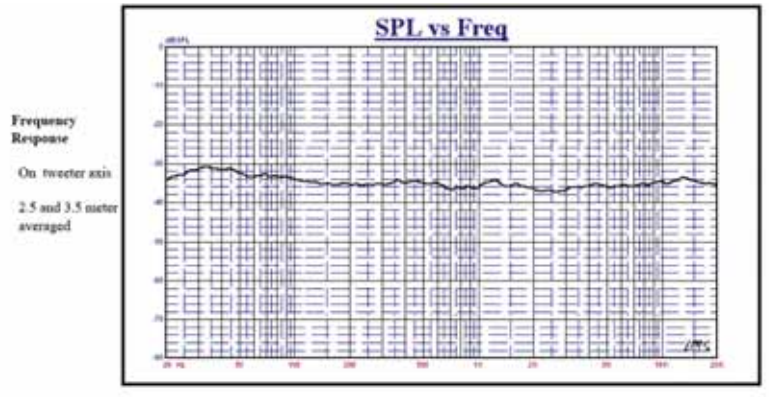


Figure 3: Frequency response (on tweeter axis; 2.5 and 3.5 meter averaged)

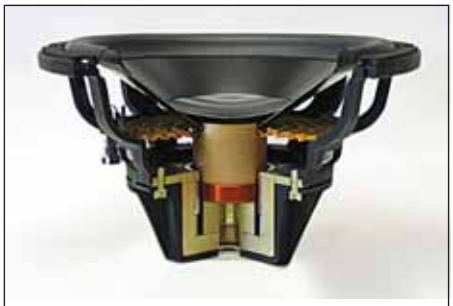


Photo 3: Aura motor cutaway

tures a totally enclosed magnetic structure that provides excellent electrical damping (**Photo 3**). By achieving more magnetic uniformity in the gap, displacements up to 1" remain tightly controlled and linear. Accompanied by Legacy's proprietary stepped voltage crossover, the woofers are immune to DC offset. Two vents are mounted in the rear of the cabinet, but according to Dudleston, the SE does not use a traditional vented bass alignment; instead, the ports are utilized to lower the tuning frequency of the enclosure before electrical transformation is employed on the bass drivers.

Exterior dimensions and weight of the SE are virtually identical to the previous version at 55" H × 15.5" W × 13" D and 195 lbs. Sensitivity is rated at 94.5 dB. Overall frequency is specified as -2 dB at 30 kHz and 18 Hz. Impedance is specified at 4 Ω.

My listening sessions took place in a room measuring approximately 14 W × 24 D × 8 H, with a system that includes a Philips DVD player used for CD playback, a Legacy Audio StreamLine preamp, and an Audio by Van Alstine Fet Valve 550 HC power amp. The speakers are positioned about 3' from the short wall, very slightly toed in.

LISTENING TESTS

I have spent many, many hours listening to these speakers, and I continue to be impressed. They play music with an amazing amount of nuance and detail, but without that overly etched, bright quality that some audiophile speakers tend to impart to the sound. Dynamics seem virtually unlimited, and bass control and power are exemplary.

As much as I enjoyed the Focus 20/20s, the SEs are better. The SEs sound more open in the midrange, more natural in the treble, and more controlled and powerful on the bottom end. They present a sense of crispness without the brightness that word often entails.

It has been a delight pulling out some older recordings that I had not listened to for a while and hearing how good they sound through these speakers. For example, I have always enjoyed a DG recording of Leonard Bernstein conducting the Shostakovich Symphonies Nos. 1 and 7.

Bernstein takes the first at a slower pace than most conductors, making the piece sound less like a romp and more like a major statement, punctuated by some bass drum whacks that the SEs reproduce with power and impact.

A relatively new recording that especially shows off the capabilities of the Focus SEs to great effect is *Fordlandia* by Johann Johansson, which combines electronic and acoustic sounds covering the gamut from bass to treble, whisper to roar.

The thought that some might attempt to enjoy such powerful music in MP3 format through 3" speakers is truly sad. This is music that can only be truly appreciated in all its sonic and musical glory on speakers such as the Legacy Focus SEs.

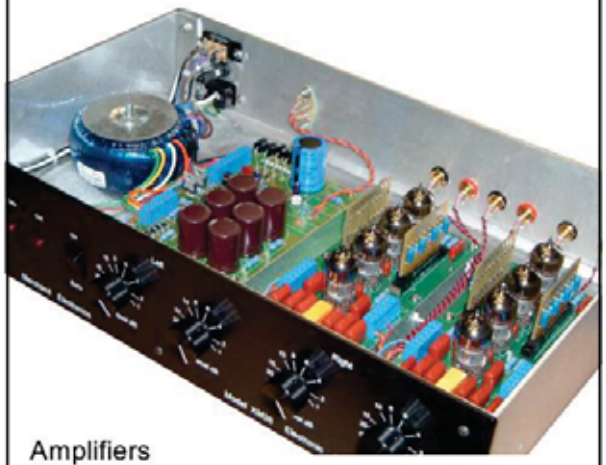
That is not to say that the SEs shine only on large-scale recordings. They also serve well producing the subtle nuances of Paul Motian's drumming, Bill Evans's balladeering, and Miles being Miles on the jazz CDs that I have had in heavy rotation recently. I picked up a compilation of the best of Peter, Paul, and Mary, and was delighted to hear their old (or should I say "young?") familiar voices in such startling sonic clarity. Talk about bringing back memories!

I have been listening to music in the same room for more than 30 years. And, my speakers have included DCM Time Windows, KEF 105s, B&W 802s, and several iterations of Vandersteen 2Cs, JSE 1s and 2s, Carver Amazings, and Legacy Focus.

For now, suffice it to say that the Legacy Audio Focus SEs offer the best sound overall I have ever heard in my listening room, combining clarity and transparency with flat, smooth frequency response and an overall sense of ease in producing music whether that music whispers or thunders its message.

Yes, $8,750 is a big hunk of change, to be sure, but rest assured that the Focus SEs offer excellent value for the money. In both appearance and performance, these speakers set a high standard and offer excellent value. ***rr***

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Impedance Matching Transformers for Ribbon Speakers

Design and build transformers for ribbon speakers that match the amplifier impedance to ribbon impedance

By Angel Luis Rivera PA-C

Working on impedance matching transformers for ribbon speakers was actually the impetus for an ESL step-up transformer. But the impedance characteristics of a ribbon speaker are different from and opposite that of an ESL. Whereas an ESL has super-high impedances at low frequencies and super-low impedances at high frequencies (along with high capacitive reactance), a ribbon speaker has a resistive impedance load that is so low it is essentially a short-circuit.

Because a solid-state amplifier cannot work into an extremely low impedance load without sustaining damage from excess current output, some DIYers simply place a power resistor at the ribbon speaker's input. While workable, this approach may be wasteful of power. Roger Sanders (of INNERSOUND fame and currently Sanders Sound Systems, www.sanderssoundsystems.com) noted that a passive crossover between the amplifier and ribbon speaker might provide enough of an impedance to make it safe for the amp. I believe that a crossover of several orders could be designed with the inductor(s) having high resistance by using small diameter magnet-wire. You could also use resistors in L-pad formation to augment resistance, as well as to control the ribbon's volume level relative to the bass/mid woofer.

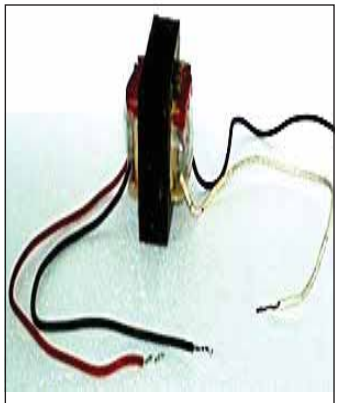


Photo 1: Sample ribbon transformer

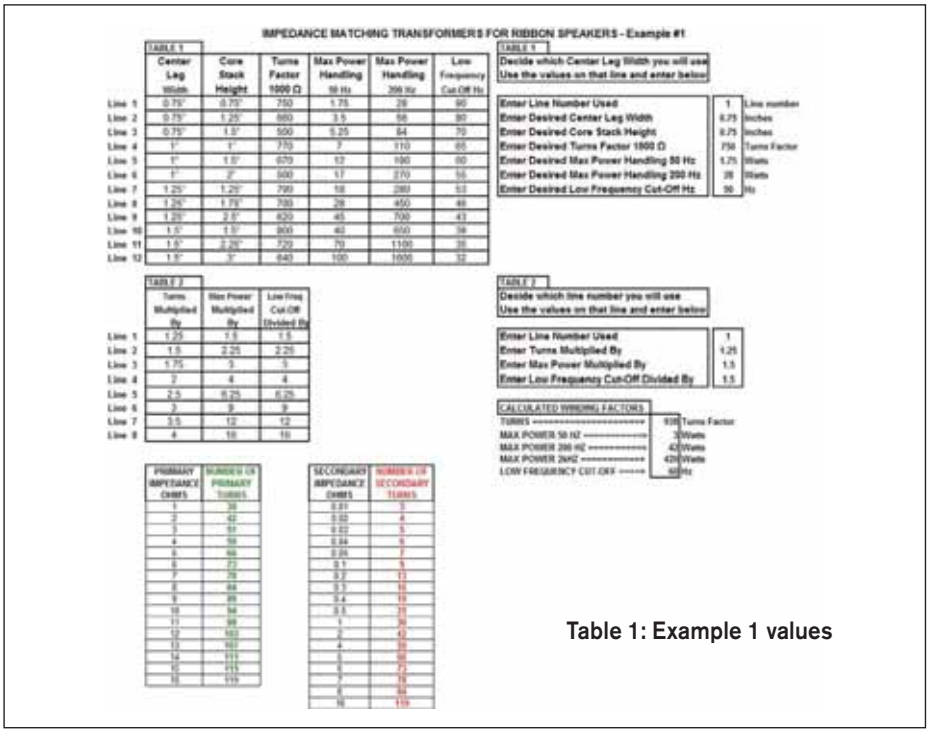


Table 1: Example 1 values

A BETTER WAY

An alternative, better method is to design an impedance matching transformer for the ribbon speaker. The goal is to match the 4/8/16-Ω impedance of the amp's speaker outputs to the nigh zero impedance of the ribbon speaker to avoid destroying the amplifier. Rather than refer to these transformers as step-down transformers (which they are), I call them impedance matching transformers.

The benefit is that since the ribbon speaker would be crossed over at 2 kHz, smaller transformers can be pressed into service to this end, as at that frequency the transformer would have ample and robust power handling capacity—see the examples. You can use smaller size, lower power amplifiers to drive the ribbons as well. Of course, you can build larger transformers with greater power handling capabilities to drive with more powerful amplifiers. Bear in mind, however, that there is a point at which, though the transformer might survive, the ribbon itself might not if too much current is passed through it.

For this article, I make use of spreadsheets to expedite the calculations necessary for the design of impedance matching transformers. There are several design examples accompanied by text to guide you through the process. The text and formulae I provide should be more than enough for you to "roll your own" spreadsheets.

TRANSFORMER DESIGN

Table 1 and **Table 2**—referred to throughout this article—are available in the "Supplemental Materials" section of the *audioXpress* website.

Select a small transformer by using values from Line 1 (**Table 1**) and enter those values. The tables in this article are based, in part, on information found

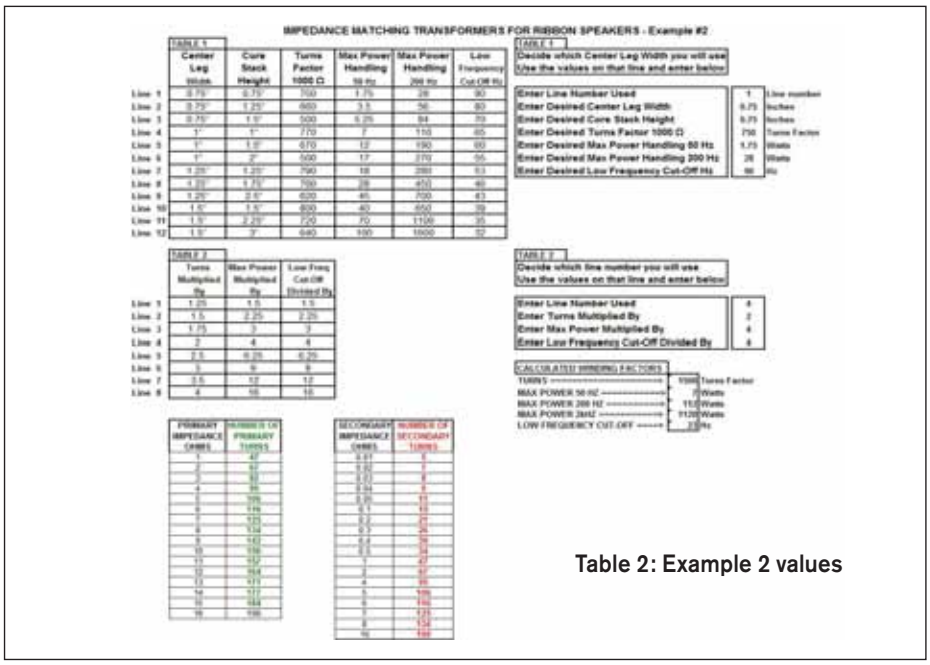


Table 2: Example 2 values

in the chapter on designing audio transformers in *Coil Design and Construction Manual* by B. B. Babani, published in England by Babani Electronics Books. First, you must decide what size transformer (**Photo 1**) would meet your requirements of size and power handling at 2 kHz to know what wattage the transformer can tolerate. Low-frequency cutoff is somewhat superfluous but still comforting to know the transformer's low-end range.

