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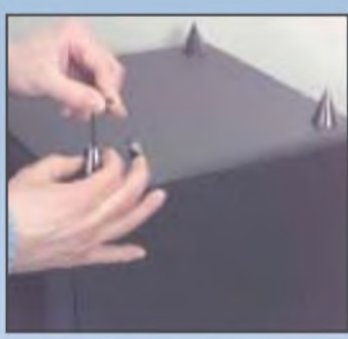

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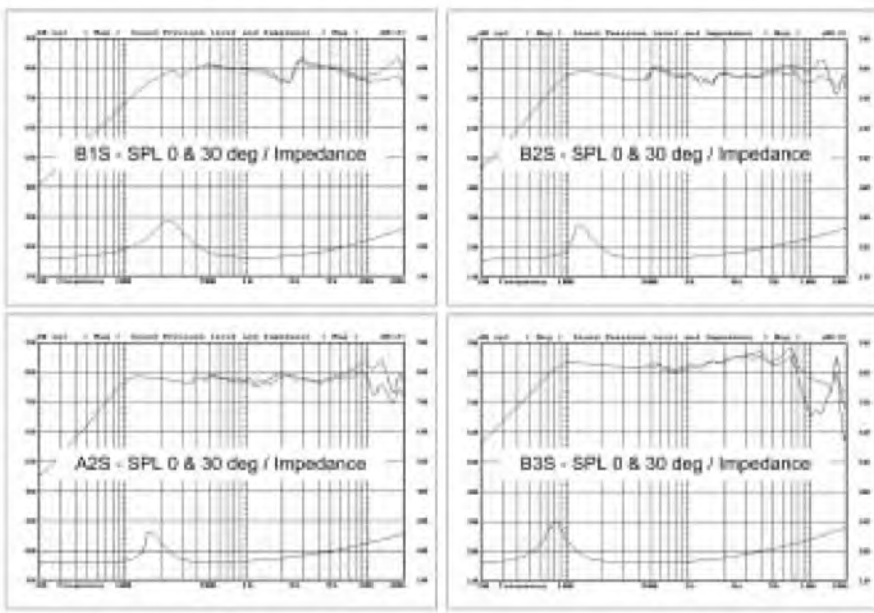

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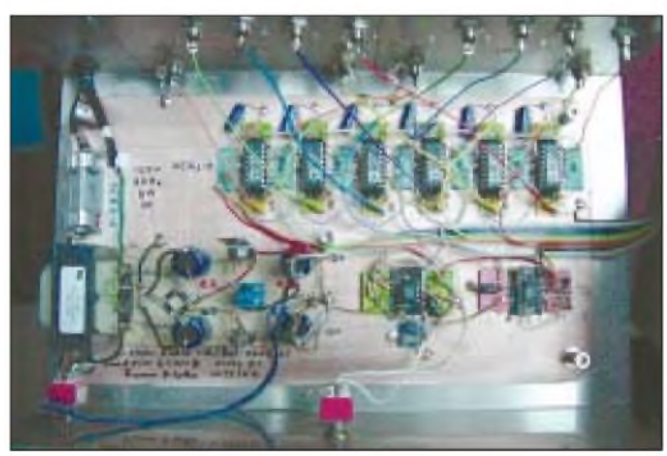

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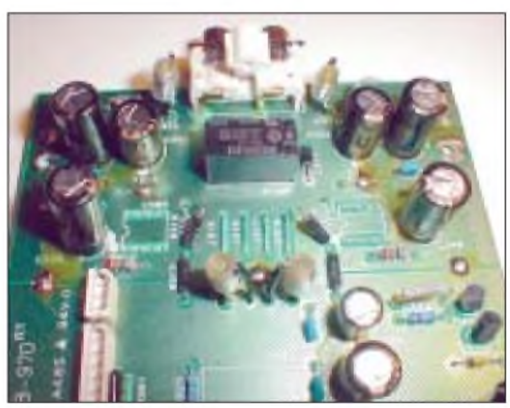

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>
> JOHN STUART MILL

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A 6-Channel Volume/Balance Control

This versatile control circuit is pure Class A analog, allowing you to use the ultra-high transparency SACD (Direct Stream Digital) or DVD-A surround formats with up to six power amp channels, while avoiding the digital processing degradation (and expense) of surround-sound processors. **By Dennis Colin**

I purchased an inexpensive SACD player (Sony DVP-NS5500V, $139, now discontinued; other Sony units are available for around $200). Someone commented that he'd rather hear an SACD on a $200 player than a CD on a $20,000 player—I agree! I'm totally spoiled and will never buy another CD! Finally, strings, cymbals, piano—everything—sounds natural, grain-free, completely smooth, airy, and lush down to the subtlest details.

And that was before I tried multichannel surround. With a good recording, this transparent naturalness extends to an enveloping soundfield that—at its best—can make you think you've been listening from just outside the concert hall doorway, and now you've walked inside!

I haven't yet heard DVD-A, which has also received rave reviews, but SACD seems to be winning. The Acoustic Sounds catalog and *The Absolute Sound* music reviews have more SACDs than DVD-As, and the margin appears to be increasing.

PROJECT CHOICES

My SACD player and many other multichannel sources don't have a master volume control. So I designed and built the unit described here (*Photos 1, 2*, and *3*).

I decided against the following alternatives:

1. Six-gang step attenuator plus six balance pots. The latter would require signal reduction at mid-setting; also, I wanted remote controllability, which would require seven motorized attenuators—very expensive.
2. The Analog Devices SSM2160 Serial Input Balance/Master Volume 6-channel control. While this uses the same ultra-high quality analog VCAs (Voltage Controlled Amplifier/Attenuator) as in the devices I used, I wanted analog, not digital, control. I didn't mind needing six (inexpensive) ICs instead of one.
3. Digital processors—what? Degrade my SACDs to "CD quality"? No thanks!

Instead, I used the Analog Devices SSM2018T analog VCA. This $8 IC has 140dB gain control range, THD of ≈ 0.01% biased in Class AB (I use Class A), noise of about 97dB below 0dBu (0.775V RMS), and a very linear dB attenuation versus control voltage law. Also, the VCA needs no trimming—repeatability from unit to unit appears to be within about 0.2dB.

FUNCTIONAL DESCRIPTION

1. Volume—The control is calibrated from 0dB (maximum volume) to –80dB; a switch allows use of an external 10kΩ linear pot ("wired remote") or a 0 to +4V control signal (0V → –80dB; +4V → 0dB).
2. Balance—Six individual channel pots provide ±5dB range (you can easily change the range if desired).
3. Maximum gain—This pot sets the "0dB volume" gain of the unit within a range of ±12dB (also changeable).

Note: The speaker diagram shown on the controller top in *Photos 1* and *2* is the I.T.U. standard multichannel layout, recommended for music. Notable differences from the THX movie standard are:

1. Five full-range speakers are recommended (but not required).
2. Front left/right units are ±30° in relation to center.
3. Rear surrounds are 110° from front center.

PHOTO 1: The completed 6-channel volume/balance control.

PHOTO 2: Top of unit.

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4. Dipole surrounds are not recommended.
5. All five speakers are equidistant from the listener.
6. No electrical delay is added to surround speakers. With most orchestral surround SACDs, the rear surround mikes receive hall ambience from the rear, therefore already appropriately (naturally) delayed.

I must comment most emphatically that with such a recording, I find the sound to be absolutely ethereal in its naturalness. Once heard, there's no going back!

CONSTRUCTION

I used a Bud box, CU-2110B (10″ × 6″ × 3.5″), Newark 91F697. Being in a hurry, I didn't bother with a PC board. I simply glued and soldered parts and wires all over the solid copper surface of a piece of unetched board material (*Photo 4*). Looks crude, but can't be beat for solid grounding! (My "day job" is designing microwave oscillators; I've built protos with this "air-bridge over ground plane" method that work over 10GHz, often better than the PC board production units.)

CIRCUIT

The audio path is simple: VCA 1 (shown in *Fig. 1A*; six units total) is fed audio through

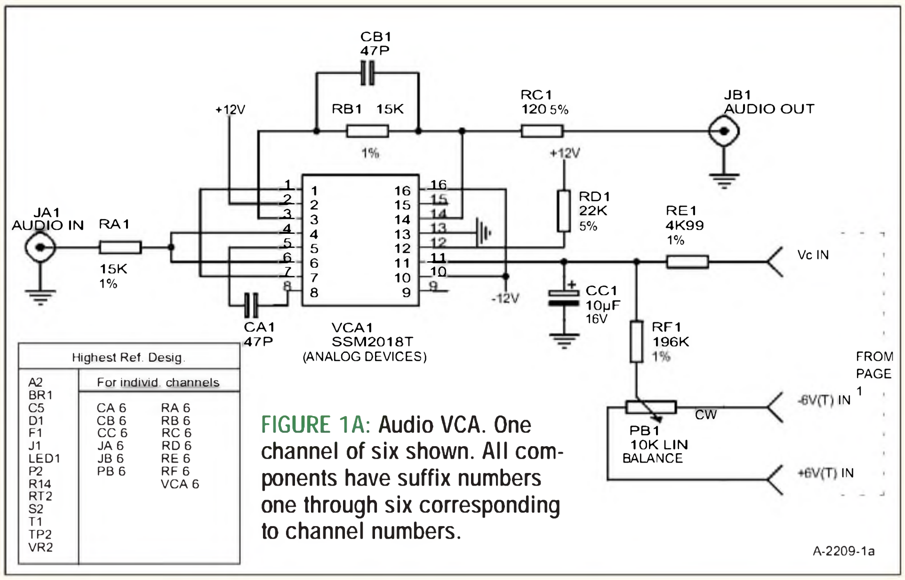

FIGURE 1A: Audio VCA. One channel of six shown. All components have suffix numbers one through six corresponding to channel numbers.

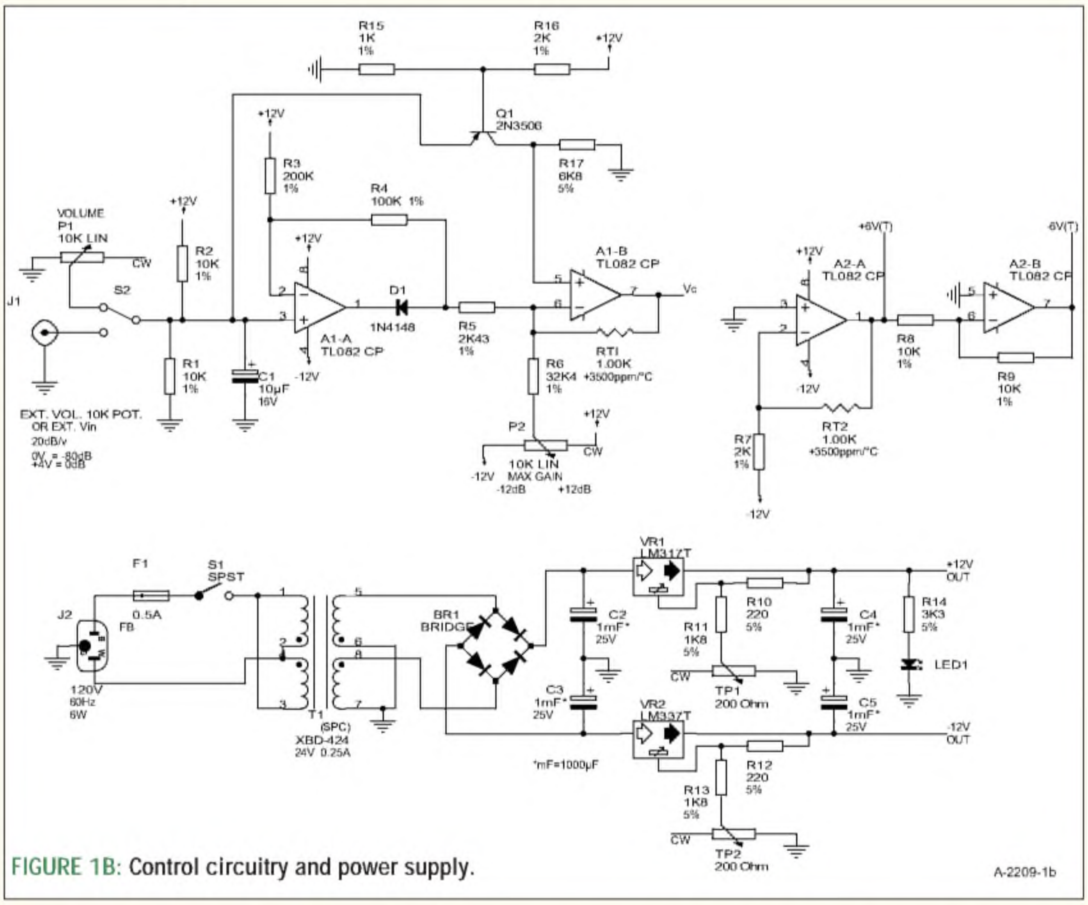

FIGURE 1B: Control circuitry and power supply.

PHOTO 3: Rear view.

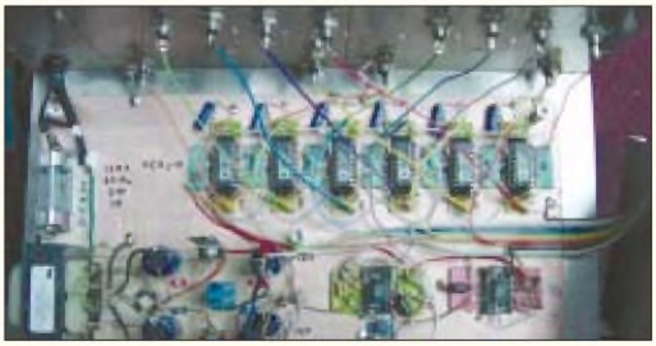

PHOTO 4: Inside the control.

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Behind the Scene:

Dr. Joseph D'Appolito has been working as consultant for Usher Audio since early 2000. A world renown authority in audio and acoustics, Dr. D'Appolito holds BEE, MSEE, EE and Ph.D. degrees from RPI, MIT and the University of Massachusetts, and has published over 30 journal and conference papers. His most popular and influential brain child, however, has to be the MTM loudspeaker geometry, commonly known as the "D'Appolito Configuration," which is now used by dozens of manufacturers throughout Europe and North America.

Dr. D'Appolito designs crossovers, specifies cabinet design, and tests prototype drivers for Usher Audio, all from his private lab in Boulder, Colorado. Although consulting to a couple of other companies, Dr. D'Appolito especially enjoys working with Usher Audio and always finds the tremendous value Usher Audio products represent a delightful surprise in today's High End audio world.

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RA (1–6) to pins 4 and 6. Audio output is from pin 14, which also feeds pin 3 through RB (and HF bypass CB). With zero voltage at the gain control pin 11, audio gain is the ratio of RB to RA, here set to unity. (Refer to the Analog Devices SSM2018T data sheet, downloadable from www.analog.com, for description and specs.) Audio frequency response is DC to 200kHz, the latter being the –3dB HF rolloff point.

CA is the recommended HF compensation cap. RD supplies 0.51mA to pin 12, which biases the VCA in pure Class A mode. Pin 11, the gain control point, has a slope at +25°C ambient of –30mV/dB, with unity gain (0dB overall) at 0V applied.

This –30mV/dB slope is proportional to absolute temperature (°K); at +25°C this represents a gain-in-dB tempco of –3300ppm/°C[1]. Uncompensated, a 15°C ambient rise (27°F, say from 70°F to 97°F) would change the "gain," if set to –40dB, to a value of –38dB (0dB gain setting is temp-independent). While a 2dB volume increase with regard to –40dB if you're listening at 97°F is not serious, I decided to provide temp-compensated control-drive signals (which I describe later).

Finally, RC (120Ω) provides unconditional stability with highly capacitive loads (long cables). The output impedance of 120Ω would need a load of 33,000pF (about 1000′ of cable) to cause 1dB loss at 20kHz. The audio input impedance is 15kΩ, somewhat low compared to practice, but this causes a signal reduction of only 0.6dB when driven by the 1kΩ output impedance typical of sources. Also, the controller has up to 12dB of gain available, with maximum volume and mid balance settings.

Maximum audio levels—in and out—are ±8V (5.6V RMS); maximum output current is ±1.5mA. With my

TABLE 1
ATTENUATION VS. REMOTE DC VOLTAGE INPUT MAX GAIN AND BALANCE POTS SET TO 0DB

V_{IN} (DC) VOLTS	AUDIO GAIN dB
0.00	–81.8
0.50	–71.3
1.00	–61.1
1.50	–51.2
2.00	–40.9
2.50	–30.7
3.00	–20.5
3.50	–10.3
4.00	–0.0
4.10	+0.4
4.20	+0.4
4.30	+0.4
4.40	+0.3
4.50	–1.8
4.53	–6.2
4.55	–13.5
4.57	–28.0
4.58	–45.6
4.59	–73.0
4.60	–104
5.00	–104
6.00	–104*
7.00	–104

Note: 0.00–4.00 is normal range.
*Open remote pot/cable.

TABLE 2
RIBBON CABLE COLOR CODE

	BOARD	POTS
blk	ground	vol. CCW
w	vol. sw.	vol. w
gry	maximum gain	maximum gain w
v	L (1)	L w (1)
b	C (2)	C w (2)
g	R (3)	R w (3)
y	LS (4)	LS w (4)
o	RS (5)	RS w (5)
r	sub (6)	Sub w (6)
brn	+6V (T)	(1) (2) (3) (4) (5) (6) CCW
blk	–6V(T)	(1) (2) (3) (4) (5) (6) CW
w	+12V	maximum gain CW
gry	–12V	maximum gain CCW

CW = clockwise end
W = wiper
CCW = counterclockwise end

(1) = Left (L)
(2) = Center (C)
(3) = Right (R)
(4) = Left Surround (LS)
(5) = Right Surround (RS)
(6) = Subwoofer (sub)

TABLE 3
PERFORMANCE SUMMARY

Gain range:
- Master volume:
- –80 to 0dB
- Maximum gain pot: ±12dB
- Balance pots: ±5dB
- Total gain range: –97 to +17dB

Frequency response (at any attenuation):
- DC to 200kHz (–3dB)
- ±0.02dB, DC–20kHz

Distortion (According to Analog Devices; not measured):
- <0.01%, up to 5V RMS in or out

Noise (20kHz BW):
- 32μV RMS out (–88dBu) @ 0dB gain
- 10.6μV RMS out (–97dBu) @ –20dB
- 6.1μV RMS out (–102dBu) @ –40dB
- 5.5μV RMS out (–103dBu) @ –80dB

Signal/Noise:
- 105dB re max. signal of 5.6V RMS (flat spectrum; much better with "A" weighting for low level hearing)

DC output offset: ±4mV maximum @ 0dB gain

Impedances: 15kΩ in, 120Ω out

Interchannel Crosstalk (immeasurable by me; calculated):
- ≤ –88dB @ 20kHz

120V AC power: ≈ 6W

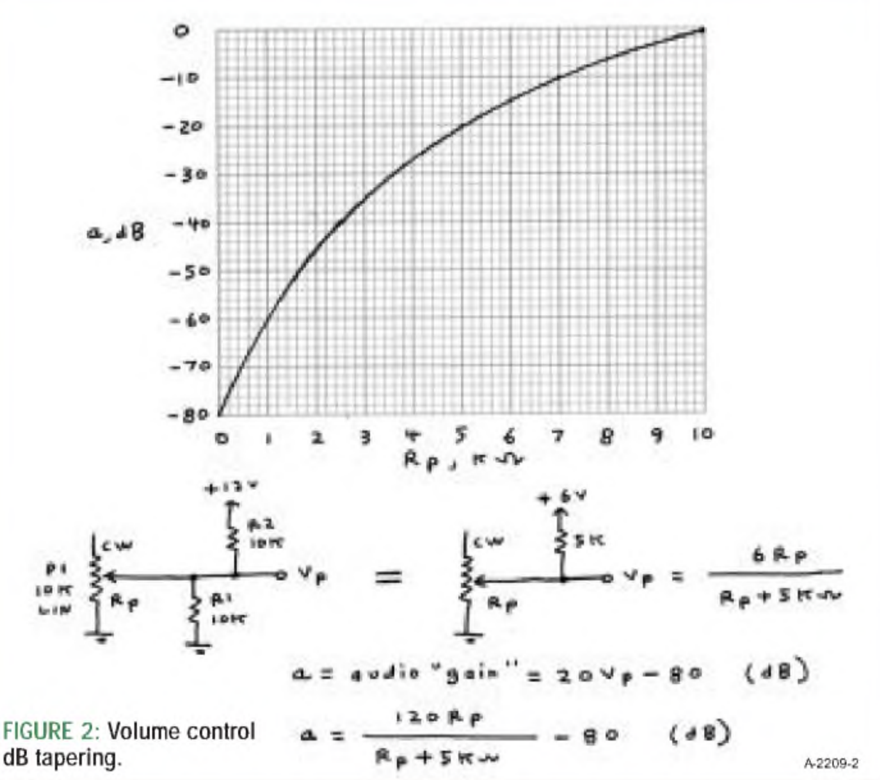

FIGURE 2: Volume control dB tapering.