Bear in mind that ribbon speakers are not made to go low in frequency and are essentially used in the treble, supplemented by woofer(s) for bass and midrange frequencies.

Select a small transformer by using the **Table 1** values from Line 1 and enter those values into the required spreadsheet cell areas. While entry of the "Line Number Used," "Center Leg Width," and "Core Stack Height" is unnecessary for the calculations, they are included to keep track of the values you select.

- Line Number Used.....1
- Center Leg Width.....0.75
- Core Stack Height.....0.75
- Turns Factor 1000 Ω.....750
- Maximum Power Handling at 50 Hz.....1.75
- Maximum Power Handling at 200 Hz.....28
- Low-Frequency Cutoff Hz.....90

Do the same with **Table 2** values and enter them into the appropriate cells. Use Line 1 there as well.

- Line Number Used.....1
- Turns Multiplied By.....1.25
- Maximum Power Multiplied By.....1.5
- Low-Frequency Cutoff Divided By.....1.5

Once you enter those values, the spreadsheet will calculate the necessary winding factors, which are then used to compute the number of transformer windings for the "number of primary turns" and the "number of secondary turns."

You need to decide which impedance your amplifier will be most comfortable with. Although I have provided many extra calculated values under "primary impedance ohms," the most practical values will be those associated with the most familiar and standard 4 Ω and 8 Ω values for solid-state amplifiers. However, there are some tube amplifiers which are mostly content with higher impedances such as 16 Ω. Design the "primary turns" for the most appropriate impedance interface for your amplifier.

For the secondaries, remember that a ribbon speaker is essentially a short. This is the raison d'être for this article and hence the design of impedance matching transformers for ribbon speakers. You can design the transformer for very low secondary impedance such as 0.01 Ω. Or, you can add a series resistor of whatever impedance value you desire—such as 4 Ω, 8 Ω, or 16 Ω—and match the transformer to that value. The

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spreadsheet will give you the appropriate "number of secondary turns." Alternately, instead of simply adding a resistor in series with the ribbon speaker, you can design a passive crossover network, as per Roger Sanders' suggestion noted in the beginning of this article, which itself would impart an impedance value by virtue of any inductors and resistors included in the circuit.

DESIGN EXAMPLE 1

Using the selected values from **Table 1** line 1:

- Center Leg Width.....0.75"
- Turns Factor 1000 Ω.....750
- Maximum Power Handling at 50 Hz.....1.75
- Maximum Power Handling at 200 Hz.....28
- Low-Frequency Cutoff Hz.....90

Using the values from **Table 2** line 1:

- Turns Multiplied By.....1.25
- Maximum Power Multiplied By.....1.5
- Low-Frequency Cutoff Divided By.....1.5

Calculations:

- Turns Factor.....750 × 1.25 = 937.5
- Max Power at 50 Hz.....1.75 × 1.5 = 2.625 W
- Max Power at 200 Hz.....28 × 1.5 = 42 W
- Low-Frequency Cutoff.....90/1.5 = 60 Hz

Observe that transformer power handling of 42 W at 200 Hz becomes 420 W at 2 kHz. Also note that final figures are rounded off in the "calculated winding factors" section of **Table 2**. So, 937.5 turns rounds up to 938 turns, and 2.625 W becomes 3 W. Here are three examples of 1000-Hz normalization to primary turns:

- 4 Ω√(4/1000) = 0.0632455 × 937.5 = 59 Primary Turns
- 8 Ω√ (8/1000) = 0.089443 × 937.5 = 84 Primary Turns
- 16 Ω√ (16/1000) = 0.126491 × 937.5 = 119 Primary Turns

Here are six examples of 1000 Hz normalization to secondary turns (just for giggles, in the event you want to add a series resistor of 1, 4, 8, 16 Ω or anything in between):

- 0.01Ω √(0.01/1000) = 0.0031623 × 937.5 = 3 Secondary Turns
- 0.1 Ω √ (0.1/1000) = 0.01 × 937.5 = 9 Secondary Turns
- 1 Ω √ (1/1000) = 0.031623 × 937.5 = 30 Secondary Turns
- 4 Ω √ (4/1000) = 0.063246 × 937.5 = 59 Secondary Turns
- 8 Ω √ (8/1000) = 0.0894427 ×2 937.5 = 84 Secondary Turns
- 16 Ω √ (16/1000) = 0.126491 × 937.5 = 119 Secondary Turns

I used green magnet wire for the primary and secondary windings because that gauge type is used as the primary on Radio Shack's power transformers. I figure if that gauge can withstand the 110–120 V and the current from the AC outlet, it should be able to stand up to a moderate-sized, moderate-powered amplifier's output.

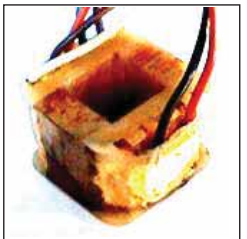


Photo 2: Intact coil and bobbin

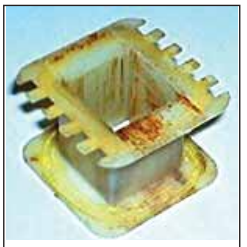


Photo 3: Hollow coil bobbin

Keep track of the number of turns as you wind your transformer coil (**Photo 2**). As you're winding, if you find that you run out of transformer "window" space without getting all your desired primary turns done, then use the spreadsheet to recalculate the final turns by experimenting with smaller values on **Table 2**'s lines. The number of primary turns will consequently be smaller, as will the secondary turns, and you can reconcile your actual physical turns with any new primary and secondary turns yielded by recalculation.

DESIGN EXAMPLE 2

As a matter of fact, I used a transformer with center leg width and core stack height of 0.75", so the coil bobbin's hollow area (**Photo 3**) measured



0.75 Ω 0.75". I initially wanted to use **Table 2**'s line 8 values. However, for a 4 Ω load on the amplifier side, this would have required 195 primary turns (and 10 secondary turns for the ribbon speaker side). Because I was doing the windings by hand, I just didn't feel like winding 195 primary turns; I also didn't want to run out of transformer "window" space. Instead, I used **Table 2**'s line 4 values, yielding a more reasonable 95 primary turns for a 4-Ω load on the amplifier side (and five secondary turns for the ribbon speaker side).

Using the same selected values as in **Table 1** line 1, you can improve transformer performance as follows. Use the same selected values from **Table 1** line 1; then go to **Table 2** line 4:

- Turns Multiplied By.....2
- Maximum Power Multiplied By.....4
- Low-Frequency Cutoff Divided By..... 4

Calculations:

- Turns Factor ..... 750 × 2 = 1500
- Maximum Power at 50 Hz.....1.75 × 4 = 7 W
- Maximum Power at 200 Hz.....28 × 4 = 112 W
- Low-Frequency Cutoff .....90/4 = 23 Hz

Notice the big improvement in the transformer's power handling capacity (almost tripled) at 200 Hz. Further note that by 2 kHz (which, as Roger Sanders pointed out to me, is the beginning range for even a large ribbon speaker to be crossed over from a woofer), power-handling capacity at 2 kHz will be 10 times that of 200 Hz: 1,120 W! This is because a transformer's power-handling capabilities increase linearly as frequency is scaled up. If biamping, this means you can use a larger power amplifier to drive the ribbon speaker directly. The extended low-frequency response of the transformer to 23 Hz is somewhat academic because the ribbon speaker would never be used at so low a frequency; but it would simply lower distortion or saturation of the transformer within the 2 kHz and up range.

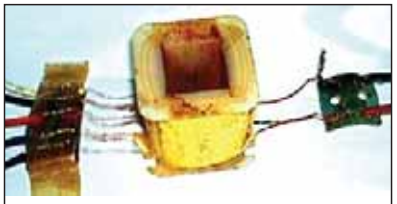


Photo 4: Sample coil and bobbin

Here are three examples of 1000-Hz normalization to primary turns:

- 4 Ω √ (4/1000) = 0.0632455 × 1500 = 95 Primary Turns
- 8 Ω √ (8/1000) = 0.089443 × 1500 = 134 Primary Turns
- 16 Ω √ (16/1000) = 0.126491 × 1500 = 190 Primary Turns

Here are six examples of 1000-Hz normalization to secondary turns (comparing them to the required primary and secondary turns in the first example):

- 0.01 Ω √(0.01/1000) = 0.0031623 × 1500 = 5 Secondary Turns
- 0.1 Ω √ (0.1/1000) = 0.01 × 1500 = 15 Secondary Turns
- 1 Ω √ (1/1000) = 0.031623 × 1500 = 47 Secondary Turns
- 4 Ω √ (4/1000) = 0.063246 × 1500 = 95 Secondary Turns
- 8 Ω √ (8/1000) = 0.0894427 × 1500 = 134 Secondary Turns
- 16 Ω √ (16/1000) = 0.126491 × 1500 = 190 Secondary Turns

DESIGN EXAMPLE 3

Use the third design example, with spreadsheet, to build a larger transformer, but with greater power handling capacity. Use the values from **Table 1** on line 4.

- Center Leg Width.....1"
- Turns Factor 1000 Ω.....770
- Maximum Power Handling at 50 Hz.....7
- Maximum Power Handling at 200 Hz..... ..110
- Low-Frequency Cutoff Hz.....65

Using the selected values from **Table 2** line 8:

- Turns Multiplied By.....4
- Maximum Power Multiplied By..... 16
- Low-Frequency Cutoff Divided By..... 16

Calculations:

- Turns Factor.....770 × 4 = 3080

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- Maximum Power 50 Hz.....7 × 16 = 112 W
- Maximum Power 200 Hz..... 110 × 16 = 1760 W
- Low-Frequency Cutoff..... 65/16 = 4 Hz

There is an even bigger improvement in the transformer's power handling capacity in design Example 3 in comparison to design Example 1, going from 3 W to 112 W at 50 Hz (increased 37 times!), and from 42 W at 200 Hz to 1,760 W! Power handling at 200 Hz is increased 42 times! Even more dramatic is the power handling at 2 kHz: 17,600 W! Notice also that this results in an increase in the number of primary turns and secondary turns (depending on the desired impedance interface). Such is the price of excellence. Here are three examples of 1000-Hz normalization to primary turns:

- 4 Ω √ (4/1000) = 0.0632455 × 3080 = 195 Primary Turns
- 8 Ω √ (8/1000) = 0.089443 × 3080 = 275 Primary Turns
- 16 Ω √ (16/1000) = 0.126491 × 3080 = 390 Primary Turns

Here are six examples of 1000-H normalization to secondary turns (to add a series resistor of 1, 4, 8, 16 Ω or some other impedance value):

- 0.01 Ω √(0.01/1000) = 0.0031623 × 3080 = 10 Secondary Turns
- 0.1 Ω √ (0.1/1000) = 0.01 × 3080 = 31 Secondary Turns
- 1 Ω √ (1/1000) = 0.031623 × 3080 = 97 Secondary Turns
- 4 Ω √ (4/1000) = 0.063246 × 3080 = 195 Secondary Turns
- 8 Ω √ (8/1000) = 0.0894427 × 3080 = 275 Secondary Turns
- 16 Ω √ (16/1000) = 0.126491 × 3080 = 390 Secondary Turns

The 0.75 × 0.75" coil bobbin I used (**Photo 4**) can accept a layer of 25 windings of the green magnet wire. I anchored the wire on completion of a layer and painted the windings liberally with nail polish enamel. I un-anchored the wire, continued winding the next layer and repeated the same with each subsequent layer until the 95 primary windings were completed. I nail-polished that last layer as well. I then wrapped tape around those windings.

Next, I wound the five secondary windings and painted them with the enamel as well; the secondary windings were also wrapped with tape. Note that the primary and secondary terminal wires were placed on opposite sides of the coil bobbin to separate them as much as possible in order to avoid any possible arcing from the difference in electrical/voltage potentials between the primary and secondary sides.

After the above was accomplished, I began filling the coil bobbin's hollow center with the transformer laminates (**Photo 5**). I stacked them by alternating the direction that the Es and Is were facing. I applied a thin coating of white glue, which dries to a clear plastic—by electrically isolating the thin laminates from each other; it cuts down on eddy currents which would be wasteful of power.



Photo 5: E and I transformer laminates

If you haven't deduced it by now, notice that the transformer does not need to be a "step-down" transformer per se if you design the primary and secondary windings to interface with the same impedance at each end by the use of a resistor at the ribbon speaker's input. This would be one way to cut down on the amount of current fed to the ribbon. Recall that in a step-down transformer the voltage will be stepped down but the current will increase.

Another approach is to design for 4 Ω on the primary (amplifier) side, and 8 or 16 Ω on the secondary (ribbon speaker) side through the use of an 8 or 16 Ω. input resistor, thus effectively making the transformer a step-up transformer in this case, and consequently, the voltage would be stepped up but the current would decrease.

Because ribbon speakers are used only in the treble region, better-quality transformer laminations would be called for, such as RADIOMETAL or MUMETAL or GOSS (Grain Oriented Silicon Steel), which are used in high-quality 70 V and audio/output transformers. This contrasts with the lower-quality standard iron found in a power transformer, which does not have high audio frequency applicability.

FINAL WORD

To encourage DIYers—commercial ribbon speaker transformers can cost several hundred dollars, as noted in Justus Verhagen's *Ribbon Loudspeakers*. I paid about $2 for the audio transformer whose laminations, bobbin, and wrapping tape were used for this project. The green magnet-wire came from a small Radio Shack power transformer which I'd had on hand for years and which I probably got for free. The only other costs were for white glue and nail polish enamel I got from my wife. Everything else was simply an investment of time in dismantling the transformers, winding the primary and secondary coils, and reconstructing the audio transformer laminates as I described above. For less than $103—a far cry from several hundred dollars—I have a custom-made impedance matching ribbon speaker transformer.

I need to complete the work I started on a 3´ ribbon speaker this transformer is intended. I also have a video demonstrating how to easily dismantle transformers, with an accompanying article. I am also re-working an article which details some novel approaches to designing step-up transformers for ESLs.

I would like to close by expressing my gratitude and appreciation to Roger Sanders for the time he has taken to respond to my e-mails and tutor me. I thank Roger for his support and for all he has taught me, both through his book *The Electrostatic Loudspeaker Design Cookbook*. I regard Roger as a mentor because he has patiently taught me and also for being an inspiration to me. ***aX***

CAUTION: Under no circumstances should you handle the transformer and its wires while they are attached to an amplifier that is turned on. Nor should you connect or disconnect the transformer to or from the ribbon speaker (or any loudspeaker, for that matter) while the amplifier is playing music. Amplifiers can put out significant voltage and current—enough to stop a heart—especially when the signal is processed by a transformer. Only 50 mA is necessary to cause ventricular fibrillation.

By Vance Dickason

Wavecor Full-Range Driver and Eminence Guitar Speaker

Testing a full-range driver and a variable guitar speaker

This month's driver submissions are both unique but from nearly opposite ends of the transducer spectrum. From Wavecor, a 2.75" diameter full-range driver intended for high-quality multimedia and lifestyle (iPod docking stations) products, the FR070WA01, and from Eminence a new and extremely clever variable Bl 12" diameter guitar speaker, the Maverick.

The Wavecor FR070WA01 is a 2.75" diameter full-range driver built on an injection molded polymer frame that is fully vented below the spider mounting shelf for enhanced cooling. The cone assembly consists of a black anodized aluminum cone with a 1" diameter anodized aluminum dust cap. Suspending the cone and dust cap are a low loss NBR surround and a Conex spider. The FR070 has a 22-mm diameter voice coil wound on a vented black glass fiber non-conducting former and terminated to a pair of gold plated terminals. Powering this structure is a dual neodymium motor that includes a copper ca on the center pole and black colore motor parts (return cup) for better hea transfer to the surrounding air. I shoul also note that Wavecor makes a companion 2.75" subwoofer for this driver, the SW070WA.

I commenced testing the FR-070WA01 full-range using the LinearX LMS analyzer and VIBox to create both voltage and admittance (current) curves with the driver clamped to a rigid test fixture in free-air at 0.3 V, 1 V, 3 V, and 6 V. As has become the protocol for Test Bench testing, I no longer use a single added mass measurement and instead used actual measured mass, but the manufacturers measured Mmd data.

Next, the eight 550-point stepped sine wave sweeps for each FR070 samples were post-processed and the voltage curves divided by the current curves (admittance) to produce the impedance curves, phase generated by the LMS calculation method, and along with the accompanying voltage curves, imported to the LEAP 5 Enclosure Shop software. Since most Thiele-Small data provided by OEM manufacturers is being produced using either a standard method or the LEAP 4 TSL model, I additionally created a LEAP 4 TSL model using the 1-V free-air curves. The complete data set, the multiple voltage impedance curves for the LTD model (see **Figure 1** for the 1-V free-air impedance curve) and the 1-V impedance curve for the TSL model were selected in the transducer derivation menu in LEAP 5 and the parameters created for the computer box simulations. **Table 1** compares the LEAP 5 LTD and TSL data and factory parameters for both of FR070WA01 samples.

LEAP parameter calculation results for the FR070WA01 were close to the factory data, except for the Sensitivity, however, mine is a calculated midband sensitivity that is part of the TS calcula-



Photo 1: Wavecor's FR070WA01



Photo 2: FR07 top

Table 1 Wavecor FR070WA01 full-range

	TSL model sample 1	TSL model sample 2	LTD model sample 1	LTD model sample 2	Factory
F_S	121Hz	117Hz	122Hz	121Hz	120Hz
R_{EVC}	3.52	3.50	3.52	3.50	3.45
Sd	0.0021	0.0021	0.0021	0.0021	0.0021
Q_{MS}	11.7	11.0	8.21	9.03	12.8
Q_{ES}	0.64	0.62	0.73	0.77	0.58
Q_{TS}	0.61	0.59	0.67	0.71	0.55
V_{AS}	0.55 ltr	0.59 ltr	0.55 ltr	0.56 ltr	0.56 ltr
SPL 2.83V	83.7dB	83.7dB	83.2dB	82.9dB	86.5dB
X_{MAX}	2.0mm	2.0mm	2.0mm	2.0mm	2.0mm

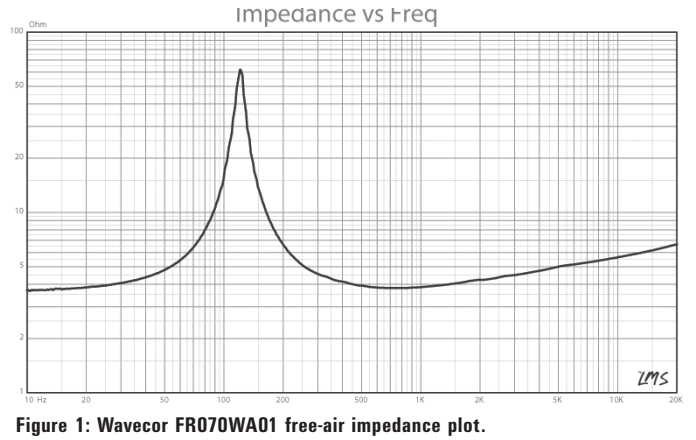


Figure 1: Wavecor FR070WA01 free-air impedance plot.

tion routine and Wavecor uses average SPL in the 400 Hz to 1 kHz range. However, I followed my usual protocol and preceded setting up computer enclosure simulations using the LEAP LTD parameters for **Sample 1**. Two computer sealed box simulations were programmed into LEAP, a 60-cubic-inch Butterworth alignment and a 10-cubic-inch Chebychev-type alignment**. Figure 2** displays the results for the Wavecor full-range driver in the two sealed box simulations at 2.83 V and at a voltage level sufficiently high enough to increase cone excursion to Xmax + 15% (2.3 mm for the FR070). This produced a F3 frequency of 133 Hz with a box/driver Qtc of 0.72 for the 60-cubic-inch sealed enclosure and –3 dB = 205 Hz with a Qtc = 1.0 for the 10-cubic-inch simulation. Increasing the voltage input to the simulations until the maximum linear cone excursion was reached resulted in 92.5 dB at 6 V for the larger sealed enclosure simulation and 100.5 dB with a 13.5 V input level for the smaller sealed enclosure (see **Figures 3** and **4** for the 2.83 V group delay curves and the 6/13.5 V excursion curves).

Klippel analysis for the Wavecor 2.75" full-range (our analyzer is provided courtesy of Klippel GmbH), and testing performed by Pat Turnmire, Red Rock Acoustics (author of the SpeaD and RevSpeaD software) produced the Bl(X), Kms(X) and Bl and Kms Symmetry Range plots given in **Figures 5-8.** The Bl(X) curve for the FR070 (see **Figure 5**) is relatively broad and symmetrical, especially for a short Xmax 2.75" diameter driver. Looking at the Bl Symmetry plot (see **Figure 8**), this curve shows a trivial 0.11 mm coil-in offset at the rest position that decreases to 0.09 mm at the physical 2.0 mm Xmax of the driver.

Figure 7 and **8** show the Kms(X) and Kms Symmetry Range curves for the Wavecor full-range driver. The Kms(X) curve is definitely very symmetrical, and has a very minor forward (coil-out) offset of less than 0.5 mm at the rest position. Displacement limiting numbers calculated by the Klippel analyzer for the FR070 were XBl @ 82% Bl is 1.7 mm and for XC at 75% Cms minimum was 1.1 mm, which means that for this Wavecor woofer, the compliance is the most limiting factor for prescribed distortion level of 10%.

Figure 9 gives the inductance curve Le(X) for the FR070WA01. Inductance will typically increase in the rear direction from the zero rest position as the voice coil covers more pole area; however the FR070 inductance stays mostly constant as the coil moves in due to the copper shorting ring. The inductance variation is only 0.05mH from the in and out Xmax positions, which is very good.

Next, I mounted the FR070 full-range in an enclosure which had a 9" × 4" baffle and was filled with damping material (foam) and measured the transducer on- and off-axis from 300 Hz to 40 kHz frequency response at 2.83 V/1 m using the LinearX LMS analyzer set to a 100 point gated sine wave sweep. **Figure 10** gives the FR070's on-axis response indicating a smoothly rising response to about 4 kHz, decreasing 7 dB to 10 kHz and some breakup peaking at 25 kHz the highpass roll-off. However, it definitely has a response on-axis out to 25 kHz, as advertised!