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Sony SACD player, I measured the highest peaks of a number of discs to be about ±3V. With this peak level, the controller can drive a 2kΩ load. No problem with any normal power amp. Also, even at this peak level, controller distortion is below 0.01%, and mostly second and third harmonics (like a tube amp, but much lower in level). After extensive listening with and without the controller, I didn't notice any sonic degradation or audible noise.

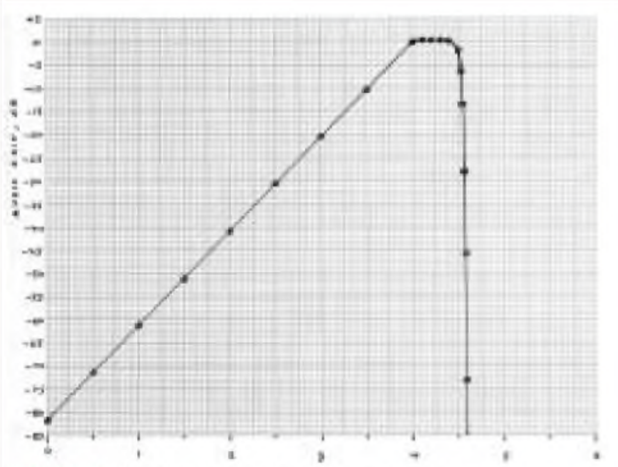

FIGURE 3: Remote control input vs. audio gain. A-2209-3

POWER SUPPLY

The supply (*Fig. 1B*) is completely straightforward and simple: regulated ±12V supplying about 80mA each. With the four 1000µF filter caps, hum and noise are completely negligible.

A note on the power transformer (T1): This is a high-isolation split-bobbin type from SPC Technologies. High isolation indeed. I measured primary/secondary capacitance of only 16pF—at 60Hz, this is an impedance of 166MΩ. This controller will not introduce any audible hum into your system.

The VCA chip is rated for ±18V maximum supply at up to +85°C (185°F). With ±12V supply at normal temperatures—even for the Sahara—the circuitry should last 10,000 years (barring corrosion, of course).

Regarding the supply voltages (trimmed by TP1 and TP2), they should be set to within 10mV of ±12V. The regulators (VR1, VR2) became rather warm without heatsinks, although not excessively. I used heatsinks to be conservative.

CONTROL SIGNALS

Master volume is controlled by either (a) P1, a 10kΩ linear pot; (b) an external 10k pot, switched in by S2, to serve as a "wired remote"; or (c) an external DC voltage of 0 (for –80dB) to +4V (for 0dB).

Since the VCA control function is linear voltage-to-linear dB, a linear pot (unloaded) would provide an 80dB attenuation range with linear dB versus control rotation. However, this would not provide fine enough resolution at normal volume settings. So I selected R1 and R2, providing a 5kΩ load to the 10k pot, to taper the dB versus rotation function[2]. As such, mid rotation produces 20dB attenuation, similar to a typical audio taper (≈ log) volume control pot. See *Fig. 2*.

As you can see in *Photo 1*, the tapering allows <1dB resolution from 0 to –10dB, smoothly steepening to allow an

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Acoustic Diffraction: Does It Matter?

This author's latest speaker study examines edge diffraction and what you can do to reduce it. By James Moriyasu

Cabinet edge diffraction has always been a major design concern for me. It is one thing to look at the sound pressure level (SPL) frequency response chart of a driver on a catalog page and another to measure the same driver in a cabinet. Instead of a smooth response that falls within 1–2dB, the tweeter's response above 1kHz develops multiple peaks and troughs that deviate by up to 2–3dB from flat. Most of these deviations from the "pure" driver response are caused by acoustic diffraction generated by the sharp edge of the cabinet. The edge of the driver mounting plate, the cavity caused by the cone of a midrange or bass driver, and the grille frame also contribute to the problem.

What causes edge diffraction is discussed in detail by D'Appolito.[1] Basically, when a sound wave reaches the edge of the cabinet it is forced to expand into a much larger volume, which causes a pressure drop and the production of a second sound wave. D'Appolito also states that the radius of a rounded edge must be comparable to a wavelength to be effective. For example, he says that a ¾″ radius rounded edge, which corresponds to a frequency of 18kHz, isn't going to help with those diffraction artifacts between 1–18kHz.

Is cabinet diffraction really a problem? According to Dickason there are two points of view regarding cabinet edge diffraction.[2] One view states that it is insignificant because it is swamped by the reverberant field caused by a room and because much listening is done off-axis, which leads to a smoother response. The other point of view holds that image quality is compromised by diffraction.

This study attempts to measure the extent of acoustic edge diffraction and test possible solutions for reducing its levels. It does not make any attempt to determine its effect on the subjective quality of sound produced by a loudspeaker. Nor does it examine asymmetrical driver placement, which tends to smooth the effects of edge diffraction but does not reduce them.

TEST SETUP

I mounted a Morel MDT-29 tweeter and a Vifa P13WH midbass on an enclosure that had front baffle dimensions of 8⅞″ wide by 12″ tall and 6½″ deep. I centered the drivers along the vertical midpoint of the front baffle (*Photo 1*). The tweeter was flush-mounted since it has a 5/32″ thick front plate. The midbass opening was rabetted to a depth of ¼″, leaving just enough clearance to cover the woofer with poster board. However, the frame of the driver is 1/8″ below the plane of the baffle, which probably causes some diffraction.

I mounted the enclosure on an IEC baffle (*Photo 2*) and used duct tape to

PHOTO 1: Morel MDT-29 tweeter and Vifa P13WH (covered with poster board) mounted in enclosure.

PHOTO 2: Enclosure with drivers mounted on IEC baffle for measurement.

PHOTO 3: A test enclosure that is 8.875″ wide and 56″ tall.

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cover gaps that were between 1/32″ to 1/16″ wide. The IEC baffle was lifted on a manual forklift so that the tweeter was 7′ from the ground. I placed the microphone 1m from the tweeter and made SPL measurements from 500Hz to 20kHz with Loudspeaker Measurement System (LMS) by LinearX.

MEASUREMENTS

I made the first set of measurements, which examines diffraction from the tweeter front plate, with the Vifa P13WH covered with a square of poster board to eliminate diffraction from the midbass cavity. The poster board was 1/64″ thick and taped into place with duct tape that is 1/128″ thick.

Figure 1 shows what happens when the flush-mounted tweeter is raised 1/32″ by loosening the screws and pulling the tweeter forward. This makes the tweeter appear as if it wasn't flush-mounted. The solid line is the tweeter SPL flush-mounted, the dotted line is when it is not flush-mounted, and the dashed line at 60dB is the difference of the non-flush-mounted over the flush-mounted responses.

There are up to 2dB increases between 3kHz and 6kHz and between 12kHz and 15kHz. There is a gradual 1dB dip at 3kHz and almost 2dB of loss between 8–11kHz. I was surprised to see this much diffraction-induced ripple below 5kHz since 1/32″ doesn't seem significant compared to the length of the sound waves at these frequencies. So, flush-mounting does significantly minimize diffraction from the edge of the tweeter mounting plate.

The next measurement examines how a midbass driver causes diffraction. In *Fig. 2* you see that after the midbass is uncovered, a 2dB depression oc-

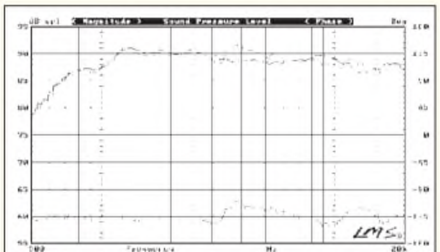

FIGURE 1: SPL of tweeter on IEC baffle with faceplate edge diffraction (dotted line) versus none; difference curve raised by 60dB.

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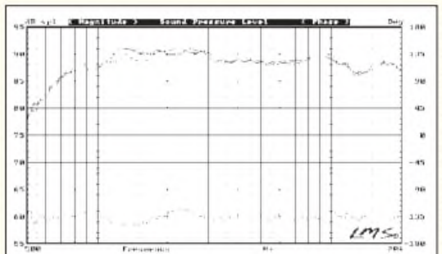

FIGURE 2: SPL of tweeter on IEC baffle with midbass covered (solid line) versus with midbass uncovered; difference curve shows diffraction from midbass cavity.

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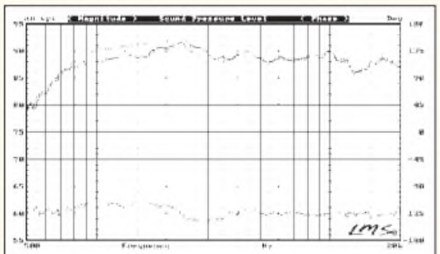

FIGURE 3: SPL of tweeter on IEC baffle with midbass uncovered (solid line) versus enclosure in free air; difference curve shows diffraction from enclosure edges.

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curs between 1200Hz and 1700Hz, while a 1.75dB bump occurs between 2kHz and 2.8kHz. The solid line is the tweeter SPL when it is flush-mounted with the midbass covered, while the dotted line shows the midbass uncovered. There are other ripples of less than a dB above 3kHz, also. So, the cavity from a closely located midbass driver is a source of significant diffraction. Aside from using a flat-faced midrange, which is uncommon, there is nothing that you can do about this source of diffraction.

Of course, in real life no one would want an IEC baffle or two in their living room. So, *Fig. 3* shows what happens when you remove the enclosure from the IEC baffle and measure the tweeter, with the woofer uncovered. The solid line is the response with the IEC baffle with the midbass uncovered, while the dotted line is the enclosure without the IEC baffle. A broad 2dB hump develops between 800Hz and 2.3kHz along with a 2dB depression between 2.3kHz and 3.5kHz due to cabinet edge diffraction. Additional ripples of less than a dB occur above 4kHz, too.

Figure 4 shows the 5″ midbass driver SPL response with and without the IEC baffle. The response without the IEC baffle is the top line. The difference curve is similar to that in *Fig. 3*, with up to a 3dB hump developing between 600Hz and 2kHz. The lack of a dip above 2kHz may be due to the increased directivity of the midbass drive. In other words, there may be less energy at 90° off-axis to generate cabinet edge diffraction.

These humps, dips, and ripples develop because of the additional path length the sound waves must travel from the driver to the cabinet edge. A

PHOTO 4: Test enclosure with 4″ radius shell.

PHOTO 5: Test enclosure with 2″ radius shell.

PHOTO 6: Test enclosure with 1″ radius shell.

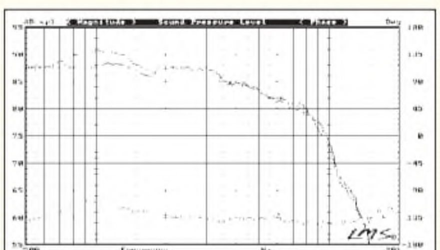

FIGURE 4: SPL of midbass on IEC baffle (solid line) versus enclosure in free air; difference curve shows diffraction from enclosure edges.

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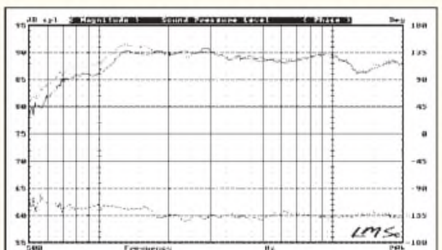

FIGURE 6: SPL of tweeter on enclosure with 4″ radius shell versus on IEC baffle (solid, lower line); difference curve raised 60dB.

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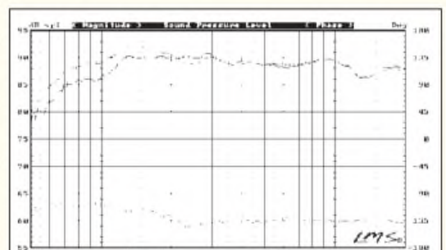

FIGURE 8: SPL of tweeter on enclosure with 1″ radius shell versus on IEC baffle (solid, lower line); difference curve raised 60dB.

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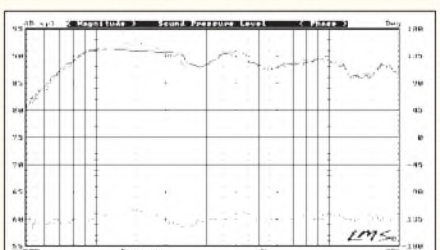

FIGURE 5: SPL of tweeter on 8.875″ × 56″ enclosure. Mounted 4.5″ down (dotted line) versus mounted 9″ down; difference curve raised by 60dB.

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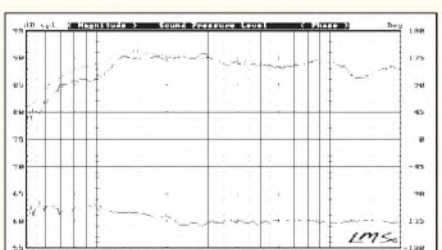

FIGURE 7: SPL of tweeter on enclosure with 2″ radius shell versus on IEC baffle (solid, lower line); difference curve raised 60dB.

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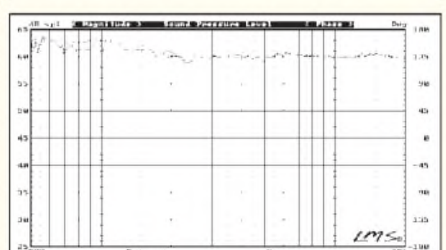

FIGURE 9: Comparison of SPL difference curve of 4″ radius (lower line) versus difference curve of 1″ radius.

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different size front baffle or different driver positions would cause peaks and valleys at different frequencies because of the path length differences.

I also conducted another experiment on a test enclosure that is 8.875″ wide and 56″ tall (*Photo 3*). In this set of measurements, the tweeter was equidistant from the sides and mounted at 4.5″ intervals down from the top. In *Fig. 5* you see that the 4.5″ mounting distance has up to 2dB more peak or depression than the 9″ mounting distance. The 4.5″ mounting distance is the top, dotted line, and the difference curve is at 60dB.

It appears that positioning the tweeter further down from the top of the cabinet lessens diffraction ripple. This is probably because the wavelength paths from the tweeter to the cabinet edges vary more. In other words, when the tweeter is 4.5″ down from the top, it is also about 4.5″ from either side and about 6.4″ from the corners. So the path lengths vary between 4.5″ to 6.4″, a ratio of 1.4 to 1.

When the tweeter is 9.0″ down from the top, it is about 10″ from the corners. So the path lengths vary between 4.5″ to 10″, a ratio of 2.2 to 1, which probably accounts for the smoother response.

I also measured the tweeter 28″ down from the top, and it is up to 1dB smoother compared to the 9.0″ mounting position. These measurements suggest that D'Appolito-type designs—which feature a midrange or midwoofer above and below a tweeter—may have a somewhat smoother response than single mid-driver designs because of the greater spread of the path lengths to the cabinet edge. However, you must take into account the additional diffraction caused by the cavity of the extra driver.

I didn't study diffraction caused by the grille frame because Joe D'Appolito regularly measures and reports on the effect in his reviews of loudspeakers. His measurements show that the typical grille frame causes 2–4dB ripples above 1kHz. "Typical" in this case means a grille frame that protrudes above the front baffle.

PHOTO 7: Test enclosure with 4″, 45° bevel shell.

PHOTO 8: Test enclosure with 2″, 45° bevel shell.

PHOTO 9: Test enclosure with 1″, 45° bevel shell.

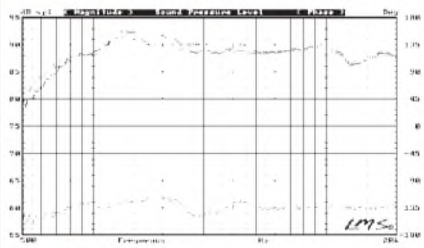

FIGURE 10: SPL of tweeter on enclosure with 4″ radius shell versus enclosure without edge treatment (solid line); difference curve raised 60dB. B-2151-10

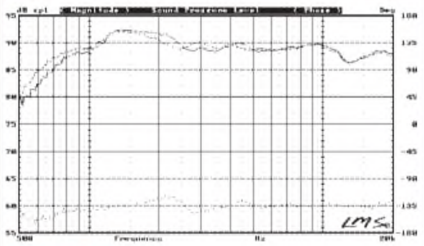

FIGURE 12: SPL of tweeter on enclosure with 1″ radius shell versus enclosure without edge treatment (solid line); difference curve raised 60dB. B-2151-12

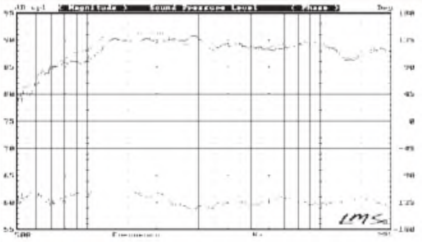

FIGURE 14: SPL of tweeter on enclosure with 4″ beveled shell versus on IEC baffle (solid, lower line); difference curve raised 60dB. B-2151-14

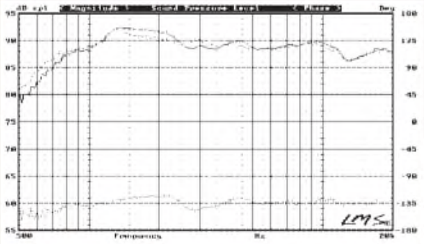

FIGURE 11: SPL of tweeter on enclosure with 2″ radius shell versus enclosure without edge treatment (solid line); difference curve raised 60dB. B-2151-11

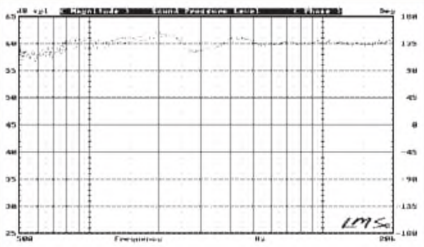

FIGURE 13: Comparison of SPL difference curve of 4″ radius (lower line) versus difference curve of 1″ radius. B-2151-13

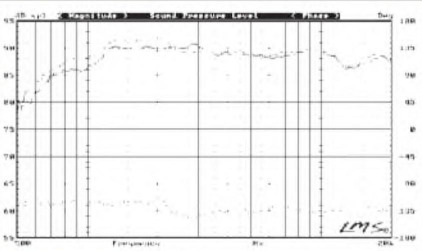

FIGURE 15: SPL of tweeter on enclosure with 2″ beveled shell versus on IEC baffle (solid, lower line); difference curve raised 60dB. B-2151-15

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EDGE RELIEF

I then attempted to reduce cabinet edge diffraction by surrounding the tweeter/midbass enclosure with some sort of edge treatment. For these tests I built "shells" with rounded-over or beveled edges. I then inserted the enclosure with the 12″ × 8⅛″ front baffle into the shell and took tweeter SPL measurements. The rounded-over shells had 4″, 2″, and 1″ radiuses; the shells were built with poster board glued to ¼″ MDF frames (*Photos 4, 5,* and *6*). The beveled shells were built to 4″, 2″, and 1″ thickness with MDF and had a 45° bevel (*Photos 7, 8,* and *9*). I built an additional shell with a dual bevel; its initial bevel was at 22° over 2″ on ¾″ MDF which was then followed by a 45° bevel on ¾″ MDF. See *Photo 10.*

PHOTO 10: Test enclosure with dual bevel, 22°, 45° shell.