Figure 11 displays the on- and off-axis frequency

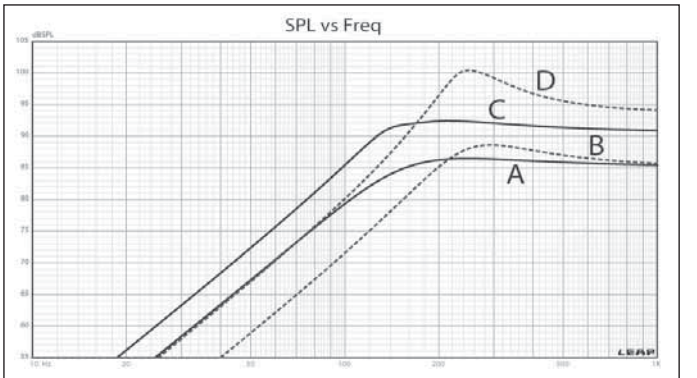


Figure 2: FR070WA01 computer box simulations (A = sealed 1 at 2.83 V; B = sealed 2 at 2.83 V; C = sealed 1 at 6 V; D = sealed 2 at 13.5 V)

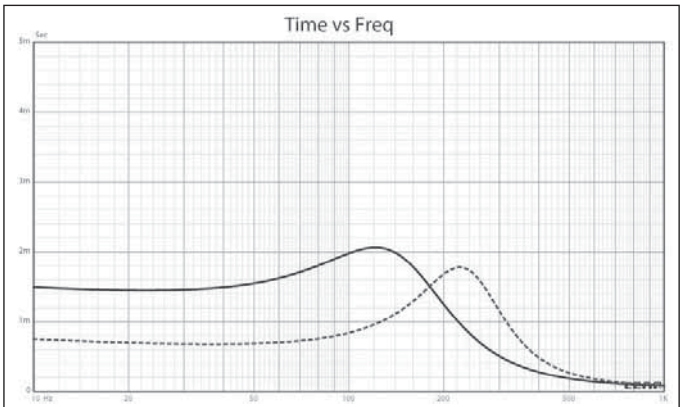


Figure 3: Group delay curves for the 2.83 V curves in Figure 2

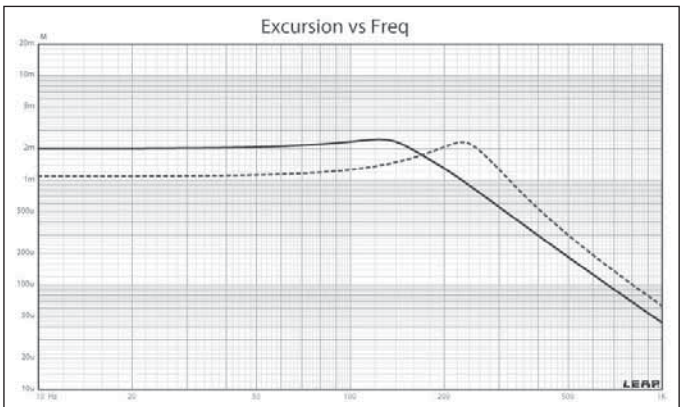


Figure 4: Cone excursion curves for the 6/13.5 V curves in Figure 2

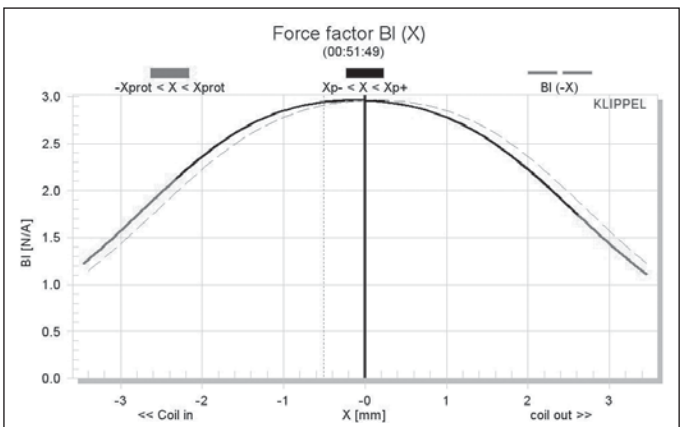


Figure 5: Klippel Analyzer Bl (X) curve for the Wavecor FR070WA01.

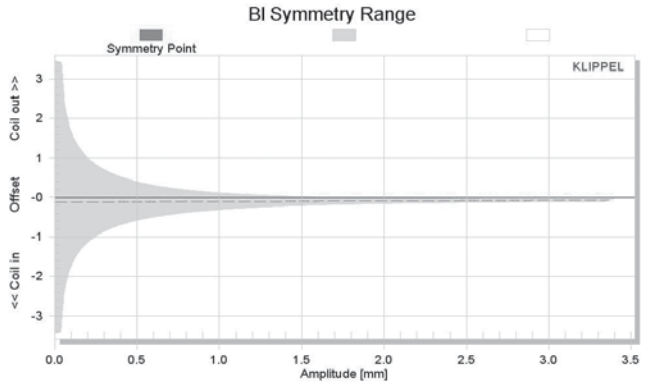


Figure 6: Klippel Analyzer Bl symmetry range curve for the FR070WA01

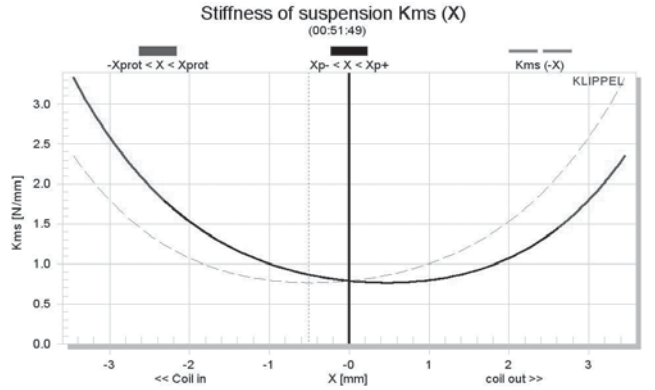


Figure 7: Klippel Analyzer mechanical stiffness of suspension Kms (X) curve for the Wavecor FR070WA01

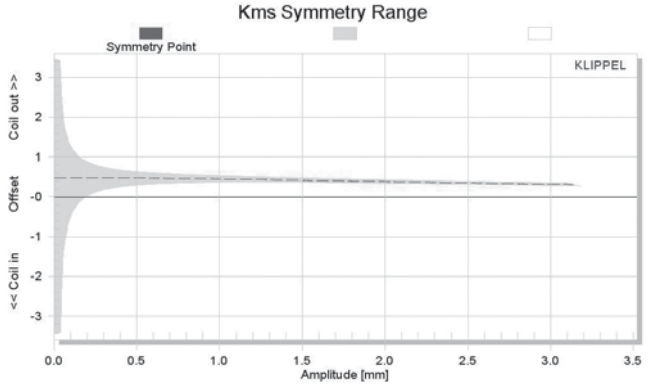


Figure 8: Klippel Analyzer Kms symmetry range curve for the FR070WA01

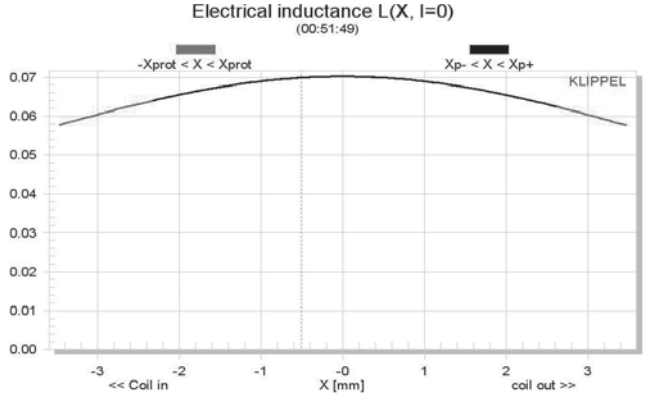


Figure 9: Klippel Analyzer Le(X) curve for the Wavecor FR070WA01

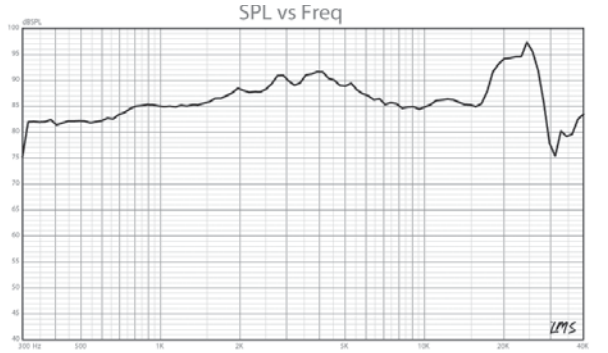


Figure10: Wavecor FR070WA01 on-axis frequency response



Figure 11: Wavecor FR070WA01 on- and off-axis frequency response

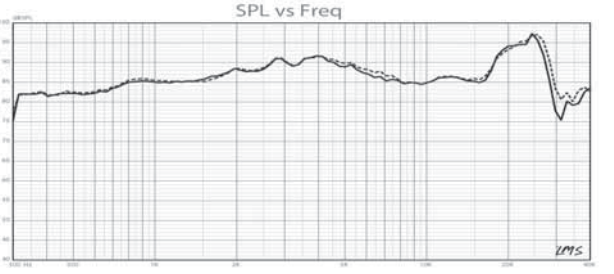


Figure 12: Wavecor FR070WA01 two-sample SPL comparison

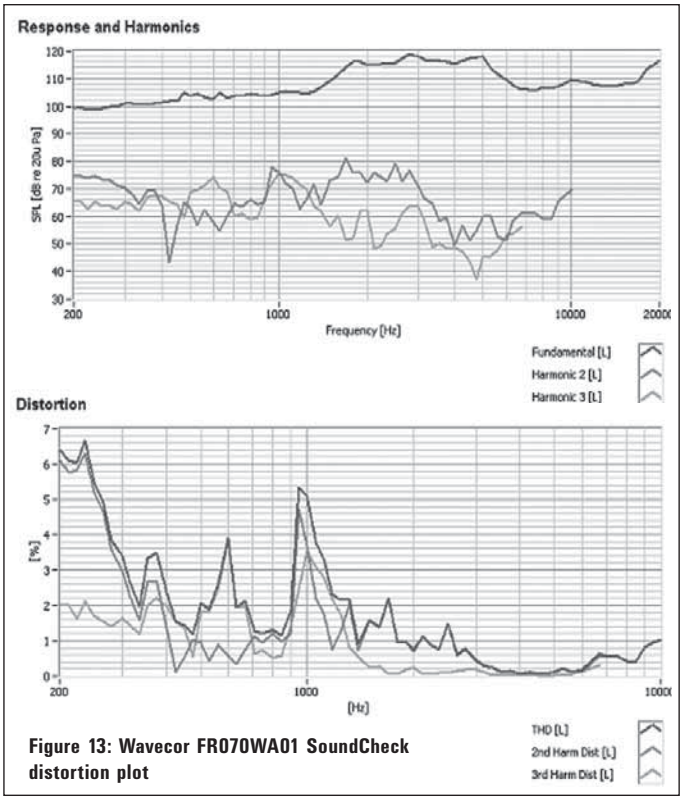


Figure 13: Wavecor FR070WA01 SoundCheck distortion plot

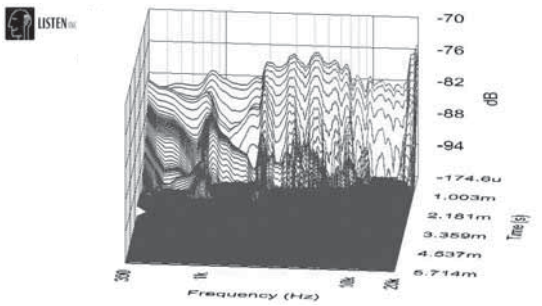


Figure 14: Wavecor FR070WA01 SoundCheck CSD Waterfall plot

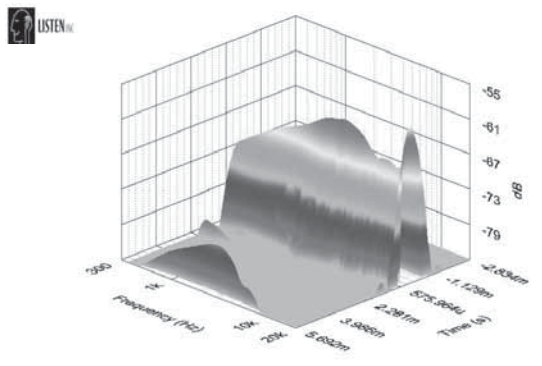


Figure 15: Wavecor FR070WA01 SoundCheck Wigner-Ville plot

Table 2: Eminence Maveric Guitar Speaker

	TSL model sample 1	TSL model sample 2	LTD model sample 1	LTD model sample 2	Factory
F_S	69.5Hz	81.4Hz	69.4Hz	80.4Hz	2.5Hz
Revc	6.04	6.05	6.04	6.05	5.99
Sd	0.0520	0.0520	0.0520	0.0520	.05195
Qms	17.1	22.7	14.7	20.7	16.26
Qes	1.05	1.20	1.08	1.25	1.17
Qts	0.99	1.14	1.01	1.18	1.09
Vas	70.44 ltr	51.45 ltr	71.3 ltr	53.2 ltr	48.7 ltr
SPL 2.83V	95.4dB	95.5dB	95.3dB	95.3dB	91.5dB
Xmax	0.047mm	0.047mm	0.047mm	0.047mm	0.047mm

Table 3: Comparison of TSL Parameters for three FDM Positions for Sample 1

	Full Volume	50% Volume Max Attenuation	
F_S	69.5Hz	69.7Hz	69.9Hz
Revc	6.04	6.04	6.04
S_D	0.0520	0.0520	0.0520
Qms	17.08	12.37	11.10
Qes	1.05	2.94	6.00
Qts	0.99	2.37	3.90
Vas	70.4 ltr	70.1 ltr	69.8 ltr
BI	8.4 Tm	5.1 Tm	3.6 Tm
SPL 2.83V	95.4dB	90.9dB	87.9dB

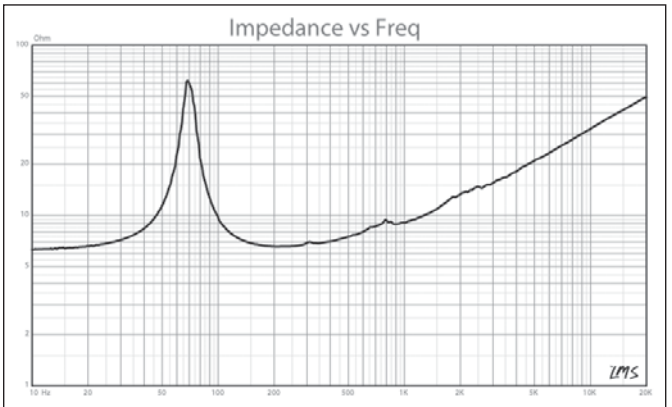


Figure 16: Eminence Maverick free-air impedance plot



Figure 17: Eminence Maverick computer box simulations (A = sealed at 2.83 V; B = bented at 2.83 V; C = sealed at 10 V; D= vented at 10 V)

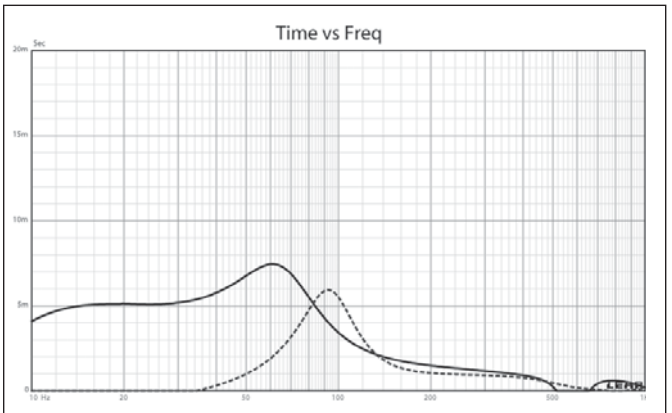


Figure 18: Group delay curves for the 2.83V curves in Figure 17

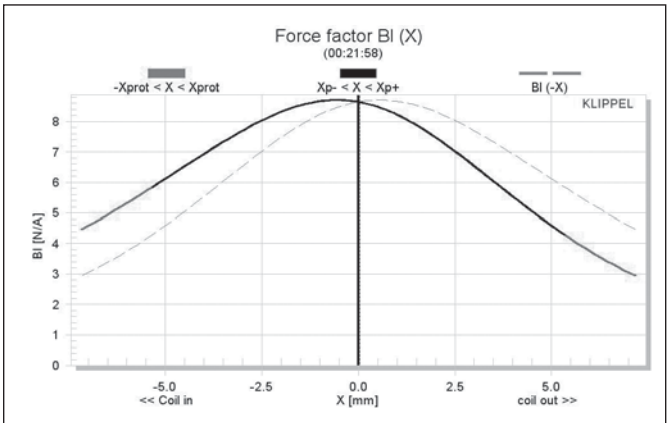


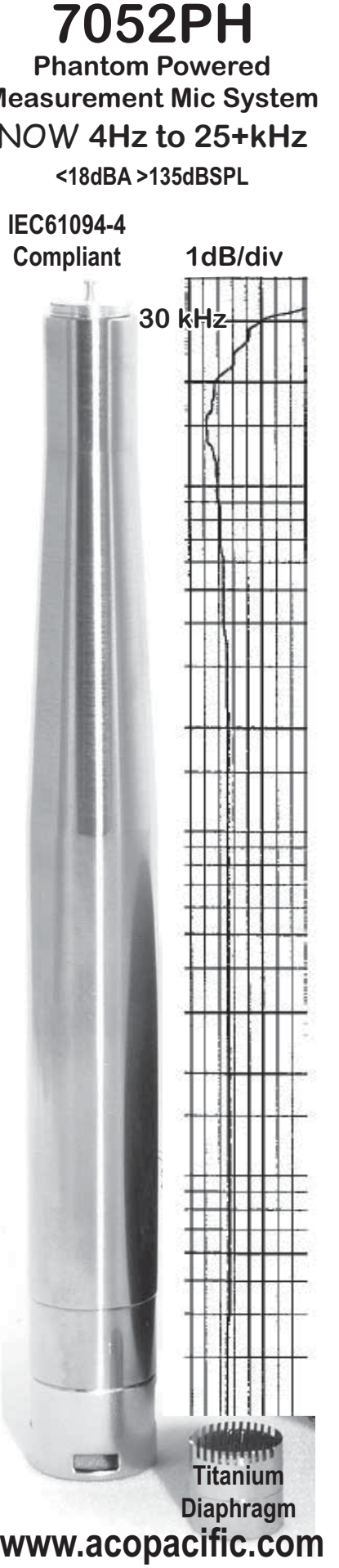
Figure 19: Klippel Analyzer BI (X) curve for the Eminence Maverick

response at 0, 15, 30 and 45°. The roll-off at 30° off-axis is almost as good as a 1" dome, so I would expect the full-range fidelity of this driver to be quite good. And the last SPL measurement is given in **Figure 12**, the two-sample SPL comparison for the 2.75" Wavecor driver, showing a close match to within less than 1 dB throughout the operating range.

For the remaining series of tests, I employed the Listen, Inc. SoundCheck analyzer with the Listen, Inc. 0.25" SCM microphone and power supply (courtesy of Listen, Inc.) to measure distortion and generate time frequency plots. For the distortion measurement, the Wavecor woofer was mounted rigidly in free-air, and the SPL set to 94 dB at 1 m (4.1V) using a noise stimulus, and the distortion measured at with the microphone placed 10cm from the dust cap. This produced the distortion curves shown in **Figure 13**. I used SoundCheck to get a 2.83 V/1m impulse response for this driver and imported the data into Listen Inc.'s SoundMap Time/Frequency software. The resulting CSD waterfall plot is given in **Figure 14** and the Wigner-Ville (for its better low-frequency performance) plot in **Figure 15**. While the intended application for this Wavecor 2.75" full-range driver is multi-media and lifestyle speakers, I would also suggest that this would make a great driver for line-source applications. For more information, on this well-crafted driver, visit the Wavecor website at www.wavecor.com.

I don't often examine MI (Musical Instrument) speakers, in fact, the last guitar speakers I had in *Voice Coil* Test Bench were a 12" Eminence Red Fang (Eminence's answer to the Celestion G12 alnico Blue "Dog" used in early Vox AC-30 guitar amplifiers) and a 10" Eminence BP102 bass guitar/PA speaker, and these were the first guitar speaker featured in 17 years of publication. However a totally unique new guitar speaker from Eminence was just too interesting to pass up. The speaker is the 12" Eminence Maverick, a speaker from the Eminence Patriot series that uses their new FDM technology (Flux Density Modulation). Before explaining Eminence patent-pending FDM technology, all of you reading this may not be aware of certain techniques used to get some of the unique sounds artists get out of a guitar amplifier and speaker. Basically, you need to understand that tube guitar amplifiers sound different at different volume levels. When a guitar tube amplifier is turned up to 10 on the volume control (11 for Spinal Tap), and tubes are at maximum output (gee, with the plates starting to glow), you get some really desirable distortion characteristics that have become the signature of blues and rock guitar playing. The problem comes into play when you just want to practice in your living room, or when you are in the studio. Playing that loud just isn't necessarily comfortable in those situations, so guitarists needed a way to stress the tubes in a guitar amp, but not be loud. A device that has been on the market for a number of years is called a power attenuator and is electrically connected between the tube amplifier and the speaker to attenuate the high-voltage output of a tube amplifier and decrease the volume of the speaker. Examples of these guitar toys are the Marshall Power Break and the THD Hot Plate attenuators. That said, the new Eminence FDM technology is essentially a tricked-out guitar speaker that accomplishes the same task, turning down the volume of the speaker when the amplifier is turned up loud. If you look at the photos provided for the Maverick, you see that the speaker has a knob located behind the back plate that is labeled FULL VOLUME turned full right, and MAX ATTENUATION turned full left. As you can guess, this very clever invention somehow controls the Bl of the speaker, and even though I know exactly how it is doing this, and because this invention is still patent pending, I'm going to leave it to readers to figure it out on their own.

Disregarding the FDM control knob, the Eminence Maverick is a typical guitar speaker constructed on a stamped frame. The cone assembly consists of an uncoated and ribbed paper cone with an integrated M shaped paper surround, and a 3.5" diameter Zurette porous cloth dust cap. Remaining compliance is provided by an elevated cloth spider. The cone assembly is driven by a 1.75" voice coil using round copper wire wound on a non-conducting polyimide



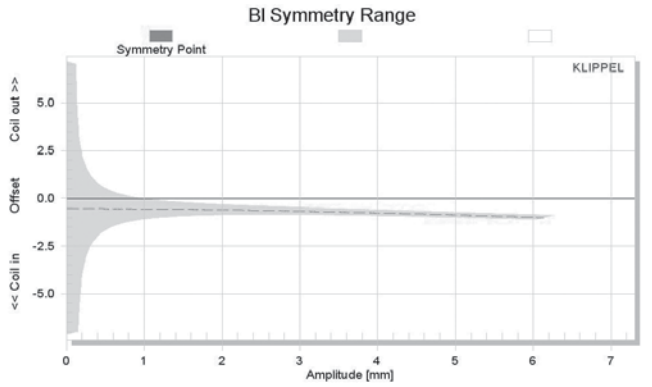


Figure 20: Klippel Analyzer B1 symmetry range curve for the Maverick

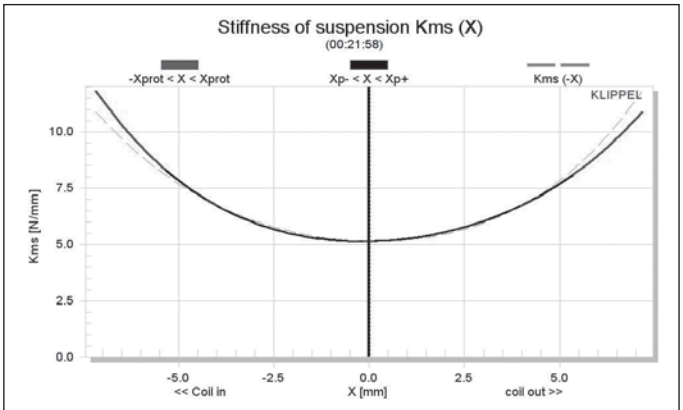


Figure 21: Klippel Analyzer mechanical stiffness of suspension Kms (X) curve for the Eminence Maverick