To see how much diffraction the edge treatments produced or didn't produce, and what frequencies were affected, I compared their SPL measurements to the ideal response, the IEC baffle. *Figure 6* compares the SPL of the tweeter with a 4″ radius to that of the response on an IEC baffle (solid, lower line). The difference curve is referenced to 60dB. Above 2kHz the diffraction effects are plus or minus a dB or less. However, below 2kHz, diffraction effects increase the SPL output by up to 2dB.

Figure 7 shows that the 2″ radius has similar performance above 2kHz but has more output below that level. *Figure 8* shows the 1″ radius has up to 3dB more output than the IEC baffle below 2kHz. *Figure 9* compares the difference curves for the 4″ radius to the 1″ radius. They are very similar above 2kHz, but below that level the 4″ radius has 1dB less output.

These measurements show that significant levels of diffraction exist below 2kHz despite the edge treatments. However, you could project that by doubling or quadrupling the radius, diffraction could be further reduced and possibly eliminated.

Knowing that some diffraction remains compared to an ideal situation is one thing. How do the edge treatments improve the ubiquitous sharp-edged cabinet? *Figure 10* compares the SPL of the tweeter without edge treatment (top line, solid) to that with the 4″ radius. The difference curve is referenced to 60dB. The radius reduces diffraction by 2dB at 2kHz, 2dB at 2.7kHz, and 1dB at 4.5kHz. Above those frequencies the ripple is less than 0.5dB.

In *Figs. 11* and *12* you see that as the radius decreases, the humps and dips become less pronounced. This means that the smaller radius shells have more diffraction than the 4″ radius shell. *Figure 13* compares the difference curves for the 4″ radius to the 1″ radius. This shows that the 4″ radius

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has 1dB less output below 2kHz, which is consistent with *Fig. 9.*

EXAMINING BEVELS

This study could have ended at this point, but I've always liked the chiseled look of a beveled edge. Despite their looks, I guessed that the 45° bevels wouldn't work as well as the radiuses. But I thought that the dual bevel might be almost as effective as the radiuses.

PHOTO 11: Example of grille frame integrated with a stepped front baffle.

Figure 14 compares the SPL of the tweeter with a 4″ bevel to that of the response on an IEC baffle (solid, lower line). The difference curve is referenced to 60dB. Above 2kHz the diffraction effects are plus or minus a little more than a decibel or less. However, below 2.3kHz, diffraction effects increase the SPL output by more than 2dB.

Figure 15 shows the 2″ bevel to have similar performance above 2kHz but, oddly enough, a little less output below that level and a little more output below 900Hz. *Figure 16* shows the 1″ bevel has up to 3dB more output below 2kHz and a fraction of a decibel more diffraction above that by comparison. *Figure 17* shows the dual bevel to have slightly more output below 1kHz, the least output between 1–2kHz, and similar effects above 2.5kHz.

Figure 18 compares the difference curves for the 4″ bevel to the 1″ bevel. They are very similar between 1–2kHz, while the 4″ bevel has 1dB less output between 600Hz to 1000Hz. The 1″ bevel is about 0.5dB better between 2.3kHz and 6kHz.

Figure 19 compares the SPL of the tweeter on an enclosure without edge treatment (top line, solid) to that with the 4″ bevel. The difference curve is referenced to 60dB. The bevel reduces diffraction by 1dB or less at 1.8kHz, 2.7kHz, and 4.5kHz. Above those frequencies the ripple is less than 0.5dB. In *Figs. 20* and *21* you see that as the bevel decreases there isn't any apparent reduction in reducing diffraction. This means that the smaller beveled shells are about as effective as the 4″ beveled shell.

However, the dual bevel was even better at reducing diffraction (*Fig. 22*). The difference curve shows that it reduces diffraction by a little more than a dB at 1.5kHz, 2.7kHz, and 4.7kHz. *Figure 23* compares the difference curves for the dual bevel to the 2″ bevel. This shows that the dual bevel reduces diffraction by 1dB more than the 2″ bevel below 2.7kHz.

It looks as though the 45° bevel really isn't the best choice for reducing edge diffraction. The dual bevel, because it starts with a more gradual 22° slope that transitions to a 45° bevel, is definitely the best of the bevels. It is still not quite as effective as a 4″ radius, however.

CONCLUSION

This study demonstrates the effects of acoustic diffraction from several

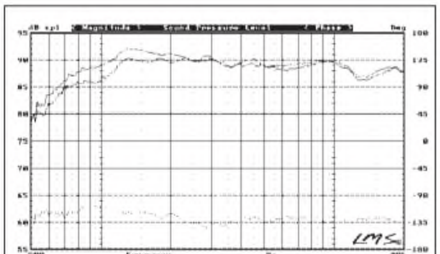

FIGURE 16: SPL of tweeter on enclosure with 1″ beveled shell versus on IEC baffle; difference curve raised 60dB.

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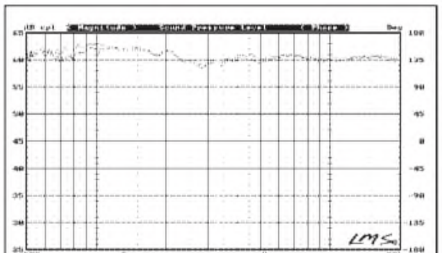

FIGURE 18: Comparison of SPL difference curve of 4″ bevel (lower line) versus difference curve of 1″ bevel.

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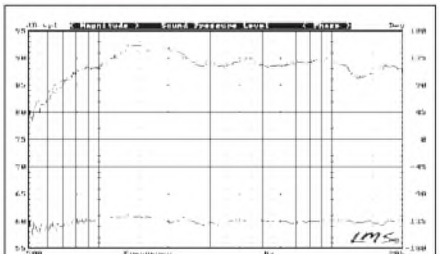

FIGURE 20: SPL of tweeter on enclosure with 2″ beveled shell versus enclosure without edge treatment; difference curve raised 60dB.

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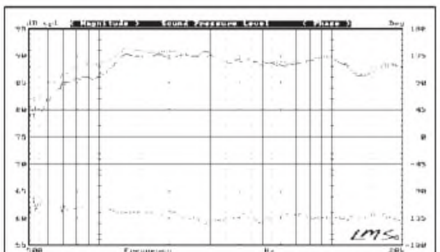

FIGURE 17: SPL of tweeter on enclosure with dual beveled shell versus on IEC baffle (solid, lower line); difference curve raised 60dB.

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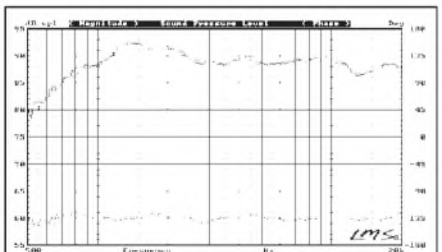

FIGURE 19: SPL of tweeter on enclosure with 4″ beveled shell versus enclosure without edge treatment (solid line); difference curve raised 60dB.

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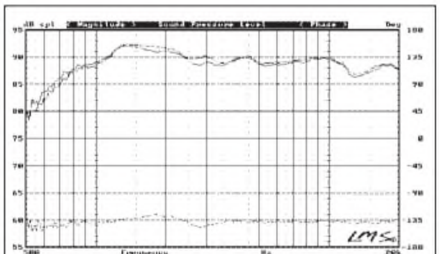

FIGURE 21: SPL of tweeter on enclosure with 1″ beveled shell versus enclosure without edge treatment (solid line); difference curve raised 60dB.

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sources. Edge diffraction from an unrecessed tweeter front plate can cause ripples in the SPL response by up to 4dB, peak to trough. Fortunately, this source of diffraction is easily eliminated by flush-mounting the tweeter.

Diffraction from the edge of the front baffle was the most persistent problem, because it caused response ripples of up to 5dB, peak to trough, between 600Hz and 5kHz. This was demonstrated by measuring a tweeter on an enclosure and comparing that to its response on an IEC baffle.

I evaluated the effectiveness of an edge treatment from two perspectives: how well it compares to an ideal response and how well it works in the real world. Compared to an IEC baffle, all of the edge treatments reduced diffraction ripple to a little over a dB above 2kHz, but below that level even a 4″ radius caused 2dB of additional output. Larger radiuses produced less diffraction than smaller radiuses but did not eliminate diffraction. 45° beveled edges were not as effective as radiuses, but a dual-bevel design was nearly as good as a 4″ radius.

The curious thing about the measurements with the edge treatments is that they don't trail off below 800Hz as in *Fig. 3*, which is the comparison of the enclosure without edge treatment to the IEC baffle. The only factor that could account for this variation is the longer path length from the tweeter to the back of the enclosure.

For example, the 4″ radius has 4.7″ more path length than the 1″ radius. But baffle size appears not to be the cause since the 4″ radius shell has less output than the 1″ shell and the 4″ radius shell is much bigger than the 1″ radius shell. Since these measurements show that diffraction causes 2–3dB of additional output from 2kHz all the way down to 500Hz—the limit of the gated measurement—and don't appear to be diminishing, these measurements imply that diffraction continues below that level.

At these frequencies the wavelengths are long enough not to cause cancellation, so all you see is a 2–3dB "step" response and no ripple. In essence, you can view diffraction as an effect that turns the entire perimeter of the cabinet front edge into a secondary sound source. This might be another reason why mini-monitors or narrow-faced

(to p. 69)

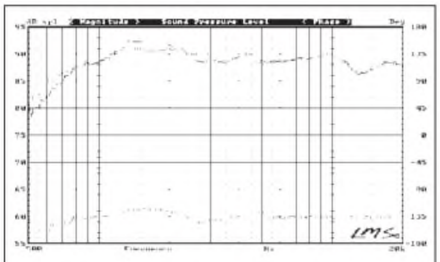

FIGURE 22: SPL of tweeter on enclosure with dual beveled shell versus enclosure without edge treatment (solid line); difference curve raised 60dB.

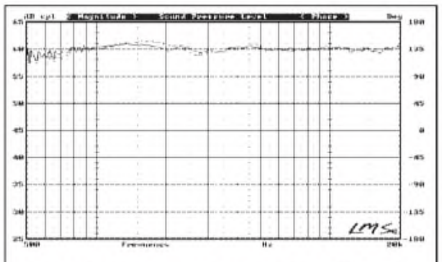

FIGURE 23: Comparison of SPL difference curve of 2″ bevel (lower line) versus difference curve of dual bevel.

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Odyssey of a Line Stage, Pt. 1

Journey with this author as he takes a simple transformer-output line stage through many experiments and choices, ending with a world-class, state-of-the-art parafeed design. **By David Davenport**

Some time ago I purchased a Lundahl LL1660/18mA transformer, intending to build a transformer output line stage. Per Lundahl provided a simple schematic diagram (*Fig. 1*), which I breadboarded. It sounded pretty good, but before I committed it to a final form, I had a couple of questions to answer.

It all started simply enough. Which was better—a voltage-regulated filament or a current-regulated filament? I had also encountered some discussions about using a fixed-bias instead of cathode-bias for a preamplifier. I had used both types on occasion in power amplifiers, but I had never before used fixed-bias in a preamplifier.

One problem I have always had with resolving these kinds of questions is comparing two conditions in similar but different situations, such as fixed-bias and cathode-bias. I could never be sure whether the differences that I heard were due to the bias mechanism or to some other, unrelated factor. Alternately, after listening to one configuration, I have modified a single amplifier and listened to a different configuration. The problem with this is the time-lapse between one listening and the next.

TEST CIRCUIT

Sometimes if a difference was gross, I could easily detect it. However, with more subtle changes I could never be sure. I needed a simple way to isolate and quickly compare two things, which I accomplished with the circuit shown in *Fig. 2*. Although there are four tube sockets shown in the schematic, in reality only one socket has a tube in it at any one time.

A good majority of the circuitry is common to all configurations, and I can compare two conditions as quickly as I can move a tube from one socket to another. In position 1, the tube was cathode-bias with a current-regulated filament. Position 2 yielded a voltage-regulated filament with cathode-bias. When a tube was in position 3, it had a current-regulated filament and fixed-bias; while position 4 provided fixed-bias with a voltage-regulated filament.

Figure 3 shows the regulators I used in all of the test beds. Early on I used a variable power supply to adjust for the slight plate voltage difference required between fixed-bias and cathode-bias. After a while, I learned that such slight voltage differences were inaudible.

LISTENING RESULTS

Results fell into three categories: little or no difference, a noticeable difference in which one option was clearly superior to another, and a noticeable difference in which I preferred one option over the other. This preference was a matter of taste, as in choosing clarity or sweetness, for example. The preferences stated here are limited to only this design and may be different in another design. Rather than go into detail for each option evaluated, I'll give you my assessment of which I preferred or thought was best. This will give you a starting point in your own designs and a comparison to your own favorite case.

Just about the time I finished this prototype, the Piedmont Audio Society had a meeting featuring preamplifiers that members had built. Although my prototype was a rat's nest of wires and not the best-sounding unit there, members found the experiment very interesting. The general consensus was that current-regulated filaments sounded better than voltage-regulated filaments, and cathode-bias was preferred over fixed-bias.

While the meeting answered a couple of questions, the members brought up many more: Have you tried such-and-such a tube, or parafeed, or Ultrapath? Someone asked how the regulated filament compared with old-fashioned unregulated AC filament. I had not thought of this; I had just assumed that any regulated DC was superior to unregulated AC.

While I had no intention of opening Pandora's box and spending a lifetime researching options, some of the questions piqued my curiosity and there

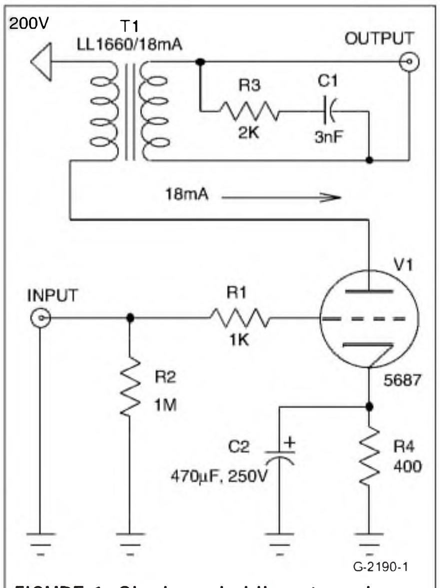

FIGURE 1: Single-ended line stage. Lundahl provided this design, using the LL1660/18mA transformer.

ABOUT THE AUTHOR

David Davenport has been involved in audio DIY for over 40 years. After retiring as an engineer with IBM for 30 years he has founded his own company, Raleigh Audio, dedicated to exploring the limits of audio electronics and providing the results to OEMs and serious hobbyists. Although this is his first article for *audioXpress*, he has written many articles for the former Audio Amateur publications, *TAA*, *GA*, and *SB*.

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were a few of my own questions unanswered. I wanted to experiment with the RC network on the output of the transformer, and I wanted to listen to the effect of increasing the output impedance of the driver tube.

DETERMINING THE NETWORK

The purpose of the RC network on the secondary of the transformer is to tame a peak in the frequency response of the LL1660 at around 80kHz. You can see the result of this peak on an oscilloscope as an overshoot or ringing on the leading edge of a 1kHz square wave. The peak, which is caused by leakage inductance and distributed capacitance, is common in transformers.

Design of the RC network is empirical, accomplished by substituting different values of resistance and capacitance while watching the resultant square wave on a scope. The objective is to find the largest value of resistance and the smallest value of capacitance that produces the best-looking square wave. The problem is you don't listen to square waves, and the best-looking square wave doesn't necessarily correlate to the best-sounding music.

So my process for determining the network is to start with the square wave to get in the ballpark and then listen to music while adjusting the RC values. I found that I preferred a 2kΩ resistor and no capacitor at all. Adding a load on the secondary of a transformer will decrease the level of the signal, but since there is more than enough gain in the circuit, this is not a problem.

A comment on the Lundahl data sheet recommends that the LL1660 be driven by a source impedance of 3kΩ and that using a lower source impedance will result in peaking, which may be reduced by adding a secondary load as I just mentioned. The impedance of the 5687 triode is a little low, weighing about 2100Ω. I reasoned that if I increased that resistance by adding an un-bypassed cathode resistor, perhaps I could eliminate the need for any kind of network on the output.

Well, I am not sure why, but this idea did not work out—either on the scope or in the sound. I needed a very large value resistor—much larger than calculated—to get any effect at all, so I abandoned this option.

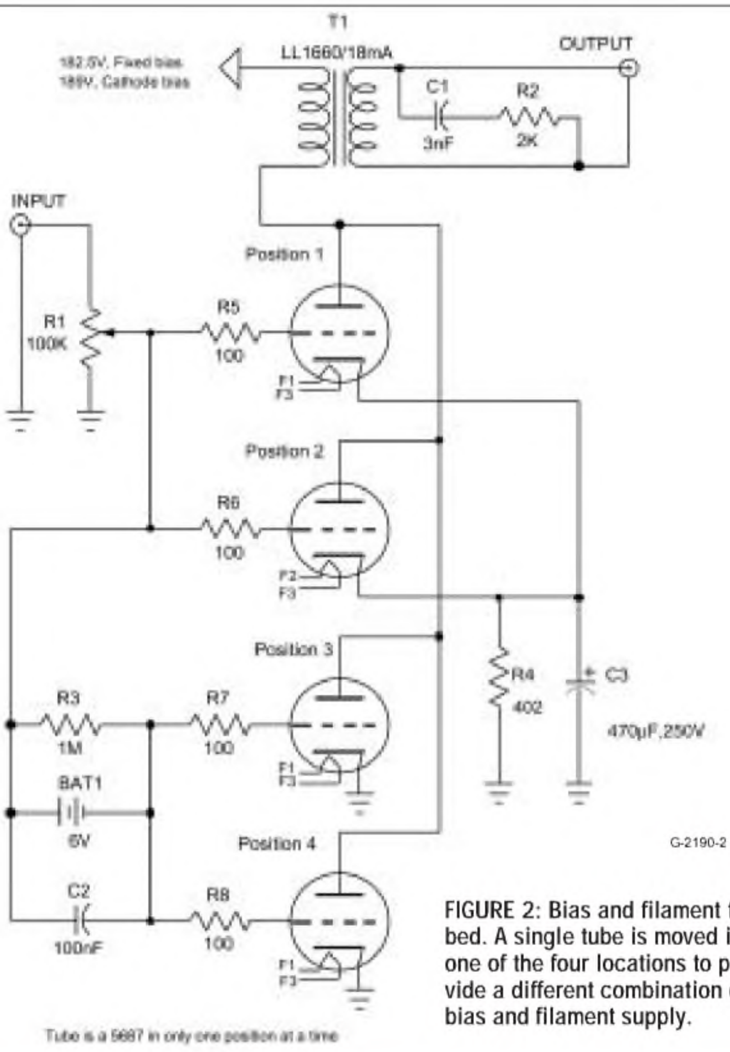

FIGURE 2: Bias and filament test bed. A single tube is moved into one of the four locations to provide a different combination of bias and filament supply.

MODIFICATION

I compared a regulated DC filament with an unregulated AC filament and was surprised by what I found. The sound of the unregulated AC filament was only subtly different from the sound of the current-regulated DC filament, and both were superior to the voltage-regulated DC filament. In the final package for the line stage, I have decided to build the power supply and preamplifier in a separate chassis. I do

THE CATHODE CONNECTION

Jack Elliano coined the term "Ultrapath" for his cathode-coupled transformer design that he introduced to the audio community in *Vacuum Tube Valley*, issue 10. In that design the signal is shunted from the top of the transformer through a capacitor directly to the cathode of the driver rather than passing through the power supply, as is the usual case.

Lynn Olson took up the gauntlet in his excellent article "Ultrapath, Parallel Feed and Western Electric" in *Vacuum Tube Valley*, issue 16. In this article he described eight circuits for single-ended and push-pull amplifiers and called the cathode-coupled parallel-feed version "Ultra Parafeed." In another article, "Western Electric, A Rosetta Stone for Triodes," at http://www.aloha-audio.com/library/Rosetta_Stone.html, Lynn traces the origins of cathode-coupled transformers to the very early days at Western Electric and suggests that perhaps the term "Western Electric coupling" would be appropriate for the cathode-coupled parallel feed configuration, giving credit to the engineers who first implemented it.

Another good reference for both parallel-feed and cathode-coupled circuits is Paul Joppa's article, "Twelve Ways to Parafeed," in *VALVE*, volume 6, number 5. This article covers the gamut and describes every possible way to configure a parallel-feed circuit, including cathode-coupled.

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not want to bring AC voltage through the umbilical cable, so I will use a direct current-regulator for the filament.

Were I to integrate everything into a single chassis, I would have no problem using an AC filament. The current-regulated filament supply does have one other advantage. It protects the filament from over-current at startup, which can prolong the life of the filament.

CATHODE-COUPLED CONFIGURATION

In a cathode-coupled configuration, the signal from the top of the transformer is returned directly to the cathode of the driver tube rather than through the power supply to ground and then through the bypassed cathode resistor (see Cathode Connection sidebar). I believe that keeping the audio signal out of the power supply is most important in a good-sounding amplifier, so I was ready to try out the cathode-coupled configuration.

Figure 4 shows my modification to the prototype for this test. I added a 400Ω resistor and 22µF capacitor that may be used either as an additional filter stage for the power supply or a cathode-coupled feed. When the capacitor is switched to cathode coupled, the cathode bypass capacitor is shorted because it is not needed since no signal flows through the cathode resistor. In one view, the fixed-bias configuration is always cathode-coupled because there is no cathode resistor.

I threw the switch to the cathode-coupled position anticipating beautiful music, and, boy, was I disappointed. Instead of beautiful music, I heard a moderately loud hum. It took some probing and a lot of head scratching, but in retrospect it is clear what happened. As well as returning the signal to the cathode, the capacitor feeds whatever noise is on the power rail directly into the cathode. The solution is to retain the cathode bypass capacitor.

With the cathode bypass capacitor in place, everything worked as I expected. The effect was not earthshaking, nor was it subtle. Rather, it was a noticeable and positive effect that I recommend to anyone building a traditional transformer output preamplifier. Since the cathode-coupled capacitor is in the signal path, it should be of high quality. In the past I had tried poor-quality elec-

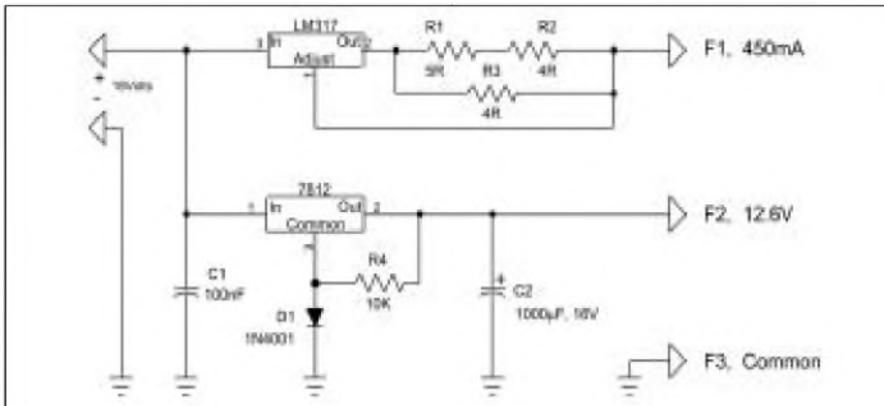

FIGURE 3: Voltage regulator and current regulator for test beds. G-2190-3

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ECC88	5.70	EL509/519	13.00	6336A	48.00	Ditto, Gold Pl.	3.00
ECF82	5.50	E84L/7189	7.50	6550WA/WB	15.00	Octal (Ch or PCB)	1.80
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ECL86	6.30	KT66R	22.50	807	10.70	UX4 (4-Pin)	3.60
EF86	6.00	KT77	13.20	811A	11.80	Ditto, Gold Pl.	5.50
E80F Gold Pin	11.00	KT88	13.50	812A	31.00	4 Pin Jumbo	10.00
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E82CC Gold	9.00	KT88 (GL Type)	30.00	RECTIFIERS		5 Pin (For 807)	3.30
E83CC Gold	8.50	PL509/519	9.90	EZ80	5.10	7 Pin (For 6C33C)	4.70
E88CC Gold	8.80	2A3 (4 pin)	15.50	EZ81	6.00	9 Pin (For EL509)	5.00
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trolytic capacitors in the signal path and always regretted it. In this case, I used a Black Gate.

Kevin Carter from K&K Audio, the Lundahl US distributor, told me that he knew a couple people who had used parallel triode sections of a 12AU7 to drive the LL1660 in a line stage. I decided to try it, so I re-wired half of the sockets on the prototype to accept the 12AU7 for this experiment. I'm sorry, but the parallel 12AU7 was a clear loser—it lacked life and dynamics when compared to the 5687.

Since it was time to listen to different tubes, I auditioned a couple of 5687s and a 7119, which all fell into the category of taste preference; I could have lived with any of them, but in the final ballot I chose the Tung Sol NOS military 5687. I know that there are other tubes that I could have listened to, and later in the project I auditioned the ECC99 and 6H30. These are not all direct replacements for the 5687; you need to check the pin assignment and filament current on these tubes.

Things were shaping up nicely: the sound of this line stage, while not the ultimate, could hold its own against most of the competition. I recommend the design shown in *Fig. 5* to anyone who wants to build a traditional single-ended line stage. The parts list is in *Table 1*. In my estimation its sound is clearly superior to any non-transformer-output line stage.

TABLE 1
PARTS LIST

PART	DESCRIPTION	SOURCE
RESISTORS		
R1	100k DACT	Aloha Audio
R2	100Ω ¼W non-inductive	Mouser 30BJ250-100
R3, R5	402Ω Caddock MK-132	Michael Percy
R4	2kΩ Caddock MK-132	Michael Percy
R6	3Ω 3W	Mouser 283-3
R7	39Ω ¼W	Mouser 271-39
CAPACITORS		
C1	22µF 350V Black Gate VK	Michael Percy
C2	470µF 16V Black Gate FK	Michael Percy
MISCELLANEOUS		
T1	Transformer, Lundahl LL1660/18mA	K&K Audio
V1	Tung-Sol 5687	ATSI Electronics
	LM317T	Digi-Key LM317T-ND

Note:
LL1660/18mA connected as per "alternative Q" of the Lundahl data sheet.

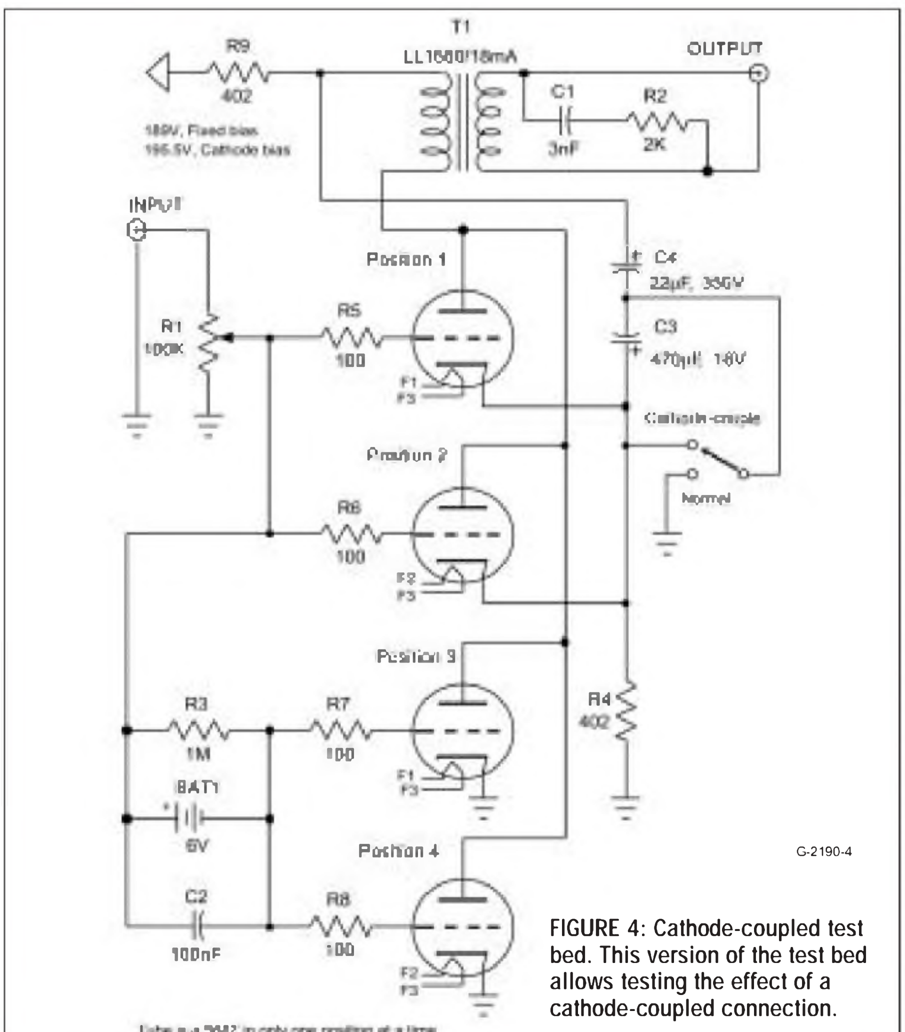

FIGURE 4: Cathode-coupled test bed. This version of the test bed allows testing the effect of a cathode-coupled connection.

SOURCES

Aloha Audio
http://www.aloha-audio.com/

ATSI Electronics
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Lake Worth, FL 33467
561-434-3799
FAX 509-696-7736
info@tubeman.com
www.tubeman.com

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Kevin Carter has what could be thought of as a balanced version of this line stage in his system. It uses the LL1660 PP transformer driven by a pair of 5687s. This balanced version sounds somewhat better than the single-ended version, although the character of the sound is the same.

Fernando Rodriguez had brought his Lynn Olson designed Raven line stage to the listening meeting, and in my book this was "best in show." The Raven is a balanced parafeed transformer output design. I speculate that what makes the balanced line stage—and particularly the balanced parafeed line stage—so good is the separation of signal from power. You can read all about the Raven at http://www.aloha-audio.com/triode1.html. ❖

[The author continues experimenting with this design next month in Part 2.—Eds.]

AUTHOR'S NOTE
In this article I have simply used the term "cathode-coupled" for circuits where the transformer is returned to the cathode of the driver.

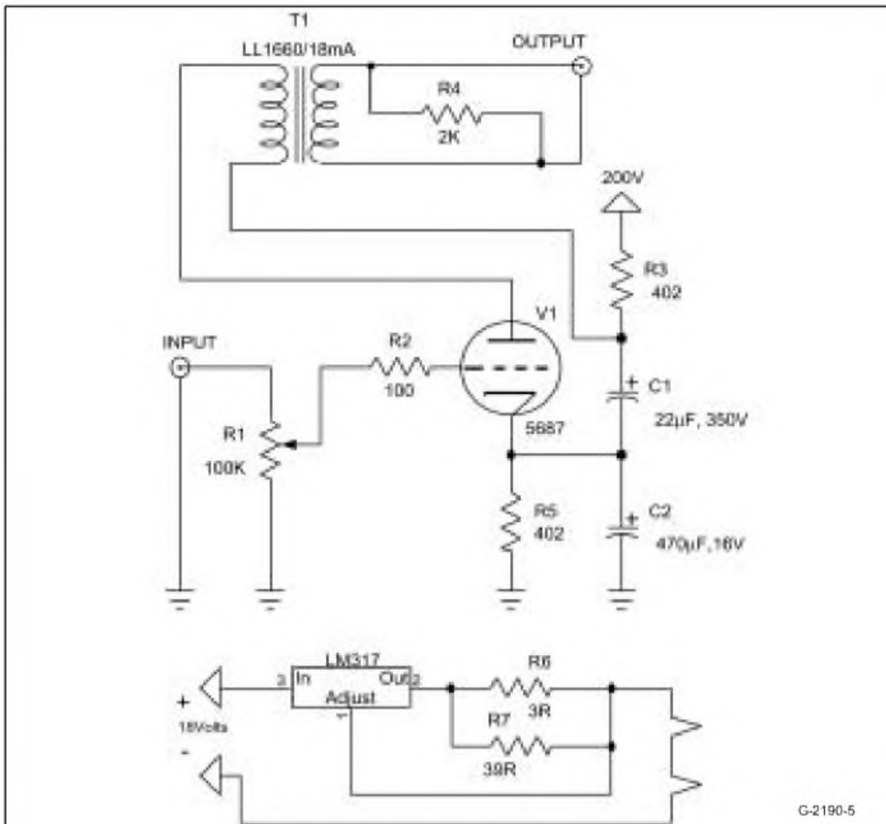
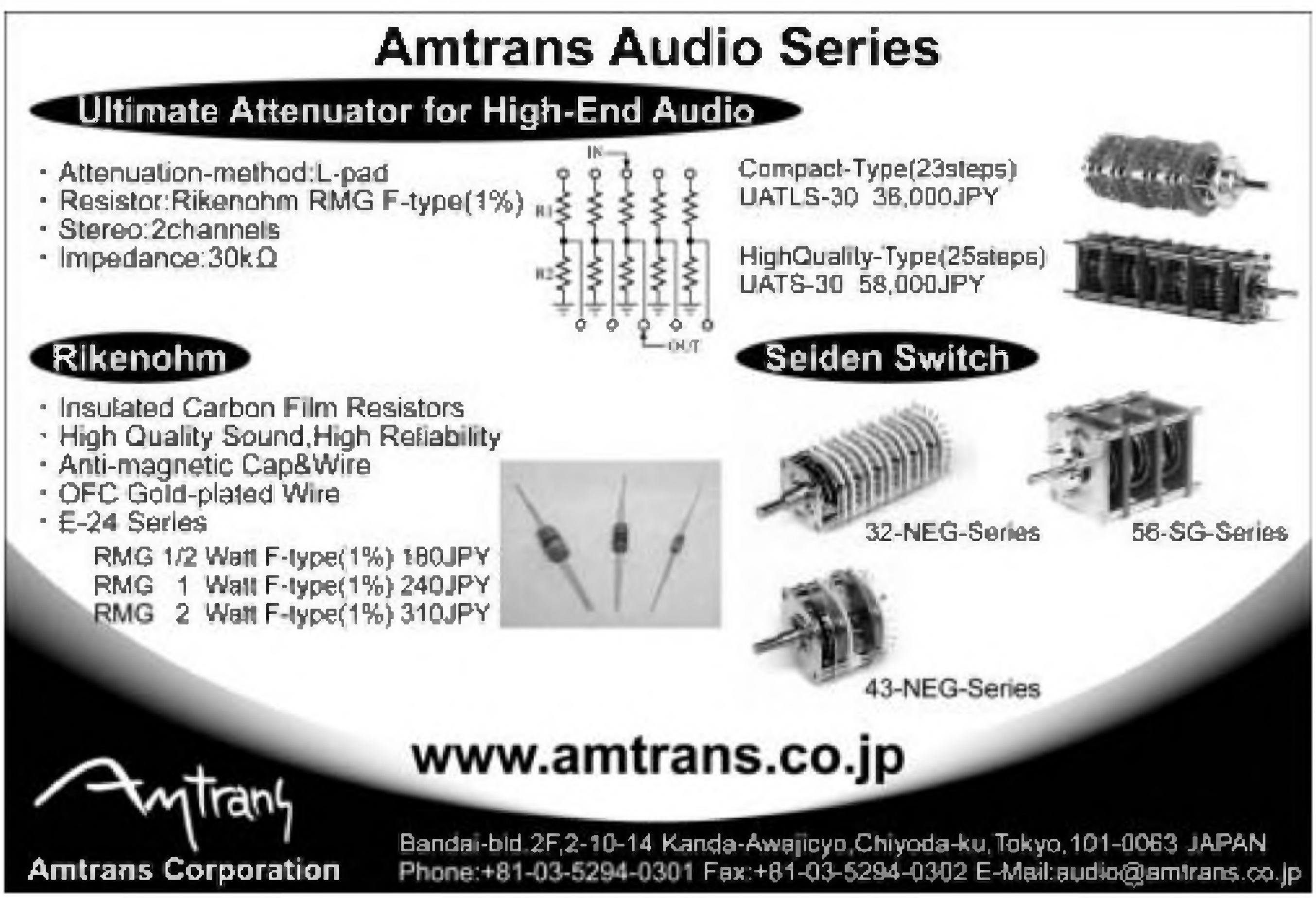


FIGURE 5: Single-ended line stage. This very good traditional transformer-output line stage came as a result of testing several options.



Upgrade Rotel's 970BX CD Player

Here is a low-cost (about $10) improvement for the Rotel RCD 970BX Compact Disk Player, in the POOGE (Progressive Optimization Of Generic Equipment) tradition. **By Charles Hansen**

The Rotel RCD 970BX CD Player (circa 1996) uses the Philips TDA1305 single-ended Continuous Calibration stereo DAC, with an AD711J as the current-to-voltage (I-V) converter. The basic analog output stage is shown in *Fig. 1*.

INSIDE THE ROTEL

Photo 1 shows the DAC/analog board. The components used here are quite good. The 1nF caps are 2% polystyrene types, and the 100µF aluminum output coupling cap (needed because of the single-ended DAC topology, which introduces a DC offset voltage) is a Rubycon Black Gate. All the resistors are 1% metal films.

The power supply is also decent. The DAC/analog board has its own TO-220 regulator ICs with Nichicon Muse or Rubycon Black Gate aluminum filter caps, bypassed with film or ceramic caps. The rectifier diodes are shunted with 10nF snubber caps. The board has two ground planes—one each for the analog and digital circuits. The crystal-controlled clock is right by the DAC chip, and its output is buffered and reclocked back to the digital board for low jitter. The DAC is a surface-mount part on the back of the PC board.

All the ICs have multiple decoupling caps: large aluminums, tantalums, and ceramics. There are none of those nasty series resistors between the +5V DC and the digital chips.

The Analog Devices AD711 was a fine op amp in the early '90s, but better devices designed specifically for audio are now available. Rotel and other CD manufacturers use the Burr-Brown OPA604 or OPA2604 in their newer CD players (and newer DACs as well). So this is the op amp I chose for my modification. The revised circuit is shown in *Fig. 2*.

In addition, I decided to bypass the 100µF output coupling cap with the largest polypropylene (MPP) cap I could fit in between the other components. *Table 1* lists the modification parts, and *Photo 2* shows the parts themselves.

CONSTRUCTION

Removing the DAC/analog board was fairly easy. The ground side of the dual gold phono jack assembly is soldered to a metal shield that runs across the rear of the chassis, so care was needed not to melt the plastic jack body. Then I unplugged the two connectors and removed the five screws holding the PC board in the chassis.