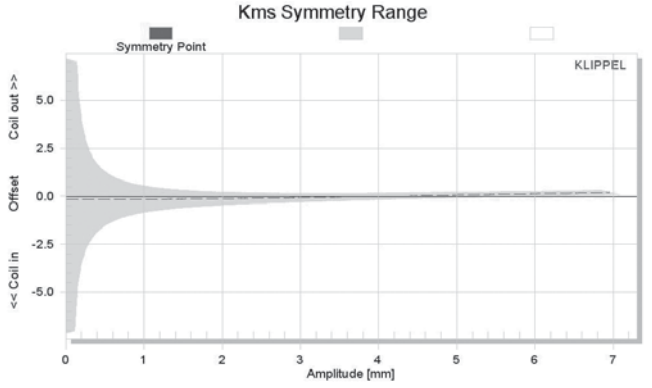


Figure 22: Klippel Analyzer Kms symmetry range curve for the Maverick

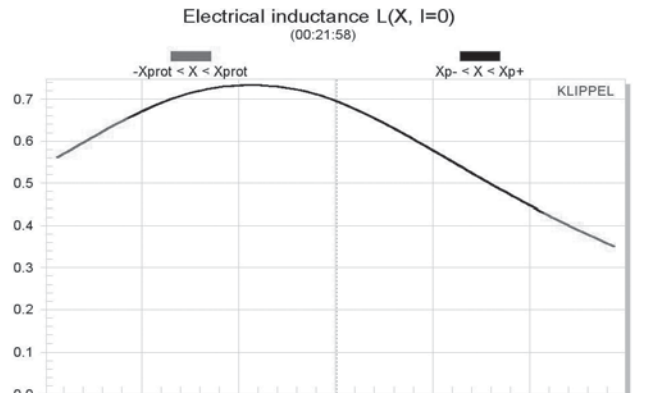


Figure 23: Klippel Analyzer Le(X) curve for the Eminence Maverick

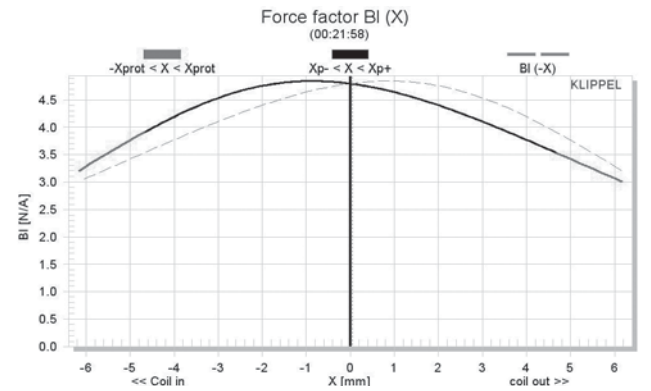


Figure 24: Klippel Analyzer Bl (x) curve for the 50% volume FDM setting on the Maverick

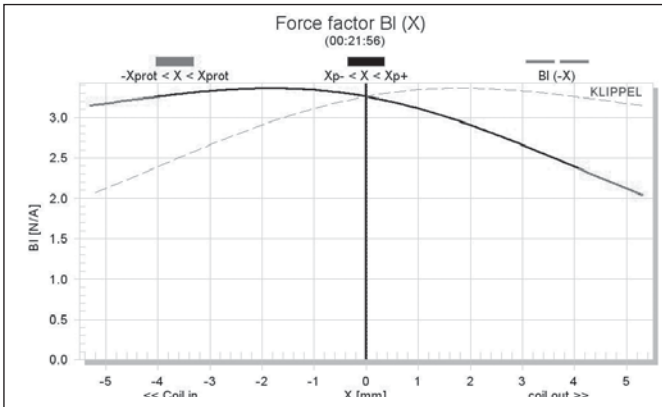


Figure 25: Klippel Analyzer Bl (x) curve for the maximum attenuation FDM setting on the Maverick

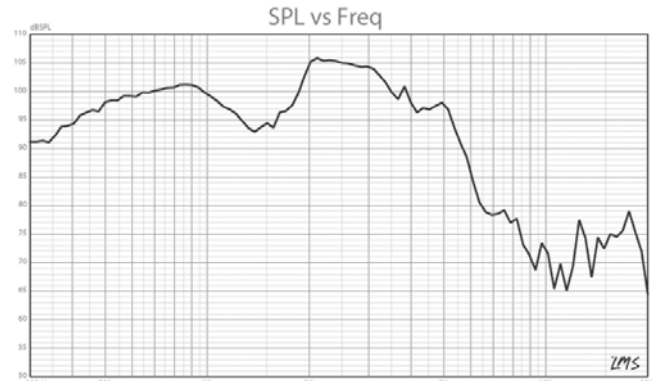


Figure 26: Eminence Maverick on-axis frequency response

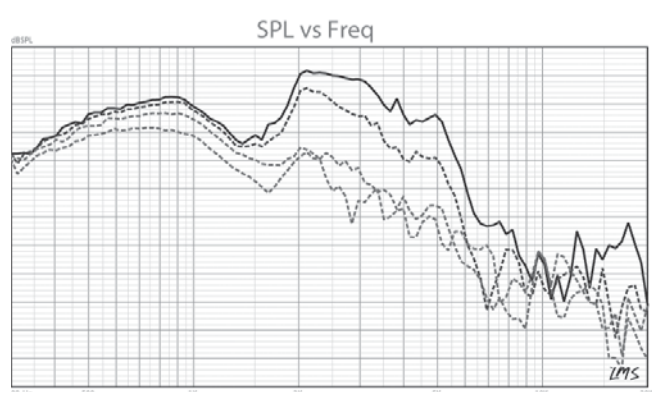


Figure 27: Eminence Maverick on- and off-axis frequency response.

former. Powering all this is a 38-oz. 130 mm × 19 mm ferrite magnet, sandwiched between the black-coated plates.

Setting up for the initial test protocol, I clamped the driver to a rigid test fixture in free-air, and generated both voltage and admittance (current) curves at 1 V, 3 V, 6 V, 10 V, and 15 V. All ten 10 Hz to 20 kHz 550-point stepped sine wave curve pairs for each driver were post-processed and the voltage curves divided by the current curves to create the six impedance curves. The impedance curves each had the LMS phase calculation procedure applied and along with the voltage curve for each sweep, imported to the LEAP 5 Enclosure Shop CAD program. Because most TS data provided by OEM manufacturers employ either a standard TS model or the LEAP 4 TSL model, I additionally created a LEAP 4 TSL model using the 1-V free-air curves. The complete curve set, the multiple-voltage impedance curves for the LTD model (see **Figure 16** for the 1-V free-air impedance curve) and the 1-V impedance curves for the TSL model were selected in the transducer derivation menu in LEAP 5 and the parameters created (using the fixed Mmd method) for the computer box simulations. **Table 2** compares the LEAP 5 LTD and TSL data and factory parameters for both Maverick samples set a Full Volume on the FDM control. I also did TSL parameter measurements with the control set at 50% full volume and at maximum attenuation. All three TSL parameter sets—full volume, 50% volume, and maximum attenuation—are compared in **Table 3**.

Thiele-Small parameter results for the Eminence 12" woofer were close to the factory data, with some variance between my two samples, but the FS/Qt ratios are close. Please note that the SPL difference is due to two different calculation methods. The LEAP 5 SPL data is a calculated number that is intended to represent mid-band sensitivity. Eminence sensitivities are expressed as the average output across the usable frequency range when applying 1 W/1 M into the nominal impedance (2.83 V/8 Ω, 4 V/16 Ω, etc.), which is perhaps a more accurate presentation of overall sensitivity of a driver than the calculated sensitivity method. Either way, it is less of an issue with a guitar speaker than a full-range speaker that does not use a crossover.

Looking at **Table 3**, which compares the TSL parameter calculations with the FDM knob set at full volume, 50% volume and maximum attenuation, both SPL and Bl decrease as the knob is advanced to max attenuation, while the Qts increases. The substantial amount of attenuation is the key to what makes this unconventional technique do exactly what a guitar player needs, a way to decrease volume of the woofer when a tube amplifier is

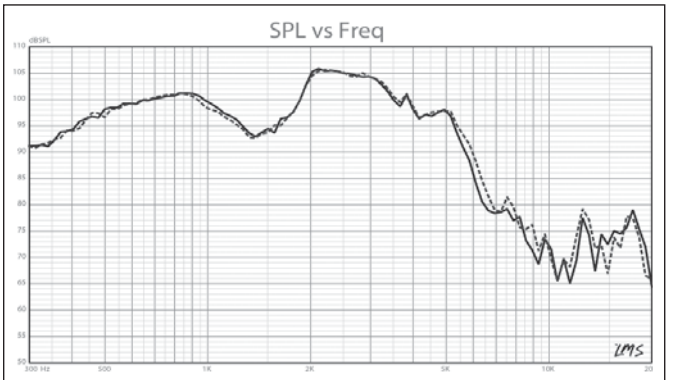


Figure 28: Eminence Maverick two-sample SPL comparison

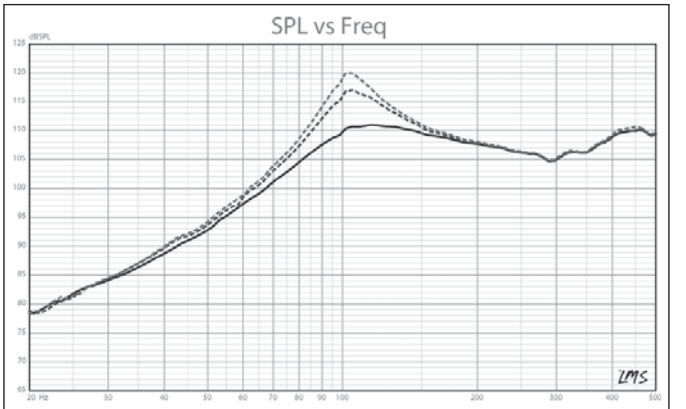


Figure 29: Eminence Maverick near-field frequency response

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turned up.

I programmed computer enclosure simulations using the LEAP LTD parameters for Sample 1 using a different technique that I normally apply in this circumstance. Since many guitar speakers are used in open-back cabinets, I decided to use a typical cabinet size and simulate the speaker in full-space with a flat baffle equal to the area of the front baffle of the guitar amplifier baffle plus the distance to the open back part of the enclosure. For this example, I used the measurements from a Fender Deluxe reverb, a single 12" speaker guitar amplifier. This yielded a total baffle area of 34" × 27", which is what I used for the first simulation (LEAP 5 will simulate almost any possible baffle and box configuration). For the second simulation, I assumed this same guitar amplifier to have a closed back.

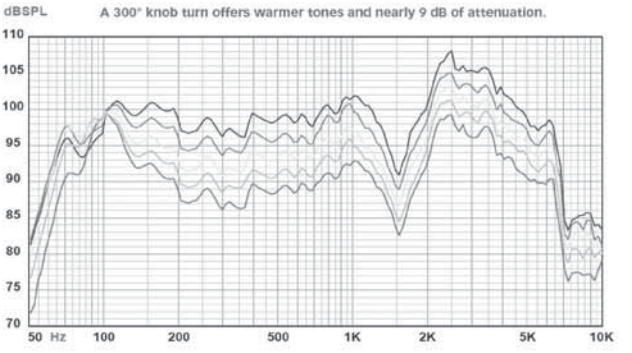


Figure 30: Eminence factory full-range SPL plot for the Maverick

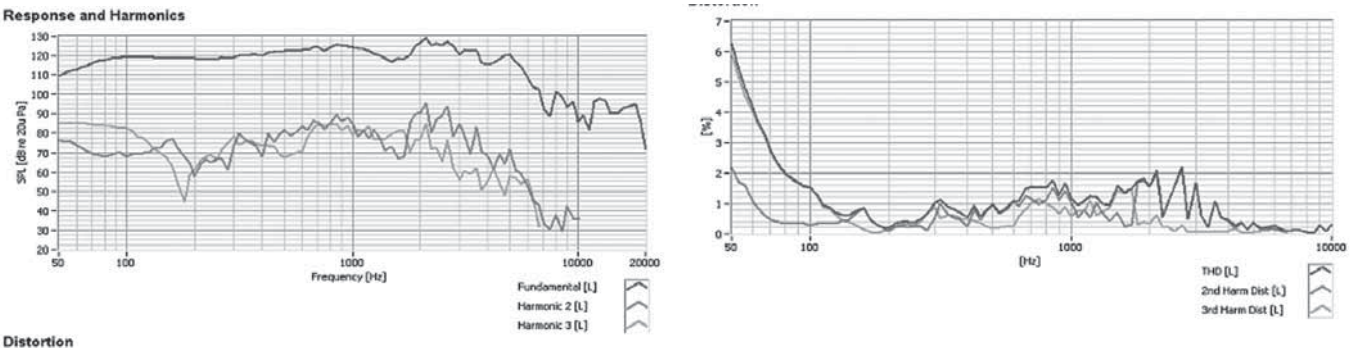


Figure 31: Eminence Maverick SoundCheck distortion plot for the full volume FDM setting