Now, with solder wick and a solder-sucker, I removed the two AD711 op amps intact. The new 470nF caps will just fit between the muting relay and the 100µF coupling caps. I removed the end of the 100Ω and 4k70 resistors that connect to the 100µF cap tracks, and drilled out their holes to 1⁄16″ so I could fit the resistor leads and the MPP cap leads back into the enlarged PC board holes. The edges of the larger holes came very close to the ground plane

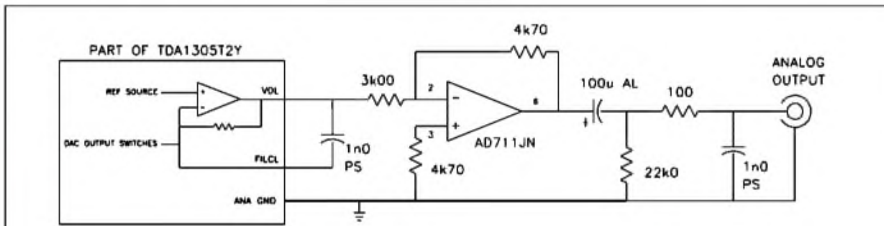


FIGURE 1: RCD 970BX analog output stage. A-2126-1

PHOTO 1: Rotel RCD 970BX DAC/analog board.

copper on the top surface, so I needed to be careful not to short the leads to ground when I soldered them. *Photo 3* shows the board with the op amps removed and one end of each resistor removed, and the holes drilled out to 1/16″.

Next I installed two Garry Electronics/WPI 8-pin low-profile solder-tail gold DIP sockets. This may allow me to take advantage of the next generation of audio op amps. The Garry sockets are not cheap, and are available in large quantities from Arrow Electronics and Allied. DigiKey carries a line of less expensive sockets from Mill-Max and Aries. Just make sure you get the best quality low-profile gold socket. You can also solder the OPA604s directly in the PC board if you are not a tweaker like me.

One lead of the MPP cap drops right into the hole for the 4k70 resistor. I insulated the other lead with some sleeving and routed it past the other components into the hole for the 100Ω resistor lead, as you can see in *Photo 4*.

With the modification done, I cleaned the flux off the PC board and checked for solder shorts. Finally, I plugged in the two OPA604s, reinstalled the board, soldered the output jack grounds to the shield, and plugged the wiring harnesses back in. *Photo 5* shows the completed modification.

DIGITAL OUTPUT JACK

Like many CD players, the Rotel has an RCA phono S/PDIF digital output jack. I wanted to replace this with a BNC RF jack. However, once I had the chassis open, I could see three significant roadblocks:

- The CD drive/digital board was in the bottom of the chassis under the drive mechanism and toroidal power transformer, requiring almost complete disassembly of the CD player.
- The 75Ω matching transformer was right up against the digital output jack, and covered with an elastic glop. Removing the jack and this conformal coating might damage the windings in the transformer.
- The RCA jack was mounted directly on the digital board, and the connection spacings were different from any

TABLE 1
REPLACEMENT PARTS LIST

VALUE, DESCRIPTION (TWO EACH)	VENDOR P/N
OPA604AP audio op amp	DigiKey OPA604AP-ND
470nF 50V 2% Panasonic P-series MPP cap	DigiKey P3474-ND
Low-profile gold 8-pin IC DIP socket	Garry Electronics (see text)

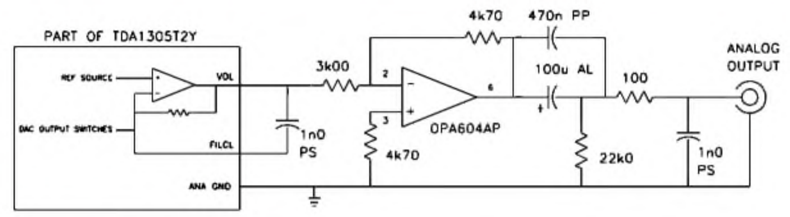


FIGURE 2: Modified analog output stage.

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5Y3GT	6J5	15CW5	5749/6BA6W
6AJ8	6J7	17JZ8	5814A
6AL5	6JZ8	30AE3	5881
6AQ5	6K7	33GY7A	5965
6AU6	6SA7	35W4	6146A/B
6AX5GT	6SG7	38HE7	6350
6BA6	6SJ7	50C5	6463
6BE6	6SK7	6267	
6BH6	6SN7GTB	6973	
6BL8	6SQ7	7025A	
6CA4	6U8A	7189A	
6CA7	6X4	7581A	
6CG3	6X5GT	KT88	
6CX8	6X8	2D21/EN91	
6CW5	12AT7	85A2/0G3	
6DL5	12AU6	108C1/0B2	
6DQ6B	12AU7	150C4/0A2	
6DR7	12AV6	572B	
6DX8	12AV7	805	
6EA8	12AX7A	807	
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of the BNC jacks I could find in my parts catalogs.

LISTENING TESTS

I replaced the cover, fired up the CD player, and found all was well. The highs were now clear and free of the barely perceptible edge the RCD 970BX originally had. However, the lows were a bit muddy, and the mid-range was withdrawn compared to the original unit. In addition, the sound stage and imaging were not what they had been. It sounded more like the newly-purchased Rotel of 1996.

I switched the control preamp off, put on Special Burn-in track 20 of Stereophile Test CD-3 (STPH 006-2) and put the player in Repeat mode for several hours. Next, I put *Hi-Fi News & Record Review* Test Disk III on, and ran the entire disk in Repeat mode for a few more hours. Both CDs are available from Old Colony Sound Lab (PO Box 876, Peterborough, NH 03458, 603-924-9464, FAX 603-924-9467, e-mail custserv@audioXpress.com).

When this burn-in was finished, the Rotel's sound quality was much improved. I selected the standard *audioXpress* audition tracks from the *HFN&RR* disk. While I don't think this is the best recording for large choral music, the massed voices in "Jerusalem"/Parry were somewhat clearer and more distinct, with good imaging and a wide soundstage.

The brasses and strings in Vivaldi's Trumpet Concerto were clear and bright, with no dissonant overtones. The harpsichord in Vivaldi and "Welcome, Welcome"/Purcell came through the orchestra with a bit better detail than before the modification. After burn-in, the bass in the Rio Napo track

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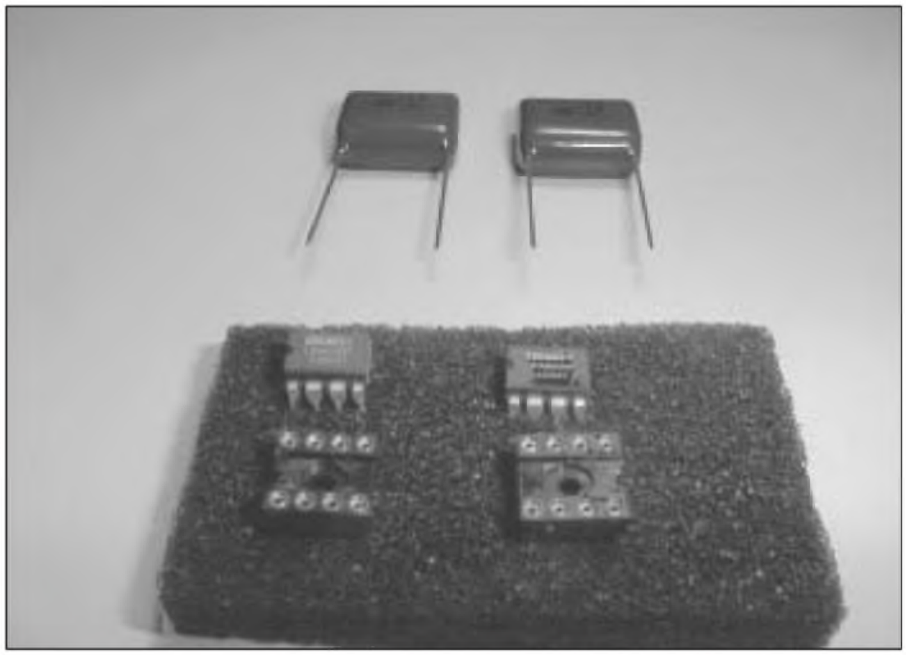

PHOTO 2: Replacement components.

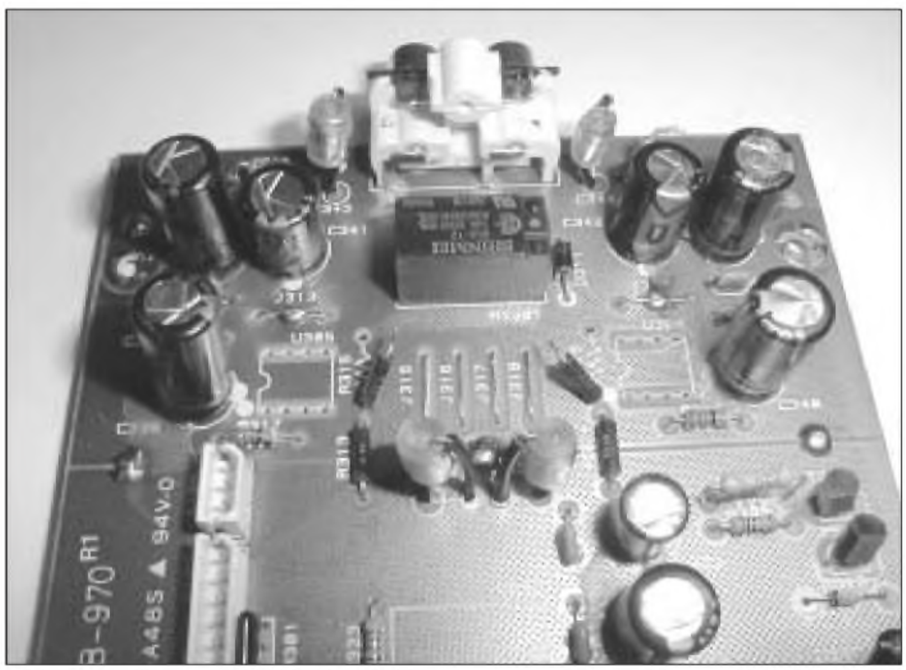

PHOTO 3: Board with ICs removed and resistors lifted.

TABLE 2
MEASURED PERFORMANCE

PARAMETER	RCD 970BX SPECIFICATIONS	UNMODIFIED	OPA604 MOD
Frequency Response:	20Hz–20kHz ±0.05dB	17Hz–20kHz +1.51dB	17Hz–20kHz +0.49dB
Channel Balance:	±0.5dB	±0.25dB	±0.25dB
Total Harmonic Distortion:	0.0025% (1kHz)	0.019% (see text)	0.019% (see text)
IMD-CCIF (19+20kHz):	0.0025% (see text)	0.012% (see text)	0.008%
Output Level:	2V RMS	2.36V RMS 1kHz	2.36V RMS 1kHz
Output Impedance:	200Ω	157Ω 1kHz, 180Ω 17Hz	150Ω 1kHz, 180Ω 17Hz
Signal to Noise Ratio:	>105dB		
Channel Separation:	>100dB (1kHz)		

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was now solid with the excellent bass extension the Rotel originally had.

I played many other CDs and found sonic improvement throughout the musical spectrum. I was especially happy with the lack of high frequency "edge" or jangle in the triangles, glockenspiels, and cymbals.

Vocal sibilants in some pop music CDs no longer had a buzzy nature. I built a switch into my preamp with a passive R-C circuit to roll off the highs a bit for those CDs that had this characteristic. But with the OPA604 and the MPP cap, the need for this switch seems to have disappeared.

MEASUREMENTS

After the listening tests, I performed tests using the CBS Labs CD-1 and Pierre Verany test CDs (both available from Old Colony Sound Lab). A comparison of the Rotel specs with the before and after measured performance is shown in *Table 2*.

The output impedance at 1kHz dropped from 157Ω to 150Ω, while the 17Hz output impedance remained at 180Ω. Channel balance was better than 0.25dB. The output had normal polarity, a positive-going pulse producing a positive-going analog output. Crosstalk between channels to 16kHz remained excellent and below the noise floor of my test equipment.

The 0dBFS output was still 2.36V RMS at 1kHz, or 1.44dB higher than the CD Red Book standard of 2V RMS. The original frequency response for the

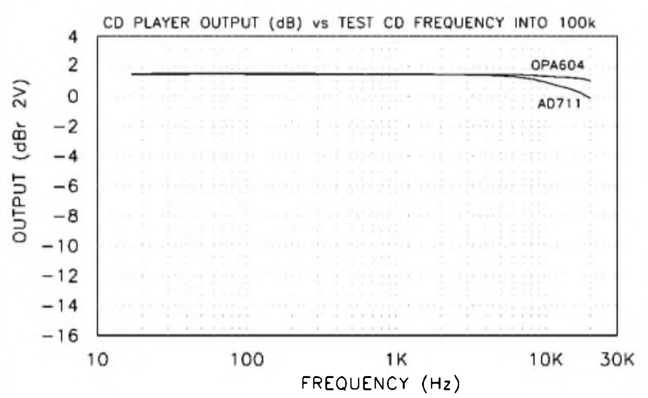

FIGURE 3: Frequency response.

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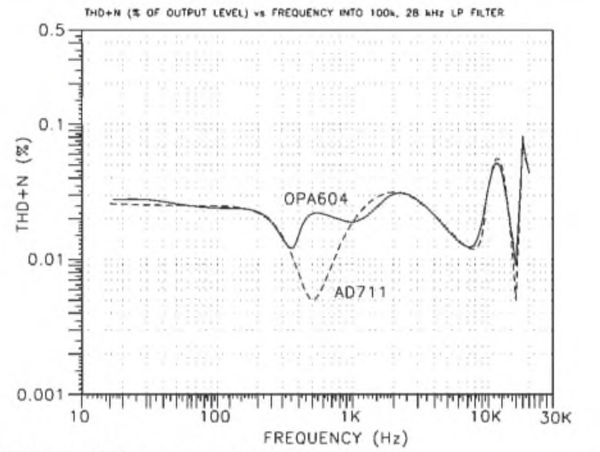

FIGURE 4: THD+N versus frequency.

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RCD 970BX (*Fig. 3*) varied from +1.51dB at 127Hz to –0.2dB at 20kHz. With the modification, the high-end response was flatter, with +1.02dB at 20kHz.

THD+N versus frequency is shown in *Fig. 4*. Normal practice when testing devices with digital-analog converter outputs is to engage a 22kHz 6-pole low-pass filter to remove out-of-band noise. My HP-339A distortion test set has two 3-pole LP filters, at 80kHz and 30kHz. By engaging both filters, the combined effect is a slightly better than 3-pole LP filter at 28kHz.

As such, my THD+N readings will be somewhat higher than if they were measured with the specified LP 6-pole filter at half the 44.1kHz digital sampling rate. THD+N was similar to the original unit, except in the 300Hz–900Hz region, but higher than the Rotel specified 0.0025%, due to the test set LP filter limitation. The residual distortion signal consisted mainly of the second harmonic modulating the 44.1kHz sample frequency. The variations in THD above 2kHz are the result of noise, spuriae, and distortion cross-products with the 44.1kHz sampling frequency, and are not unusual in digital equipment.

The spectrum of a 50Hz sine wave at 0dBFS played through the original RCD 970BX is shown in *Fig. 5*, from DC to 1.3kHz. The calculated THD+N was 0.012%, with the second harmonic at –72dB and the third at –74dB. With the other non-harmonic signals, including two mystery spikes at 570Hz and 670Hz, the measured THD+N was 0.024%. There are no AC power line harmonics evident in the spectrum.

After the modification, the calculated

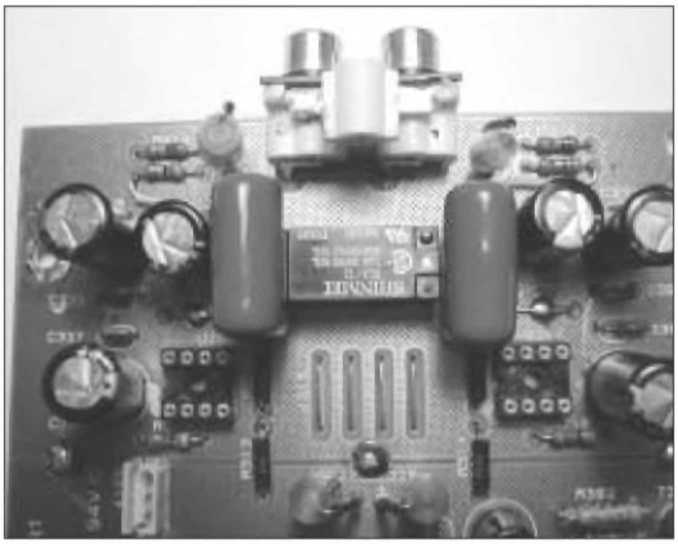

PHOTO 4: Detail of MPP capacitor installation.

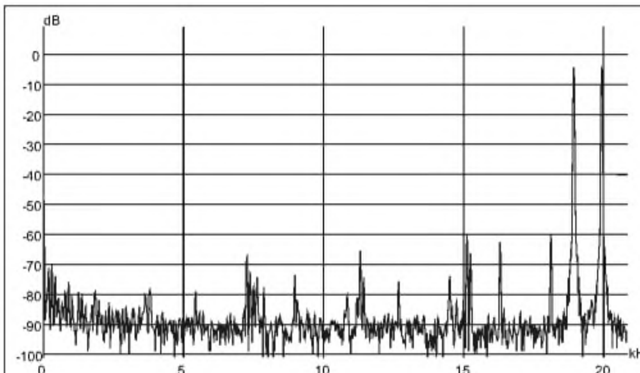

FIGURE 7: Intermodulation distortion, 19 + 20kHz 0dBfs (AD711). A-2126-7

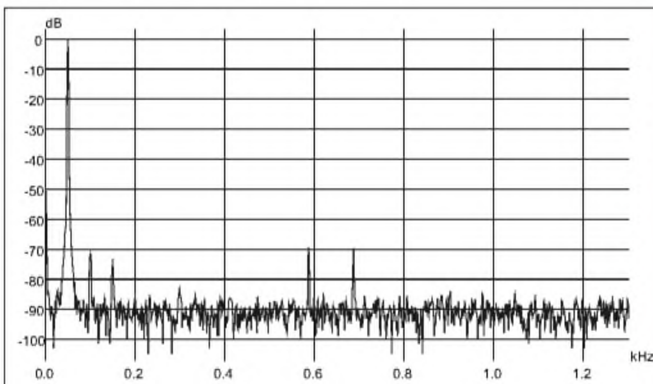

FIGURE 5: Spectrum of 50Hz sine wave (AD711). A-2126-5

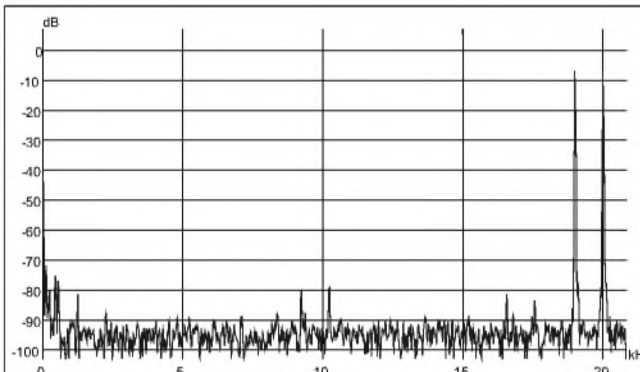

FIGURE 8: Intermodulation distortion, 19 + 20kHz 0dBfs (OPA604). A-2126-8

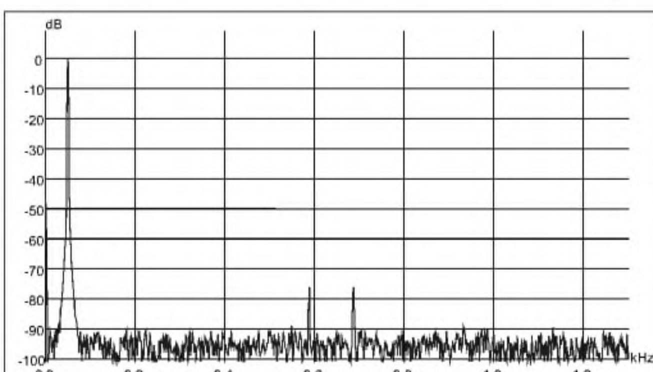

FIGURE 6: Spectrum of 50Hz sine wave (OPA604). A-2126-6

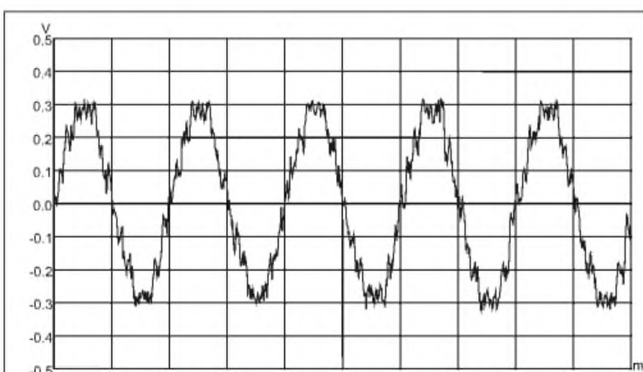

FIGURE 9: Undithered 1kHz sine wave at –90.31 dBFS. A-2126-9

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THD+N dropped to 0.0035%, with no significant harmonics above –93dB and only extremely low-level noise artifacts (*Fig. 6*). The non-harmonic signals and the two mystery spikes help produce a THD+N that still measures 0.024%. Interestingly, when I changed the sine wave frequency to 61Hz, and then 100Hz, these two spikes disappeared.

Figure 7 shows the spectrum of response to equal level 19kHz and 20kHz signals, each at –6dBFS, from DC to 20.8kHz. The 1kHz intermodulation difference product measured in the original (AD711) unit measured 0.012%, while the IMD in the modified unit (*Fig. 8*) was 0.008%, about the lower limit of my measurement capability. In addition, the IMD spectrum is cleaner with the OPA604 and the MPP cap.

Figure 9 shows the reproduction of an undithered 1kHz sine wave at –90.31 dBFS, which is essentially identical before and after modifications. At this level the signal consists of ±1 bit of data, producing two different voltage levels that are symmetrical about the horizontal axis (time). These discrete voltage steps are not obvious, probably due to out-of-band high frequency noise. ❖

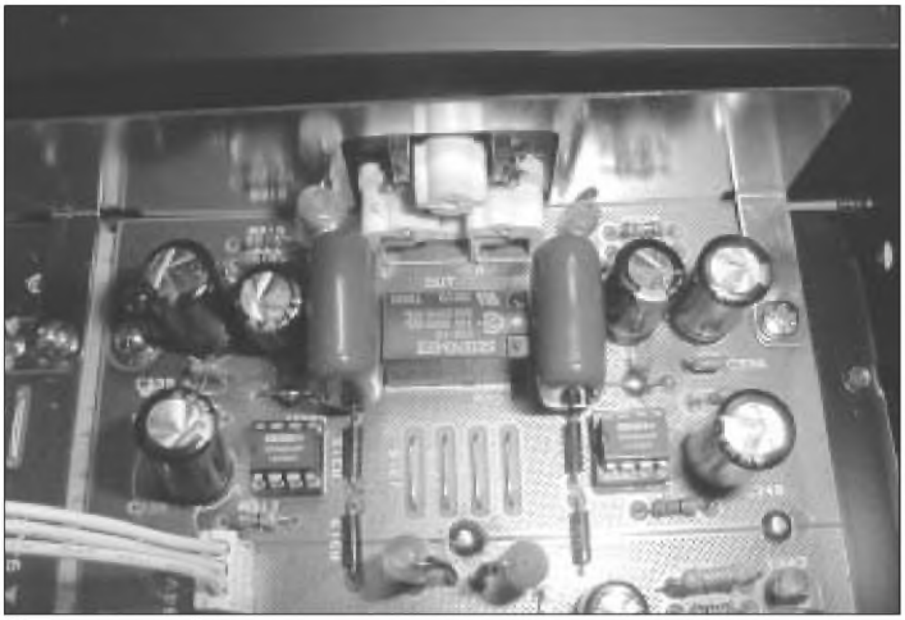

PHOTO 5: Modified board reinstalled in chassis.

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JJ Electronics' ECC99: A New Power Triode Driver

Here's a good candidate for you to consider for your future tube-amp designs. **By Hans Bubeck**

PHOTO 1: JJ Electronics' ECC99.

JJ Electronics, Slowenia, has introduced the double triode ECC99, specifically as a driver tube for such power triodes as the 2A3 and W300B. The ECC99 offers a high forward conductance (G_M) of 9.5mA/V, a low plate resistance (Rp) of 2.3kΩ, and a maximum power capability of 5W per system (*Tables 1* and *2*, datasheets). These values should drive power triodes.

The ECC99 fits in a noval socket, and the pinout is the same as for the 12AT7/ECC81 family. This article discusses the test results I obtained in comparing the ECC99 with other popular driver tubes, such as the 5687 and 7119/E182CC. The key parameter I tested was the total harmonic distortion (THD) in relation to the anode voltage swing capability. I also tested the tubes in driving a push-pull triode power stage. Here I used the VV30 from AVVT, a tube that is similar to the W300B (*Photo 1*).

TEST CIRCUIT AND BIAS

To make testing simple, I designed a test board consisting of a preamplifier and phase-splitter stage (12AX7/ECC83), with the driver stage in the standard amplifier configuration, and the power stage in push-pull configuration (*Fig. 1*). Obviously, a driver circuit in a cathode-follower configuration may give better results in driving power triodes; however, I just wanted to compare the tubes and not to optimize the whole amplifier.

With a 360V supply, I chose the plate resistor of 15kΩ and set the plate current at 12mA per system. Consequently, the plate voltage was 180V. This setup should allow for a sufficient plate voltage swing. To get these conditions for all tested tubes, I generated the appropriate grid voltage with a common cathode resistor of 220Ω for the ECC99, 330Ω for the 5687, and 250Ω for the 7119/E182CC.

I tested two tubes per part number: The WA5687 came from Sylvania (Syl) and Tung-Sol (Tung); the 7119/E182CC from Valvo (V) and Philips (P).

RESULTS

In comparing the basic parameters given in *Table 1*, it is clear that all three triodes are indeed very similar. The high G_M and low Rp of the 7119/E182CC is stated at a fairly high plate current and will be closer to the other tubes at an equal plate current level.

Amplification (v) at Ia = 2mA, Ra = 15kΩ

According to *Table 2*, the 7119/E182CC had the highest amplification of 19, as you'd expect from *Table 1*. The ECC99 was very close however; while the 5687 was noticeably lower at around 14. The matching for all tube systems was better than 2%, except for the Philips 7119/E182CC.

ABOUT THE AUTHOR

Hans Bubeck graduated from the State College of electronic engineering and communications at Esslingen/Germany in 1967. He spent most of his professional time with Hewlett-Packard in marketing and selling electronic components in Europe. He is married and has two daughters. In his spare time he likes to go fishing, play tennis, and collect antique radios. Hans is an enthusiast in building his own hi-fi tube amplifiers for listening to his jazz collection. You can visit these projects at his homepage, www.ampdesign.de. For further discussions on this report, you can e-mail Hans at hans_bubeck@t-online.de.

THD MEASUREMENTS

I measured THD by connecting the AC signal source (1kHz) directly to the grids and obtaining the THD with a distortion meter at the plates. The graph (*Fig. 2*) shows the THD (%) in relation to the amplified peak-to-peak AC plate voltage. At the given bias, both ECC99s

TABLE 1

DATASHEET	G_M mA/V	Rp kΩ	v	aT Ia mA
ECC99	9.5	2.3	22	18
5687	8.25	2.1	17	21
7119/E182CC	15	1.6	24	36

TABLE 2

TUBE	V_1	V_2	DELTA (%)
ECC99-A	17.35	17.5	0.85
ECC99-B	17.8	18.1	1.7
E182CC-V	19	18.65	1.8
E182CC-P	19.5	19.0	2.5
5687-Syl	14.5	14.7	1.4
5687-Tung	13.9	13.7	1.4

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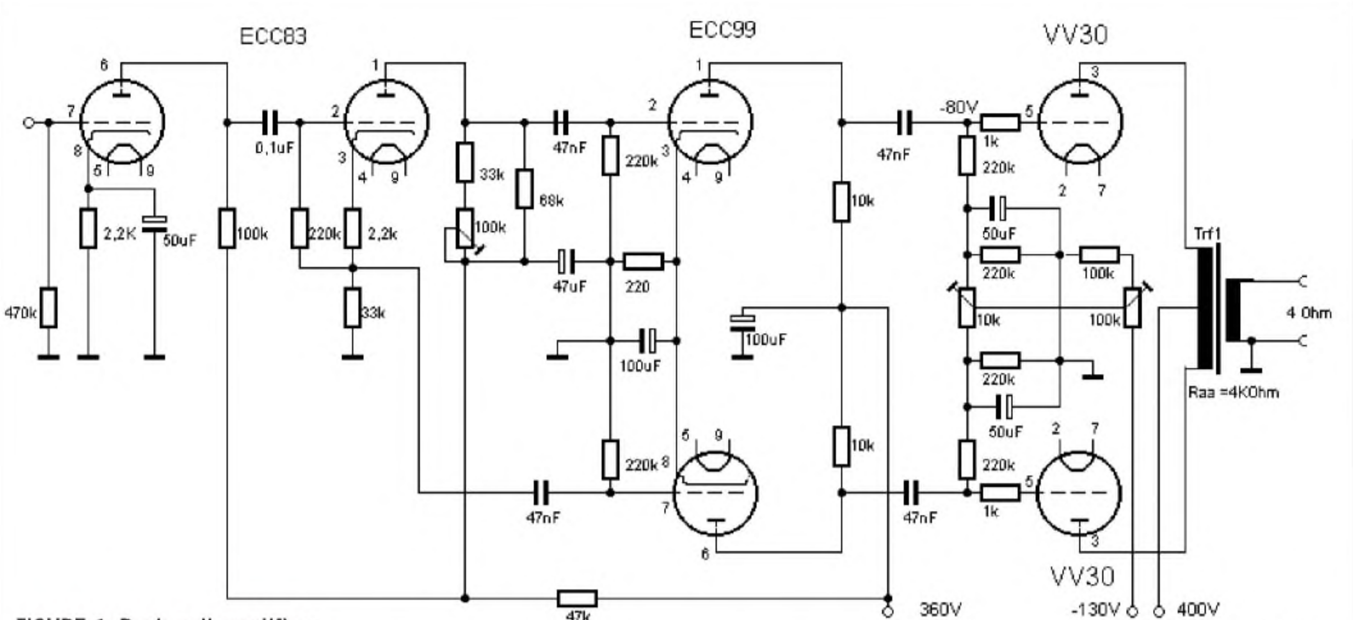

FIGURE 1: Push-pull amplifier.

came in with the lowest THD, followed by the Sylvania 5687, then the Tung-Sol 5687. Both 7119/E182CC had the highest THD. This first test indicates that the ECC99 indeed should be a good driver tube for power triodes.

The final comparisons were with a matched pair of AVVTs VV30 power triodes, which I got from JAC Music in Germany for this test. I biased those at Ia = 50mA with a grid voltage of –80V. At 10W into 4Ω, no negative feedback, THD was below 1% for all tubes except the 7119/E182CC, which was slightly above. At 15W, THD was still below 2% for all tube configurations. With a nega-

TEST EQUIPMENT USED

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tive feedback of about 12dB, the THD dropped to 0.5% at 15W.

Basically, the results from *Fig. 2* were confirmed, with the ECC99 offering the lowest distortion at high output levels. At lower levels (below 1W), all of the tubes were very close together and differences were difficult to measure. I also checked on the upper frequency limits and the pulse response; however, there were no relevant differences between the tubes.

CONCLUSION

The tests showed that the ECC99 has a low total harmonic distortion at high plate output voltages coupled with high amplification. This makes this tube very suitable as the driver stage for power triode amplifiers.

Given the low cost of less than $15, the ECC99 is certainly the tube I will use for my amplifier designs. ❖

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PHOTO 2: Testing THD with VV30 power triodes.

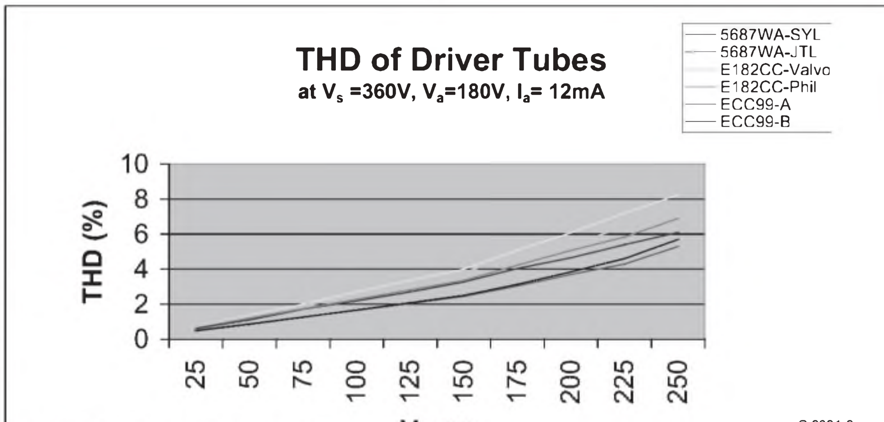

FIGURE 2: THD of driver tubes.

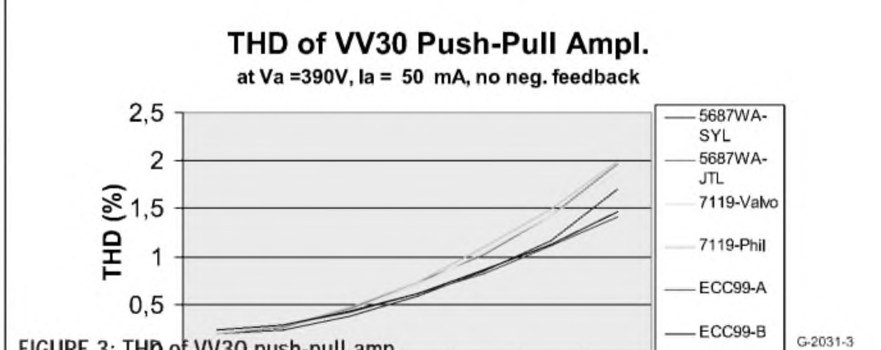

FIGURE 3: THD of VV30 push-pull amp.

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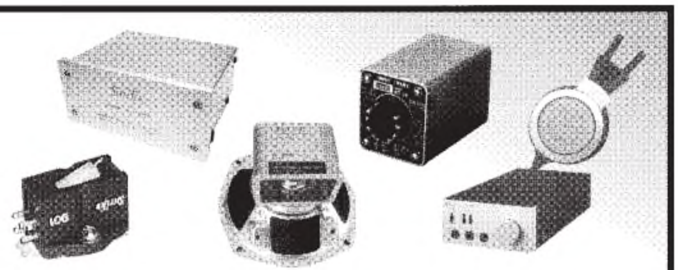

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Jensen JE-34K-DX	3	47	20Hz~20kHz	550	Area II $30
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SRS-4040 Signature System II	Ask
SRS-3030 Classic System II	Ask
SRS-2020 Basic System II	Ask
SR-001 MK2(S-001 MK II+SRM-001)	Ask

■Speaker

Model	Specifications					Price* (US $)	Postage** (US $)			
	D (cm)	Ω	Response	db	w		I	II	III	IV
Fostex FE208Σ	20	8	45Hz~20kHz	96.5	100	296	62	74	120	156
Fostex FE168Σ	16	8	60Hz~20kHz	94	80	236	42	50	73	98

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Model	Specifications				Price (US $)	Postage** (US $)			
	W	Pri.Imp(kΩ)	Freq Response	Application		I	II	III	IV
XE-20S (SE OPT)	20	2.5, 3.5, 5	20Hz~90kHz	300B,50,2A3	396	47	56	84	113
U-808 (SE OPT)	25	2, 2.5, 3.5, 5	20Hz~65kHz	6L6,50,2A3	242	42	50	73	98
XE-60-5 (PP OPT)	60	5	4Hz~80kHz	300B,KT-88,EL34	620	62	74	115	156
FX-40-5 (PP OPT)	40	5	4Hz~80kHz	2A3,EL34,6L6	320	47	56	84	113
FC-30-3.5S (SE OPT) 〔XE-60-3.5S〕	30	3.5	20Hz~100kHz	300B,50,PX-25	620	62	74	115	156
FC-30-10S (SE OPT) 〔XE-60-10SNF〕	30	10	30Hz~50kHz	211,845	620	62	74	115	156
X-10SF 〔X-10S〕	40	10W/SG Tap	20Hz~55kHz	211,845	1160	90	110	180	251
NC-14 (Interstage)	—	[1+1 : 1+1] 5	25Hz~40kHz	[30mA] 6V6 (T)	264	30	40	50	70
NC-16 (Interstage)	—	[1+1 : 2+2] 7	25Hz~20kHz	[15mA] 6SN7	264	30	40	50	70
NC-20F [NC-20] (Interstage)	—	[1 : 1] 5	18Hz~80kHz	[30mA] 6V6 (T)	640	42	50	73	98
NP-126 (Pre Out)	—	20,10	20Hz~30kHz	[10mA] 6SN7	264	30	40	50	70

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F-7003 (Permalloy)	10	5	15Hz~50kHz	300B,50	836	60	70	110	145
F-2013	40	10	20Hz~50kHz	211,242	786	70	84	133	181
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Optimizing Frequency Response in the Bass Range

This noted speaker-software designer offers yet another tool to assist you with box design. By Marc Bacon

When deciding on box size, the speaker designer faces a wide range of box size choices. Typically, a small box results in higher Q with less damping in the bass. Conversely, a large box size results in subjectively tighter bass. Dickason explains this well—for both closed and vented boxes—in *The Loudspeaker Design Cookbook* (available from Old Colony Sound Lab, 888-924-9465, E-mail custserv@audioXpress.com).

For closed boxes, filter theory states that the maximum extension for the –3dB point is reached when the box Q is 0.707. Critical damping occurs with a large box at Q = 0.5. Box Q over 0.707 results in some overshoot.

In the real world, listening rooms provide lift to the bass frequencies below about 150Hz. This is dependent on the position of the bass driver with regard to room boundaries, room dimensions, whether the room is closed and can pressurize at low frequencies, and the flexibility of the walls.

Without knowing exact characteristics of rooms, it is impossible to accurately predict bass response. However, literature is available that describes methodology as well as results of subjective bass listening tests, allowing you to design and build boxes that work in various listening rooms. These texts all agree that boxes with higher f_Bs require higher Qs than those with lower f_Bs. This occurs because boxes with more bass extension have more room lift, and therefore a higher apparent Q.