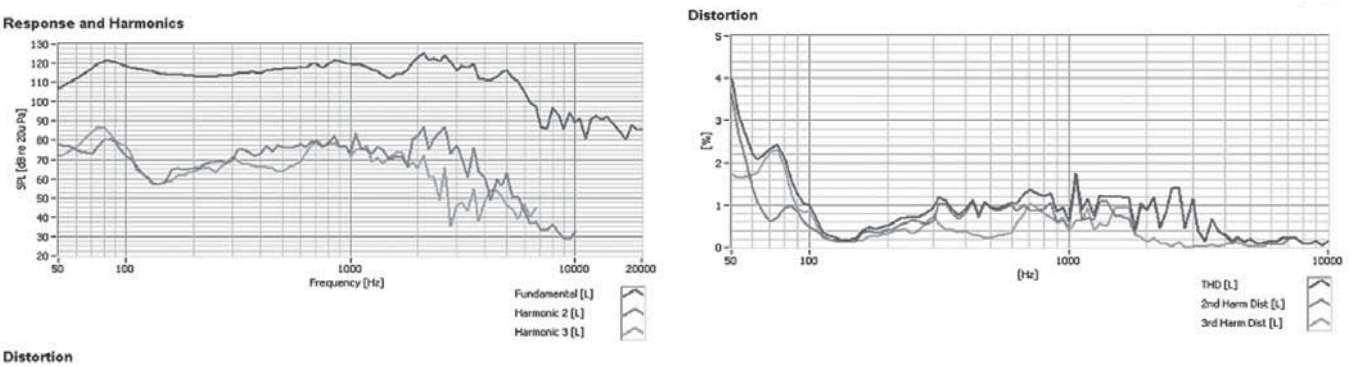


Figure 32: Eminence Maverick SoundCheck distortion plot for the 50% volume FDM setting

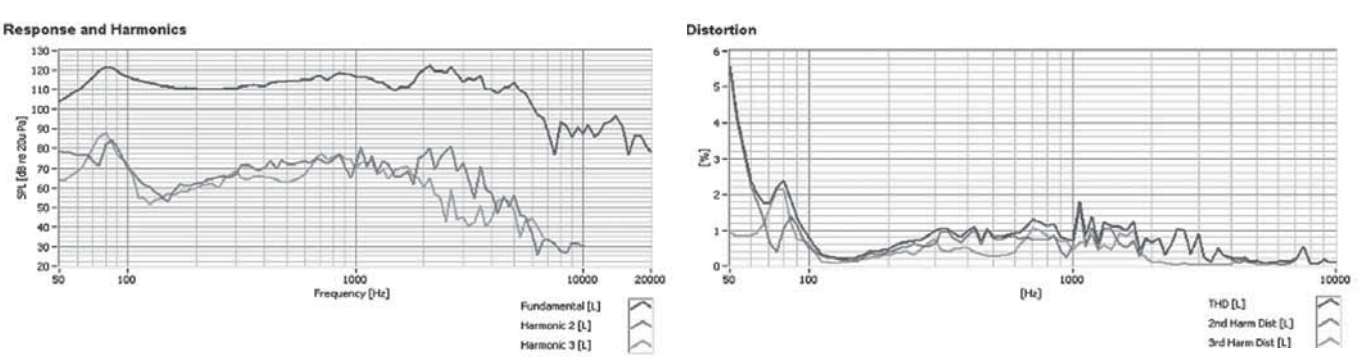
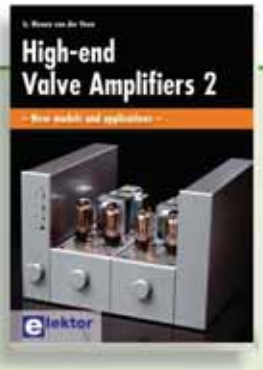


Figure 33: Eminence Maverick SoundCheck Distortion plot for the maximum attenuation FDM setting

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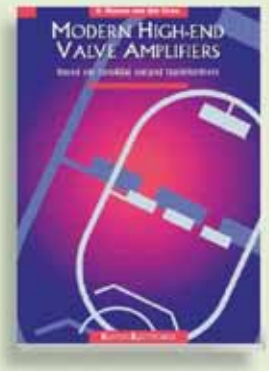


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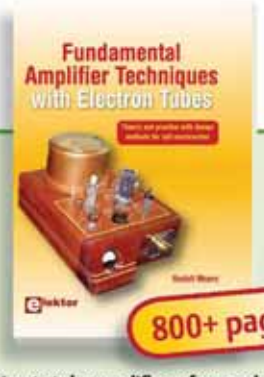


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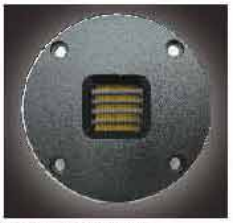
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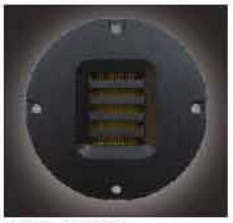
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http://www.solen.ca

This volume was roughly equal to half of a dual 12" closed-back Fender Band-Master cabinet, or about a 2 ft^3 closed box with 25% fiberglass fill material. **Figure 17** depicts the results for the Maverick in the 34" × 27" flat baffle and the 2 ft^3 sealed box at both 2.83 V and an arbitrary 10 V, mostly since this is an equal hung (coil length is about the same as the gap) configuration. This calculation resulted in a F3 frequency of 68 Hz for the open-back simulation and for the 2 ft^3 sealed closed-back enclosure a –3 dB = 86 Hz. Looking at excursion curves for a driver who is considered at its best when it is distorting substantially is probably not particularly relevant. For this reason, I just arbitrarily set the voltage to 10 V and show the resulting SPL, which was 107 dB for the open-back simulation and likewise 107 dB for the closed-back simulation (see **Figure 18** 2.83 V group delay curves).

Klippel analysis for the Eminence Maverick produced the Bl(X), Kms(X) and Bl and Kms Symmetry Range plots given in **Figures 19** to **22**. The Bl(X) curve for the Eminence woofer (see **Figure 19**) is fairly narrow, as would be expected for a very short Xmax driver, but it is also moderately symmetrical with a small amount of coil-in offset. Looking at the Bl Symmetry plot (see **Figure 20**), the rearward coil-in offset is only 0.54 mm. **Figures 21** and **22** give the Kms(X) and Kms Symmetry Range curves for the 12" woofer. The Kms(X) curve is very symmetrical with a very small amount of coil-out offset. Looking at the Kms Symmetry Range curve, there is only 0.15 mm offset at rest out to 4 mm. Displacement limiting numbers calculated by the Klippel analyzer for the Maverick guitar speaker were XBl at 82% Bl = 2.4 mm and for XC at 75%, Cms minimum was 4.1mm, which means that for the Maverick, the Bl is the most limiting factor at the prescribed distortion level of 10%. **Figure 23** gives the inductance curves Le(X) for the Eminence guitar speaker. Inductance will typically increase in the rear direction from the zero rest position as the voice coil covers more pole area, which is what you see with the Maverick.

Patrick also did Klippel measurements with the FDM knob set at 50% and at Max Attenuation. **Figures 24** and **25** show the Bl(X) curves, respectively. You can see both the magnitude and shape of the Bl curve change as the "volume" is turned down.

Next, I mounted the Maverick guitar speaker in an enclosure which had a 14" × 14" baffle and was filled with damping material (foam) and measured the trans-

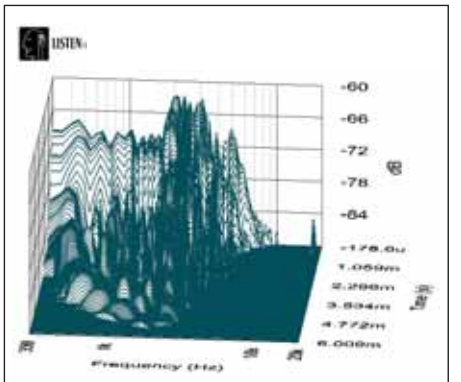


Figure 34: Eminence Maverick SoundCheck CSD Waterfall plot

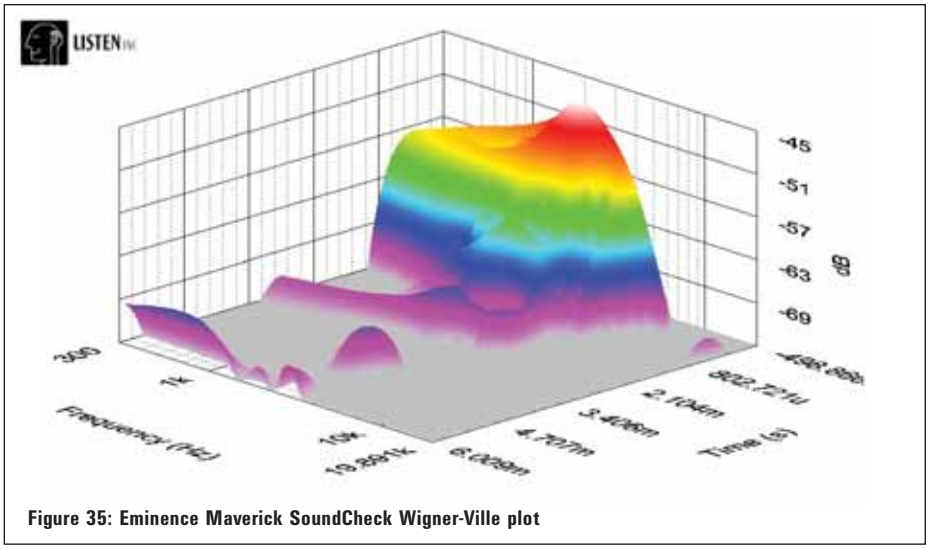
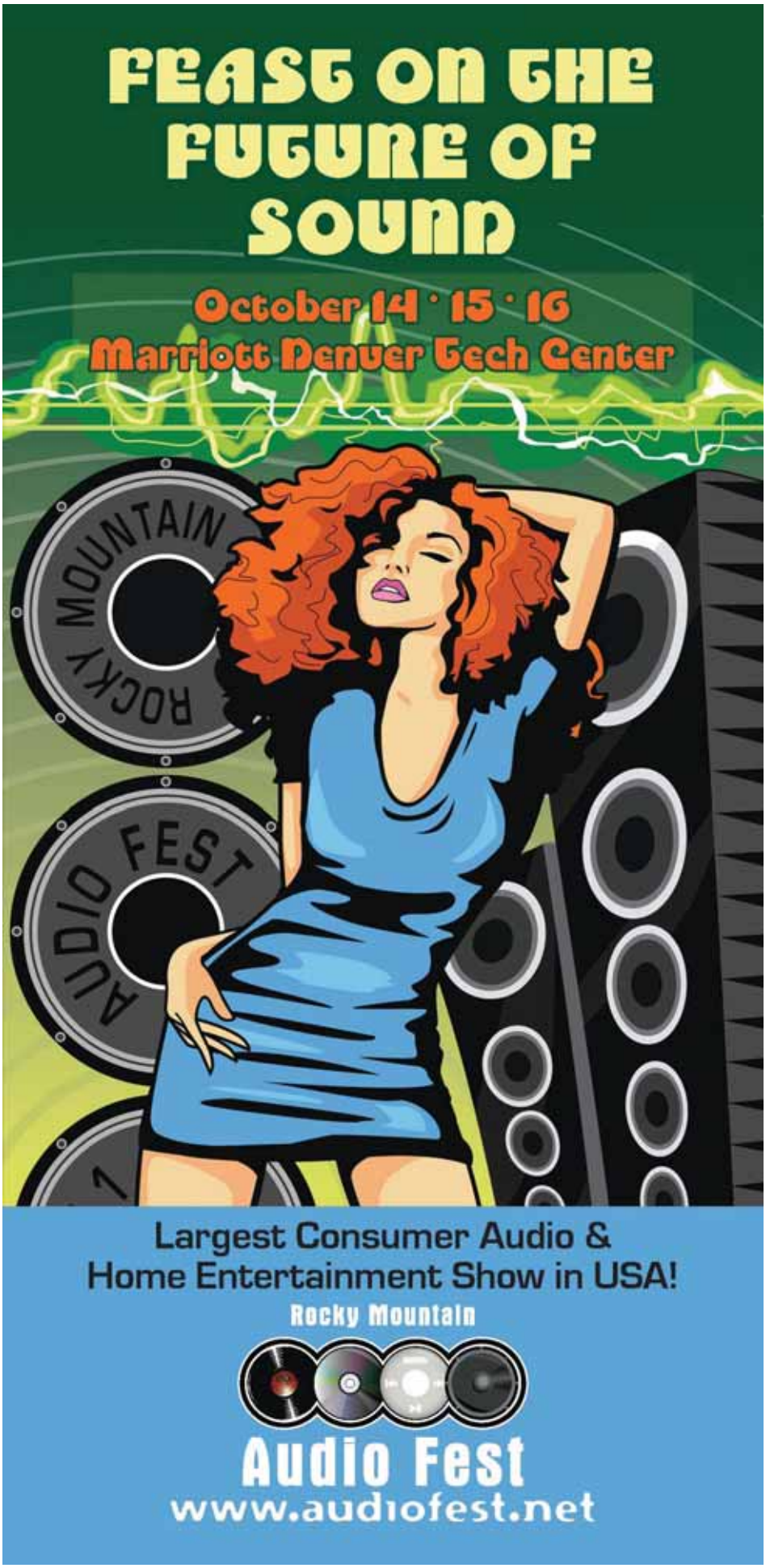


Figure 35: Eminence Maverick SoundCheck Wigner-Ville plot

ducer on- and off-axis from 300 Hz to 40 kHz frequency response at 2.83 V/1 m using the LinearX LMS analyzer set to a 100-point gated sine wave sweep. **Figure 26** gives the Maverick's on-axis response, but there is no point commenting on the SPL of this type of speaker as often the anomalies are the reason guitarists like the sound quality! **Figure 27** displays the on- and off-axis frequency response at 0, 15, 30 and 45°. **Figure 28** gives the two sample comparison, showing this pair to be well matched.