CLOSED-BOX DESIGN

Martin Colloms' *High-Performance Loudspeakers* lists the following closed-box alignments as being subjectively the most pleasing:

f_B	Q_{TC}
65	1.1
50	0.6
40	0.52

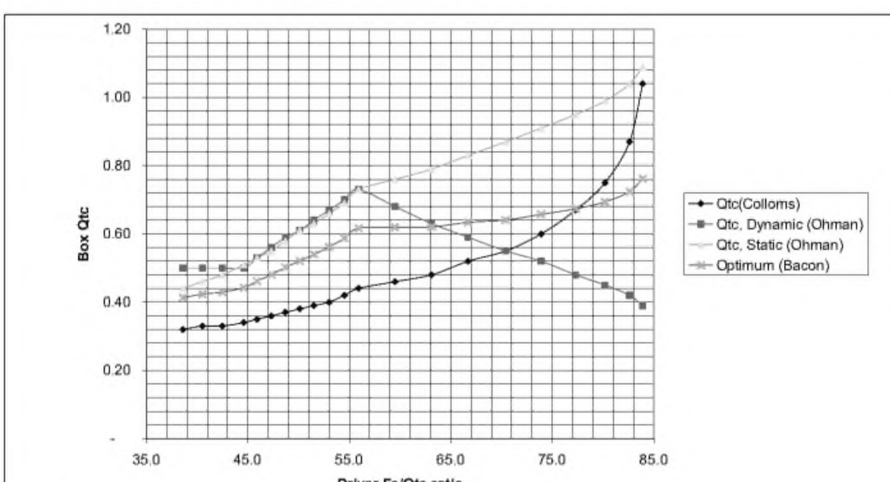

FIGURE 1: Best closed-box Q_{TC} as a function of driver f_S/Q_{TS} ratios.

An interesting article entitled "Optimum Frequency Response Curves in the Bass Range" appears on the web at http://home.ljusdal.se/sd/optimum.html. It describes the methodology that was used to evaluate people's subjective preferences for both static (like organ music) and dynamic (like drums) bass. The article is informative in that the testing was done in an environment that allowed true free-field evaluation. Even more interesting is that even without room boundaries, people preferred lower Qs with more bass extension. The author, Ingvar Ohman, lists the following as optimum closed-box alignments:

Dynamic music:
Max f_B = 85Hz
Above 33Hz, $Q_{TC} = 25/f_B$
Between 20 and 33Hz, a linear slope Q_{TC} from 0.5 to 0.7
Below 20Hz, Q_{TC} = 0.5

Static music:
Max f_B = 85Hz
$Q = 1/(2.5) \times (f_B/33)^{.65}$

I did some curve fitting of Colloms' recommendations, as well as to Ohman's dynamic and static music curves. The results appear in *Fig. 1*, where optimum Q_{TC} is plotted against ratio f_C/Q_{TC}. The graphs are shown in tabular form in *Table 1*.

All three methods show close agreement for box frequencies 55Hz. Above that point, Colloms' recommendations and the "static" curves tend to favor higher Q as a subjective replacement for low bass, while classical music lovers tend to trade off bass extension for better transient response. In all fairness to Colloms, I extrapolated his work to f_Bs higher and lower than his recommendations.

I then developed an "optimum" curve that is the geometric mean of the

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three values. This curve is useful in that it should satisfy the requirements of a large variety of music, rooms, and tastes.

How would you go about using the information to design real-world closed boxes? Start by looking up the f_S/Q_{TS} ratio in the table. For most situations, use the optimum value. For more subjective bass, choose a value between the optimum value and the "static" curve. For better transient response, choose a value between the optimum value and the "dynamic" curve.

Here's an example using a driver with the following parameters:

TABLE 1
TABULAR FORM OF *FIG. 1*

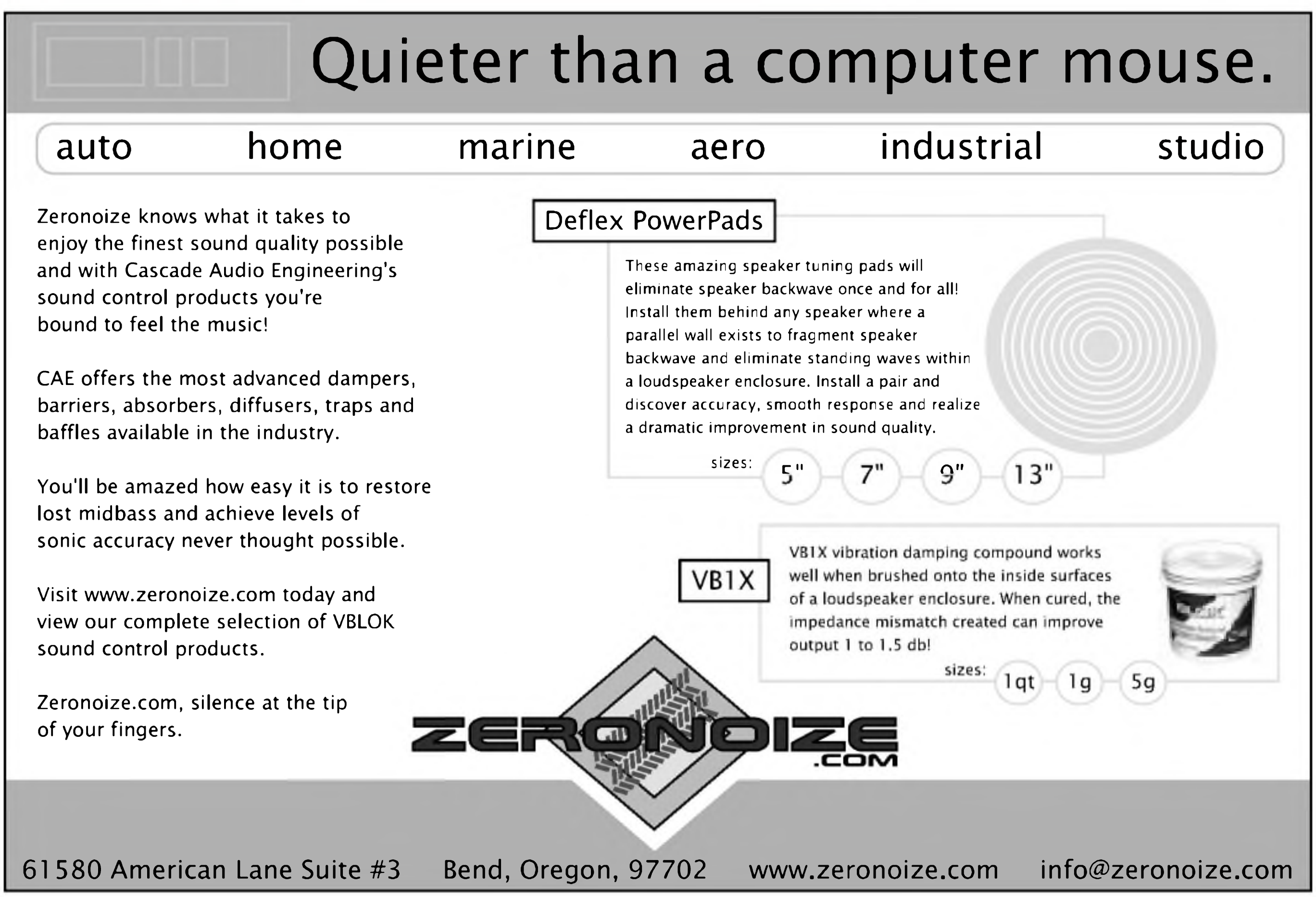
F_S/Q_{TS}	Q_{TC} (COLLOMS)	Q_{TC}, DYNAMIC (OHMAN)	Q_{TC} STATIC (OHMAN)	OPTIMUM (BACON)
38.6	0.32	0.50	0.44	0.41
40.5	0.33	0.50	0.46	0.42
42.5	0.33	0.50	0.48	0.43
44.6	0.34	0.50	0.51	0.44
45.9	0.35	0.53	0.53	0.46
47.3	0.36	0.56	0.55	0.48
48.7	0.37	0.59	0.58	0.50
50.1	0.38	0.61	0.61	0.52
51.5	0.39	0.64	0.63	0.54
53.0	0.40	0.67	0.66	0.56
54.5	0.42	0.70	0.69	0.59
55.9	0.44	0.73	0.73	0.61
59.5	0.46	0.68	0.76	0.62
63.1	0.48	0.63	0.79	0.62
66.7	0.52	0.59	0.83	0.63
70.4	0.55	0.55	0.87	0.64
73.9	0.60	0.52	0.91	0.66
77.3	0.67	0.48	0.95	0.67
80.2	0.75	0.45	0.99	0.69
82.6	0.87	0.42	1.04	0.72
83.9	1.04	0.39	1.09	0.76

V_{AS}: 60 ltrs
f_S: 25Hz
Q_{TS}: 0.370

Step 1: $f_S/Q_{TS} = 25/0.370$, or 67.50
Step 2: Look up the appropriate corresponding box Q_{TC} (0.64).
Step 3: Find the corresponding box frequency from $f_B = Q_{TC}/Q_{TS} \times f_S = 43.0$Hz.
Step 4: Find the appropriate box size from $V_B = V_{AS}/((f_B/f_S)^{2.1}) = 30.6$ ltrs.

Using the same procedure with the "static" and "dynamic" curves, the minimum box size is 14.3 ltrs with a Q_{TC} of 0.84 and a maximum box size of 40 ltrs with a Q_{TC} of 0.59. The results of the three approaches are shown in *Figs. 2, 3,* and *4*.

This approach allows you to easily design optimum box sizes for your application that will meet design objectives in the real world. When minimal box size is the primary concern, you can safely use a box as small as the "static" size without disappointment. If transient response is the main criterion, you can pick the "dynamic" alignment without fear of having wasted



box size for little gain. The "optimum" curve will suit a large number of situations.

As an even easier means of designing optimal boxes, the EasySuite series of programs, sold by Old Colony Sound Lab, uses the same three fifth-degree polynomial equations for quickly picking optimal box sizes for all f_S/Q_{TS} ratios between 40 and 100 that I used to develop this article.

VENTED BOX DESIGN

Designers are often tempted to design vented boxes for a maximum bass extension, without consideration of room effects. A formula that appears in several Radio Shack books by Weems gives the box size for achieving this result:

$$V_B = Q_{TS}^{2.87} \times V_{AS}$$
$$f_B = 0.42 \times f_S \times Q_{TS}^{-0.9}$$

The problem with this alignment is that it is very sensitive to changes in driver parameters, box Q, room effects, and so forth, and generally provides for boomy bass.

A better alignment, I believe, is achieved by designing the box size as above, but tuning the box to a frequency of about 0.8 of the f_B. The proper formulas are then:

$$V_B = Q_{TS}^{2.87} \times V_{AS}$$
$$f_B = 0.34 \times f_S \times Q_{TS}^{-0.9}$$

This alignment has close to a third-order rolloff, and is much less sensitive to the problems enumerated above. It possesses a better transient response, as well. Of course, since vented boxes offer two possibilities for tuning, namely box size and box frequency, there is a whole range of acceptable responses. With this alignment, however, you can hardly go wrong even on a first try and without a lot of measuring equipment to verify manufacturers' parameters.

For example, consider a driver with the following parameters:

$$f_S = 30\text{Hz}$$
$$Q_{TS} = 0.30$$
$$V_{AS} = 50 \text{ ltrs}$$

Graphs of the two alignments are

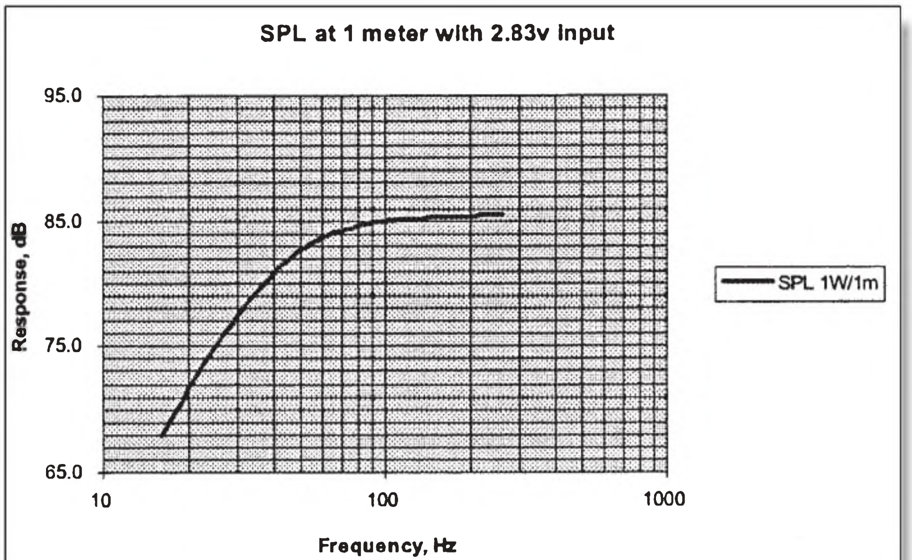


FIGURE 2: "Optimal" closed-box alignment for sample driver.

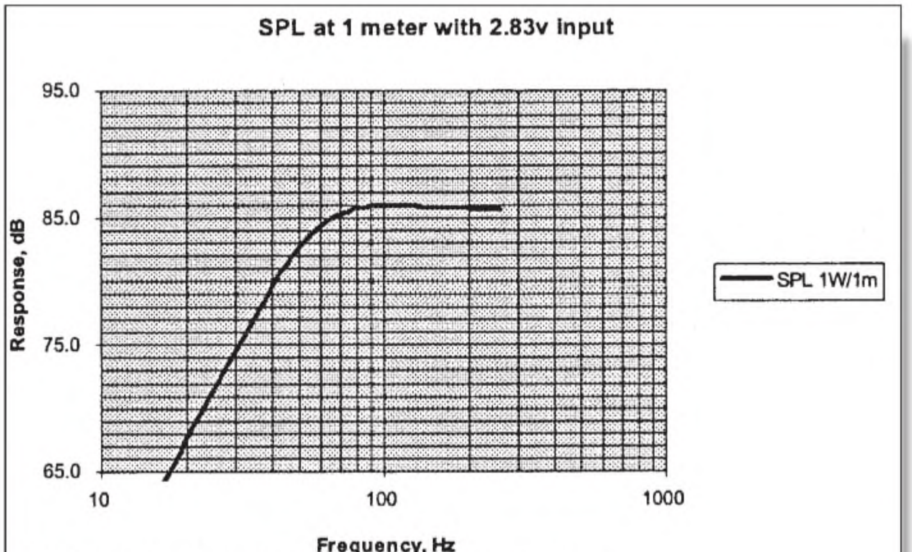


FIGURE 3: "Static" closed-box alignment for sample driver.

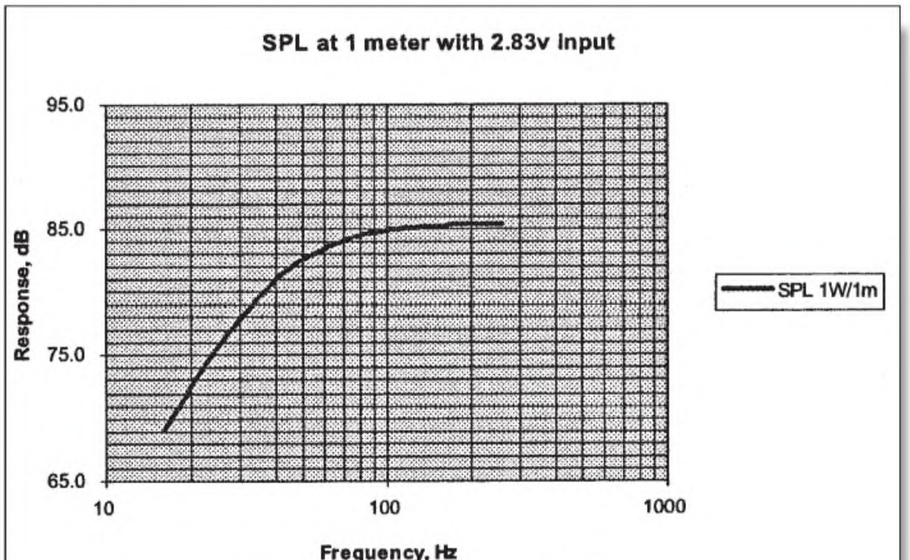


FIGURE 4: "Dynamic" closed-box alignment for sample driver.

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shown as *Figs. 5* and *6*. Notice that the second alignment, though it does not provide the same extension on paper, exhibits a much less sharp "knee" in the response curve. This allows better transient response and is more forgiving of mistuning than trying for maximum theoretical extension.

ROLLOFF RATES AND TRANSIENT RESPONSE

Filter circuit transient response is directly related to the rolloff rate. How can a vented box with its steeper rolloff than that of a closed box still have an acceptable transient response? You can find the answer in the level of cone movement around the box frequency.

Closed boxes have a large cone movement, whereas the vent in a vented box reduces the cone excursion to a minimum at the box frequency. There is a caveat, however. At very low frequencies, the airspring in a closed box limits movement, while a vented box unloads completely. Driving vented boxes hard without a subsonic filter can ruin them.

This article provides alignments that work. Simply find the f_S/Q_{TS} of the driver. If it is below 50, follow the rules for closed boxes. If it is more than 83, follow the rule for vented boxes. For values of f_S/Q_{TS} between 50 and 83, choose either closed or vented boxes.

Happy speaker building! ❖

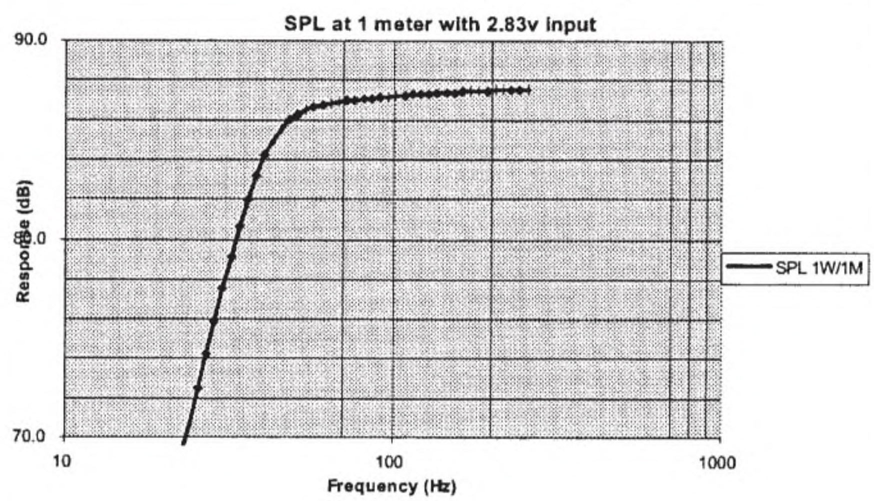

FIGURE 5: Maximum bass extension alignment for vented boxes per Weems, driver Q_{TS} = 0.3, f_S = 30, V_{AS} = 50 ltr.

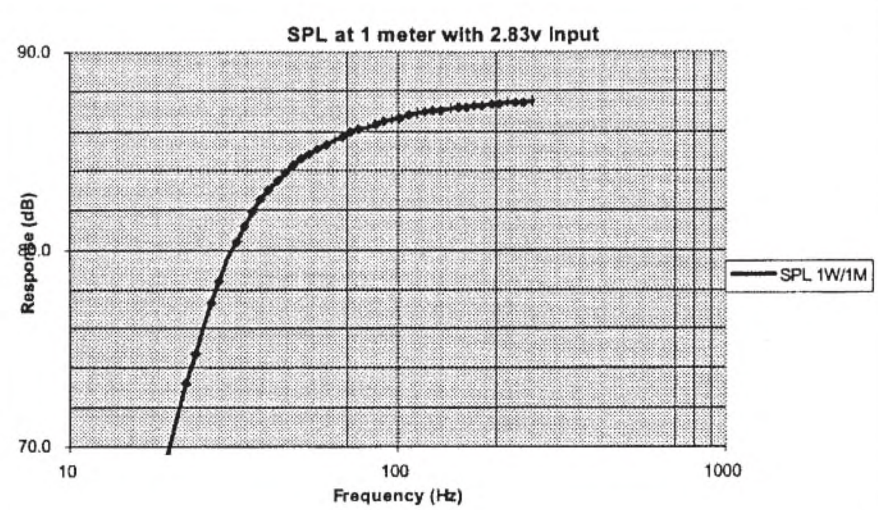

FIGURE 6: Bacon's proposed alignment for vented boxes, which allows for better transient response and is more forgiving of environment. Driver Q_{TS} = 0.3, f_S = 30, V_{AS} = 50 ltr.