I also did a series of near-field measurements to get a better look at the driver Q changes as the FDM knob is rotated. I normalized the curves to the full-volume setting to create the graph in **Figure 29**. As can be seen, when the volume is lowered, the Q of the driver goes up. You can get a better overall look at this with the full-range plot done by Eminence in **Figure 30**. Here you can easily see the EQ effect as volume is lowered, making the driver less "bright", which in guitar guy terms means "warmer."

For the remaining series of tests, I employed the Listen, Inc. SoundCheck analyzer with the Listen, Inc. 0.25" SCM microphone and power supply (courtesy of Listen, Inc.) to measure distortion and generate time frequency plots. For the distortion measurement, the Eminence guitar speaker was mounted rigidly in free-air, and the SPL set to 104 dB at 1 m (5.8 V) using a noise stimulus. The distortion was measured with the microphone placed 10 cm from the dust cap. This produced the distortion curves shown in **Figure 31** for the full-volume setting. **Figures 32** and **33**, give the distortion plots for the 50% volume setting and the maximum attenuation setting respectively. I used SoundCheck to get a 2.83 V/1 m impulse response for this driver and imported the data into Listen Inc.'s SoundMap Time/Frequency software. The resulting CSD waterfall plot is given in **Figure 34** and the Wigner-Ville plot (for its better low-frequency performance) in **Figure 35**. Hope you enjoyed looking at this very unique and clever driver from Eminence. For more information on this and other Eminence Pro drivers, visit the website at www.eminence.com. *aX*



THANK YOU, ED

I am holding in my hand the summer 1970 issue of *Audio Amateur*, addressed to Lynn Olson at Story House, Claremont Men's College, in Claremont, California. I was 20 then, and 61 now—college and a full career at Audionics, Tektronix, and writing for various magazines has gone by. If I recall right, I've subscribed to *Audio Amateur*, *Speaker Builder*, *Glass Audio*, and now *audioXpress* for just about all of that time—filling a five-foot shelf. I also want to thank you for the opportunity to edit "V&T News"—that was a fun experience. I don't know if I was any good as an editor, but I enjoyed myself, and played a small role in getting JJ Electronics to produce the ECC99 tube (a modern version of the 7119 with a 12AU7 pinout). That was thanks to the V&T News position. I don't think they would have considered it otherwise. The editorship of V&T News may have played a small role in getting Lundahl transformers into the USA, and that was a positive development as well.

Most of all, I admire that you've resisted the horrific corruption in the high-end press that's happened over the last 25 years. You've kept it honest in an industry that is filled with scandal—all well hidden, but well-known to insiders.

It took incredible courage to publish *Glass Audio* in the late eighties, at the low point of vacuum-tube manufacturing and prestige in the English-speaking audio world. I doubt the triode revival of the nineties would have happened without *Glass Audio* getting there five years earlier. The DIY movement in the English-speaking audio world owes an enormous debt to your publications—and you were going against a headwind from the rest of high-end industry for many years.

Thank you for four decades of enlightening, informative, and fun-to-read publications, which I always looked forward to reading when it arrives in the mail. I don't know if you know it or not, but you've changed the face of audio in the English-speaking world, and I want to thank you for that as well.—*Lynn Olson (Erie, CO)*



A NOTE TO ED DELL

I read your note about the sale of your publications in the latest *audioXpress* with some sadness, simply because I've been a subscriber for a very long time. I know I wasn't an inaugural subscriber to *Audio Amateur,* because at some point I remember purchasing the back issues that preceded my subscription. I found your publication some time between 1971 and 1974, probably, shortly after I arrived in Ann Arbor for graduate school. I can remember sitting on the floor in my rented room, reading AA—odd how some images persist in memory. I've got a full collection of AA and AX on paper.

In any event, your publication has brought information and knowledge to this very non-engineering amateur for many years, for which I'm very grateful. My first amateur undertaking was hooking up my suitcase-portable RCA two tube mono "record player" to the 12" speaker of the 1937 Zenith radio I had begged from my grandfather's basement. Wait—the first undertaking was building a bass reflex enclosure for the speaker, using a book from the library, since an uncle had extracted the radio and speaker from the original console and had put the speaker in a wall PA

speaker enclosure. (It worked better if I had the radio on so the B+ voltage energized the speaker's field coil.) I've been chasing good sound—the real goal—on the cheap ever since. And your magazines have been a joy. Thank you.—*Chris Campbell (Traverse City, MI)*

PLEASING NEWS

I am really pleased to hear of Elektor's acquisition of Audio Amateur, Inc., and all its publications. From an editorial and content standpoint, I can't think of any publisher better suited to take over Ed's operation. It seems a natural and exciting development. As you may know, I am one of Ed Dell's longest-running authors, having started with him some 30 years ago. He's been a great editor and friend, but I'm glad that he will finally be able to enjoy a well-deserved retirement. I'm confident that *audioXpress* will be in good hands under your direction and I look forward to my continued association with the magazine, and to working with you.—*Gary Galo (Potsdam, NY)*





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Contributors

Ken Bird ("Castle Tower Omni Speakers," p. 17) has had a 40–year career in engineering and product management in consumer, industrial, and telecommunications electronics. Ken has since retired to his native Missouri and now pursues his interests in building speakers and tube amplifiers, along with model railroading, amateur radio, (WOKLB), and digital photography.

Robert Nance Dee ("Build a BCD-Digital Potentiometer," p. 14) is a retired electronics engineer. He worked with the first military computers, has several patents, and has written many magazine articles. He enjoys machining, watch making, bicycling, cabinet making, and philosophy. He is an amateur arborist, an environmentalist, and a vegetarian who thinks his life is a hobby. His passion for audio, in every form, spans 50 years and started in high school while working part time in a radio television repair shop. He lives off the grid in a house he built surrounded by animals and fruit trees in the Catskill Mountains. His audio projects are named after his animals and friends.

Vance Dickason (Test Bench: "Wavecor Full-Range Driver and Eminence Guitar Speaker," p. 33) has been working as a professional in the loudspeaker industry since 1974. He is the author of the *Loudspeaker Design Cookbook*—which is now in its seventh edition and published in English, French, German, Dutch, Italian, Spanish, and Portuguese—and The Loudspeaker Recipes. Vance is currently the editor of *Voice Coil, The Magazine for the Loudspeaker Industry*, which is published on a monthly basis. For several years, Vance has been working as an engineering design consultant for various speaker manufacturers and is responsible for numerous award winning designs, including twenty THX home theater certifications. Speakers that Vance designed that have won magazine and industry design awards include the Artison Portrait, Atlantic 170, 270, 370, 450 and 8200, and the coNEXTion Sonoma 10 and z600c.

Ton Giesberts ("Measurement Filter for Class D," p. 8) of Elektor Labs started working at Elektor in 1987. His technical interests include analog design and audio power amplifiers. Ton bikes to work (about 4.2 miles, or 6.3 km) because of his care for the environment. When he isn't working, Ton enjoys watching movies, especially sci-fi films.

Robert W. Nehring (Reliable Review: "Legacy Audio Focus SE Speaker," p. 24) is a music lover who served as the editor of *The $ensible Sound* for many years, but who hesitates to be identified as an audiophile because of the negative connotations associated with that term. He enjoys music of all sorts and wishes he had musical talent.

Angel Luis Rivera PA-C ("Impedance Matching Transformers for Ribbon Speakers," p. 28) has been a physician assistant for 26 years and has worked for The Veterans Administration in surgery for the last 12 years. Several of his articles have been published in *Speaker Builder* and *audioXpress* since 1990.

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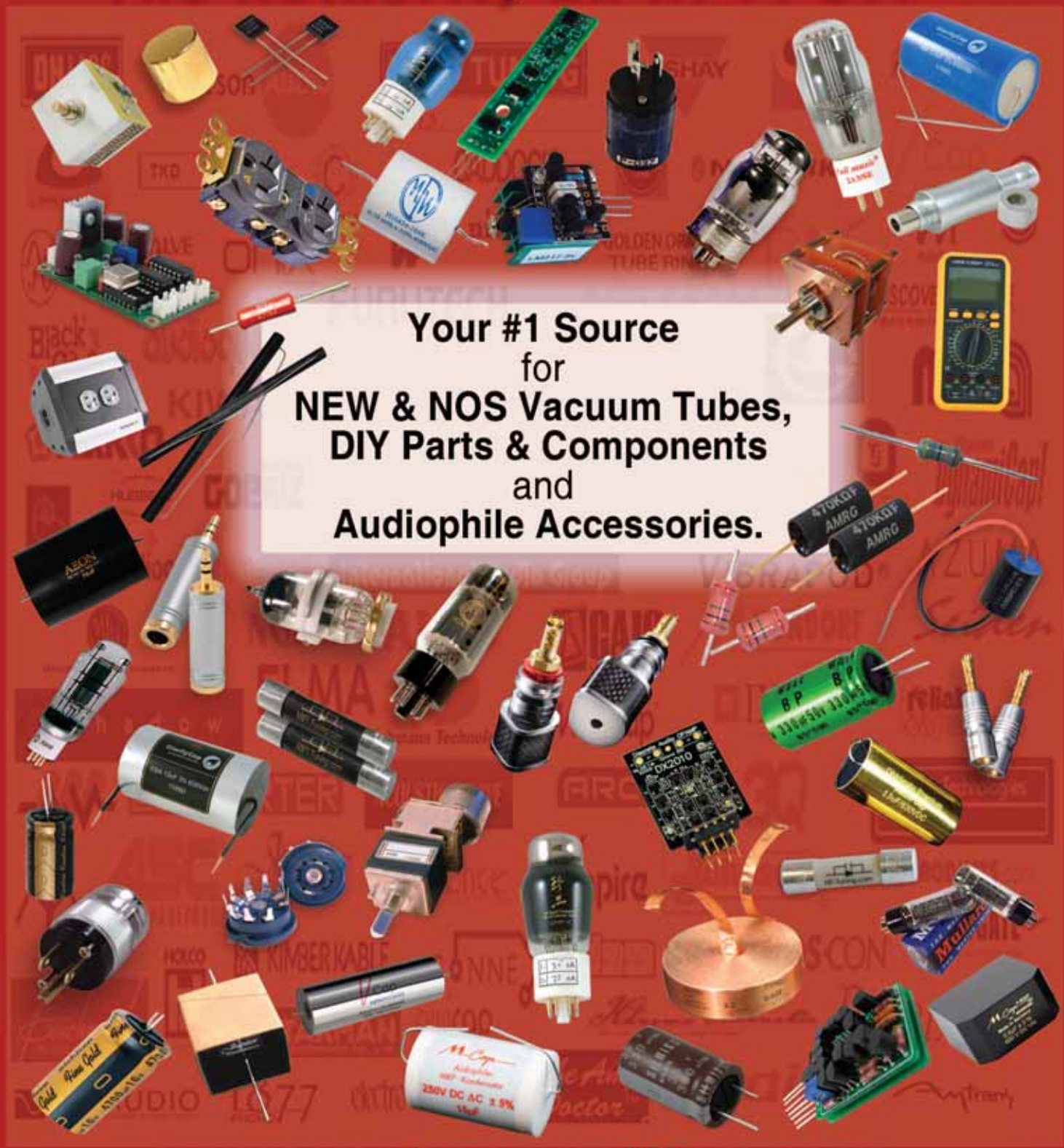
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