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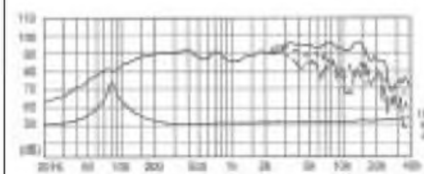

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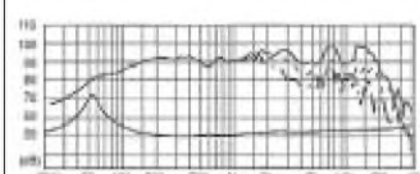

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Inductive RIAA Compensation

This follow-up to the topic of RIAA compensation suggests a change of components for sonic improvement.

By Darcy E. Staggs

In the 3/96 issue of *Audio Amateur & Electronics*, contributor Michael Danbury presented a preamp design in which the RIAA compensation was achieved with inductors, rather than the more customary capacitors. At that time, there was some doubt about the supply of suitable inductors. I located sources for the inductors and adapted Mike's circuit to my op-amp phono stage (Burr-Brown OPA-627). My cartridge is the latest Shure V-15, loaded with 96kΩ, which improves low-level detail.

SONIC IMPROVEMENTS

My capacitor-feedback circuit was computer-designed, and the components were picked from accurately measured samples. The circuit's response was very precise, but somehow it sounded disjointed, no matter which type of capacitors (polystyrene, polyester) or resistors (Holco) I used. After converting to inductors, I can now describe the sound as "having the dynamics of CDs with the ambience and beautiful high frequencies re-

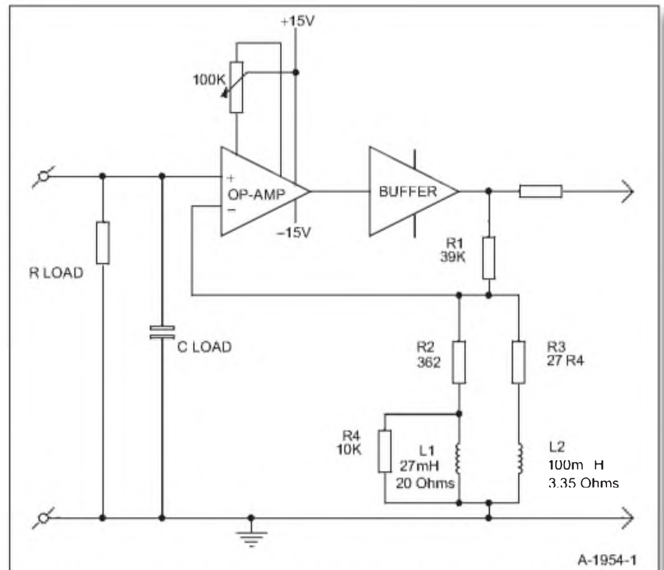

FIGURE 1: Example op-amp/ inductor RIAA stage, after M. Danbury.

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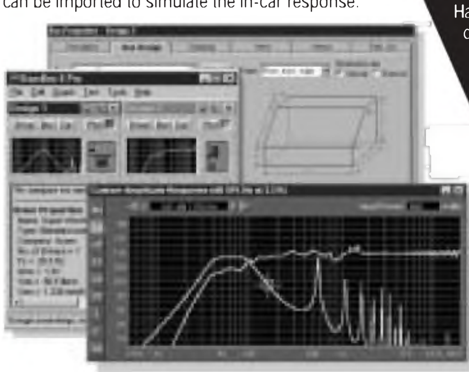

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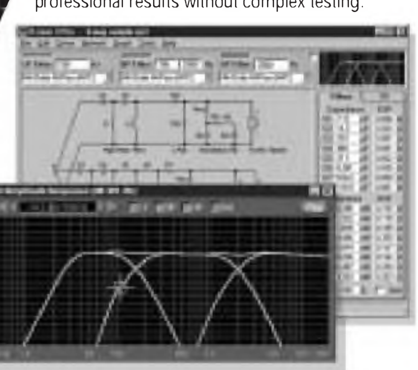

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stored." There is a dynamic ease and lushness across the entire spectrum. No more capacitors.

I used a computer model of the op amp, plus the circuit in *Fig. 1*, and ran many trials to settle on the best-fit choice of available resistor and inductor values. The resulting error in RIAA response is 0.27dB at 20Hz, 0.0dB at 1kHz, and 0.40dB at 20kHz. Circuit gain at 1kHz is 41.1dB, set high on purpose to more closely match that of my CD player. I thank Burr-Brown for making such a quiet op amp.

The shielded 27mH inductor is from Mouser, p/n 434-02-273J, and has a DC resistance of 20Ω. The 100mH inductor is made from a pot-core (shielded) assembly from Amidon Associates (amidoncorp.com), p/n PC 2616-77, and available 30-gauge enameled wire, which I wound on the plastic coil former included with the inductor kit. Its DC resistance measures 3.35Ω. All resistors are Holco H4s.

The Amidon pot-cores contain a chart and simple equation for figuring out the number of turns of wire needed to achieve the desired inductance. This proved to be very accurate, since I measured the final inductance just to be sure.

Because this circuit has high gain at low frequencies, you need to either null the output voltage with a potentiometer (*Fig. 1*) or install a nulling servo and wait for it to settle before selecting phono as a sound source. The specs for your particular op amp will contain recommended nulling circuitry. Also, the 10kΩ resistor across inductor L1 is necessary for stability purposes with this op amp and my layout, and since it doesn't affect the sound, you may as well use it in your version as well.

Although I dreaded winding my own inductors, it turned out to be very easily and quickly done, thanks to the Amidon components. If I had known about the sonic improvements in store for me, I would have tackled this project in 1996! ❖

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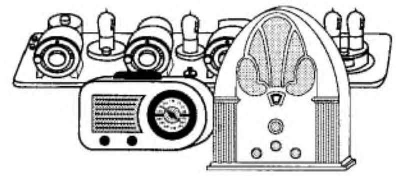
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Building Adire's HE10.1 High Efficiency Coaxial

By Edward T. Dell, Jr., Joseph DAppolito, and Dennis Colin

PHOTO 1: Back and front views of the assembled Adire HE10.1s.

Adire Audio publishes the following specifications for this kit: Woofer: 10″ high efficiency driver with integral coaxial horn; Tweeter: 1″ compression dome coaxially mounted; Crossover: sixth-order acoustic all air-core coils and polypropylene caps; Impedance 8Ω (7Ω nominal); Response: 60–20,000Hz, ±3dB; Efficiency: 96dB @ 2.83V RMS; Size (HWD) 17.5 × 12 × 13.5″.

Adire Audio, 1111 Elliot Ave., West, Seattle, WA 98119, Phone 206-789-2919, Fax 800-437-2613, techsupport@Adireaudio.com, http://www.adireaudio.com. Kit price $279 per pair.

Adire describes this kit as follows: "The HE10.1 is a high-performance, high efficiency coaxial driver system, designed for use where high efficiency is required, such as PA monitors and use with low-power amplifiers (specifically SET amplifiers). It features a 10″ paper cone driver with a coaxially mounted compression driver loaded into a 90° conical constant directivity horn, which yields a system sensitivity of 95dB SPL @ 2.83V RMS."

CONTENTS

The resulting speakers are relatively small vented boxes. They weigh about 31 lb each when assembled. I painted mine a color called British Red (*Photo 1*).

The parts supplied are essentially the two 10″ Eminence Beta 10CX lf/mid drivers and two Adire ACD1 1″ compression drivers with crossover parts, input terminals, wire, and assorted hardware items for driver and crossover parts mounting. The kit is beautifully packed but comes without instructions, which are available from the Adire website; but if you haven't access to a computer, you should request a copy of these with your order.

Parts supplied are listed in section 2 of the instructions and reproduced here in *Table 1* and shown in *Photo 2*. The 14ga wire is generously adequate and of good quality with a coding stripe to keep polarity correct. Tie wraps work well for mounting crossover parts. Woofer/mid mounting hardware consists of T-nuts and socket cap machine screws.

Adire tells you about needed tools and parts in part 3 of the instructions. They suggest hardboard or plywood as a base for the crossovers. You'll need two pieces that are 5⅝″ × 7½″. I used ¼″ thick pieces of Masonite® and drilled ⅛″ holes for the ties. Adire provides an excellent full-size layout for the crossover components (*Fig. 1*), suggesting that you make copies as templates for your mounting boards. In addition, you'll need at least six wood screws and standoffs to mount the crossover boards on the floor of the cabinets.

Adire gives extensive and detailed instructions for assembling the crossover boards. Section 5 goes on for nearly five pages of suggestions. The wire leads of the four air-core inductors are long enough to provide extra wire for connecting some parts. Generally I did point-to-point connections above the board and had plenty of wire to complete both units.

I was not comfortable with arranging amp input and speaker output connections with wire soldered directly to the components, however. I found a 12-position "Euro Jumbo" dual screw connector strip at the local electronics store (which an author in one of the other magazines refers to as "the Rat Shack") at an outrageous price of $4.19 and cut it into units of two and four lugs for input and output, respectively. I mounted these on the base with 4-40 machine screws, lock washers, and hex nuts. Be sure the terminal's holes are large enough for the #14 wire supplied. These provided very rugged and easy-to-use connectors for attaching the crossovers to the

PHOTO 2: Complete kit parts supplied with Adire's HE10.1.

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drivers and the dual input cup.

Crossover assembly is fairly straightforward, the hardest part being scraping the insulation off the inductor leads. The location guide is excellent and makes a useful template for mounting the parts. The assembled crossover is shown in *Photo 3*.

IN ADDITION

What the instructions mean by listing "needed tools" is not really for the complete speakers, but just the crossovers. They are correct that the kit supplied may be assembled using the tools listed, but you will naturally need to build some boxes for the speakers to be fully functional. There are quite a few things you will need in addition to the kit, if you wish to have useful loudspeakers.

You will need slightly more than a half a sheet of 4 × 8′ ¾″ MDF to make the two enclosures. *Figure 3* is a cutting guide, which is only roughly to scale. I asked my lumberyard to cut off 49″ from one end of the full sheet of MDF, which fit nicely into my car. If you set your table saw to a 12″ width and cut four pieces from the larger half of the MDF, you then have only to reset the saw to 16″ to cut the sides, fronts, and backs from these. Then re-set the saw to 13.5″ to produce the tops and bottoms.

ADJUSTMENTS

Adire offers very little in the way of suggestions on how to build and assemble the boxes. Their instructions include a diagram of front and side elevations in their Section 7. Unfortunately, there are a couple of errors and a line or two that should be solid but are dotted.

I re-drew the sketches, which I hope will be more helpful, in *Fig. 4*. The six panels for each box are quite similar in size. It is a good idea to mark them clearly on what will be the inside face of each. If you use biscuit joinery as I did (explanation follows), such marking will be even more important.

Essentially the side panels fit between the front and back panels, and the tops and bottoms sit over and under the sides and front. Most speaker builders seem to prefer using screws to assemble speaker boxes, along with generous applications of glue. I was intrigued by Norm Abram's (of PBS's New Yankee Workshop fame) use of biscuit joinery. Biscuits are oval-shaped pieces of compressed wood which come in three sizes, 0, 10, and 20. You can

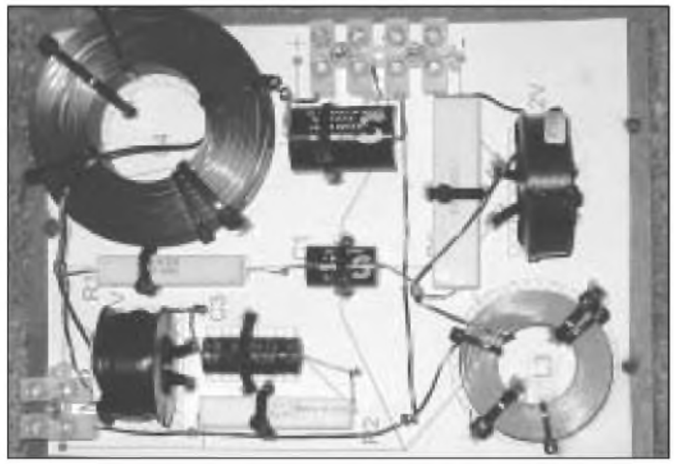

PHOTO 3: Assembled crossover with added compression connectors.

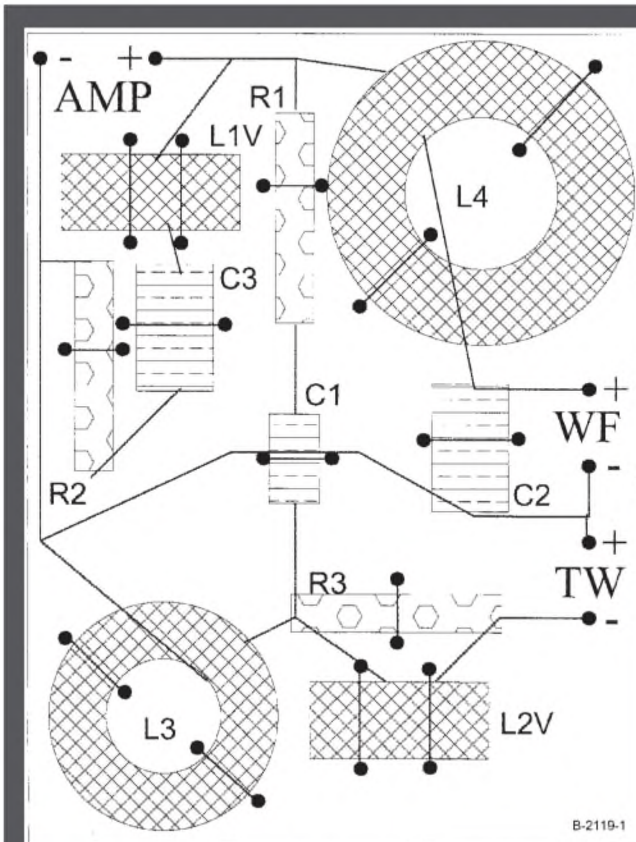

FIGURE 1: Suggested layout (from Adire Audio assembly instructions).

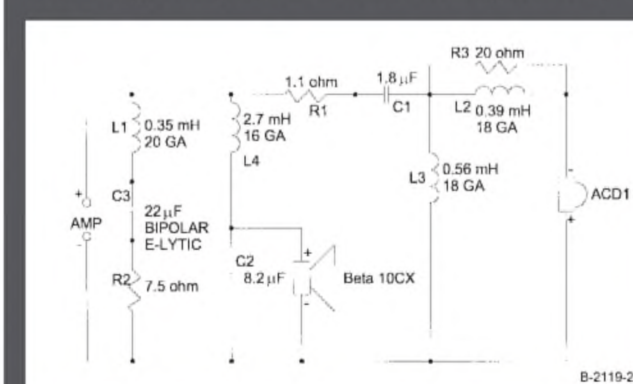

FIGURE 2: Crossover schematic (from Adire Audio assembly instructions).

RESOURCES

McFEELY'S Square Drive Screws, 160 Wythe Rd., PO Box 11169, Lynchburg, VA 24506-1169, 800-443-7937, FAX 800-847-7136, www.mcfeelys.com. Jasper Circle Jig, threaded inserts, screws.

Price Cutter.com, P.O. Box 1100, Chardon, OH 44024, 888-288-2487, FAX 440-286-3920, www.pricecutter.com. Jasper and other circle jigs, biscuit cutting jig for routers, extensive router cutter selection.

TABLE 1
PARTS

YOUR KIT SHOULD INCLUDE THE FOLLOWING PARTS (QUANTITIES GIVEN ARE FOR A PAIR)

PART	QTY	USE
1.8µF 250V DC polypropylene capacitor	2	C1 in the tweeter crossover
8.2µF 250V DC polypropylene capacitor	2	C2 in the tweeter crossover
22µF 160V DC electrolytic capacitor	2	C3 in the impedance network
0.35mH 20 GA perfect lay air-core coil	2	L1 in the impedance network
0.39mH 18 GA perfect lay air-core coil	2	L2 in the tweeter crossover
0.56mH 18 GA perfect lay air-core coil	2	L3 in the tweeter crossover
2.7mH 16 GA perfect lay air-core coil	2	L4 in the woofer crossover
1.1Ω 10W sandcast resistor	2	R1 in the tweeter crossover
7.5Ω 10W sandcast resistor	2	R2 in the impedance network
20Ω 10W sandcast resistor	2	R3 in the tweeter crossover
BETA 10CX 10″ midrange/woofer	2	Woofers
ACD1 1″ compression driver	2	Tweeters
DIC dual input cup	2	Dual pair input cup
14 GA/2C 14 GA twin conductor cable	10	Internal wiring
0.25″ female FAST-ON connector	16	Terminal connectors
21cm long wire tie wrap	28	Crossover assembly
Large T-nut/socket cap screw set	16	Woofer mounting

purchase a dedicated "biscuit cutter" at prices between $100–$200. There are also templates available with special router bits, with which you may use your router, plunge or fixed type, to cut the special slots for the biscuits.

I decided on #10 biscuits and purchased a DeWalt unit that had the features I liked. The blade is mounted horizontally to cut slots into the edge or face of a panel, conveniently located to center on one-half the thickness of the popular ¾″-thick material. It may be re-set for other thicknesses and adjusted for joining other construction angles.

I added a section to my drawing of *Fig. 4* to indicate where I put biscuits for joining the box panels for this prcject. If you take care to mark positions on the panels and match the correct edges, marking both at the same time, it is very easy to cut slots for the biscuits in a very short time.

The larger ovals shown in the figure are in slots cut into the edges. The thin ones represent cuts into the face of the panels. All the slots on the sides are cut into the panel edges. All slots in the tops and bottoms are cut into the faces. The front and back panels have slots in their top and bottom edges, and in the faces to match the side panels.

MAKING CUTS

The manufacturer suggests that its woofer/mid does not need to be mounted in a routed mortise so that the front edges of the driver are flush with the front panel. To my mind, however, any disjunction around the driver will inevitably cause some diffraction effects—which may or may not be audible. However, I opted to cut a 5/16″ deep mortise to a 10 [illegible]/8″ diameter with a plunge router, prior to cutting the driver opening to 9 [illegible]/16″ diameter. I used the quite wonderful Jasper Circle Jig Model 2002 for cutting the holes and the rim recess, including the 3″ hole for the port.

The Jasper (Model 400) is a thick piece of acrylic with countersunk holes for mounting a plunge router. It also has holes for a [illegible]/8″ pin to fit into a hole at the center of the cutout. The pin is long enough for ¾″ stock and must also be driven into the backing scrap stock under your panel. You use carpet tape (double-sided) to hold the work in place. This is especially useful with panels as small as these where traditional clamps block the template jig as it guides the router around the circle.

The instruction booklet for the Jasper unit has the most complicated mathematical formulas for its use that I have ever encountered. Since I was using a ½″ straight bit, it seemed easiest to subtract ¼″ (half the diameter) from the mortise or the hole's diameter and set the pin holding the jig to that position. The Jasper is easier to use for larger holes than smaller ones near its inner limit. The 3″ pin hole is covered by the router base and very difficult to locate.

If you use the biscuit method for assembly, it is a good idea to clean out the slots with a vacuum and do a dry fit of all parts. *Photos 4a* and *b* are views of a partial dry run. If your markings are accurate, the parts will line up perfectly.

I opted to use a different method of mounting the lo/mid driver. Adire provides nice T-nuts which would have worked fine, except that with only [illegible]/16″ thickness in the panel edge around the driver hole, I thought the three-

PHOTO 4A: Biscuits in place on inner face of the front panel with mated side and bottom.

PHOTO 4B: Front panel with threaded brass inserts installed.

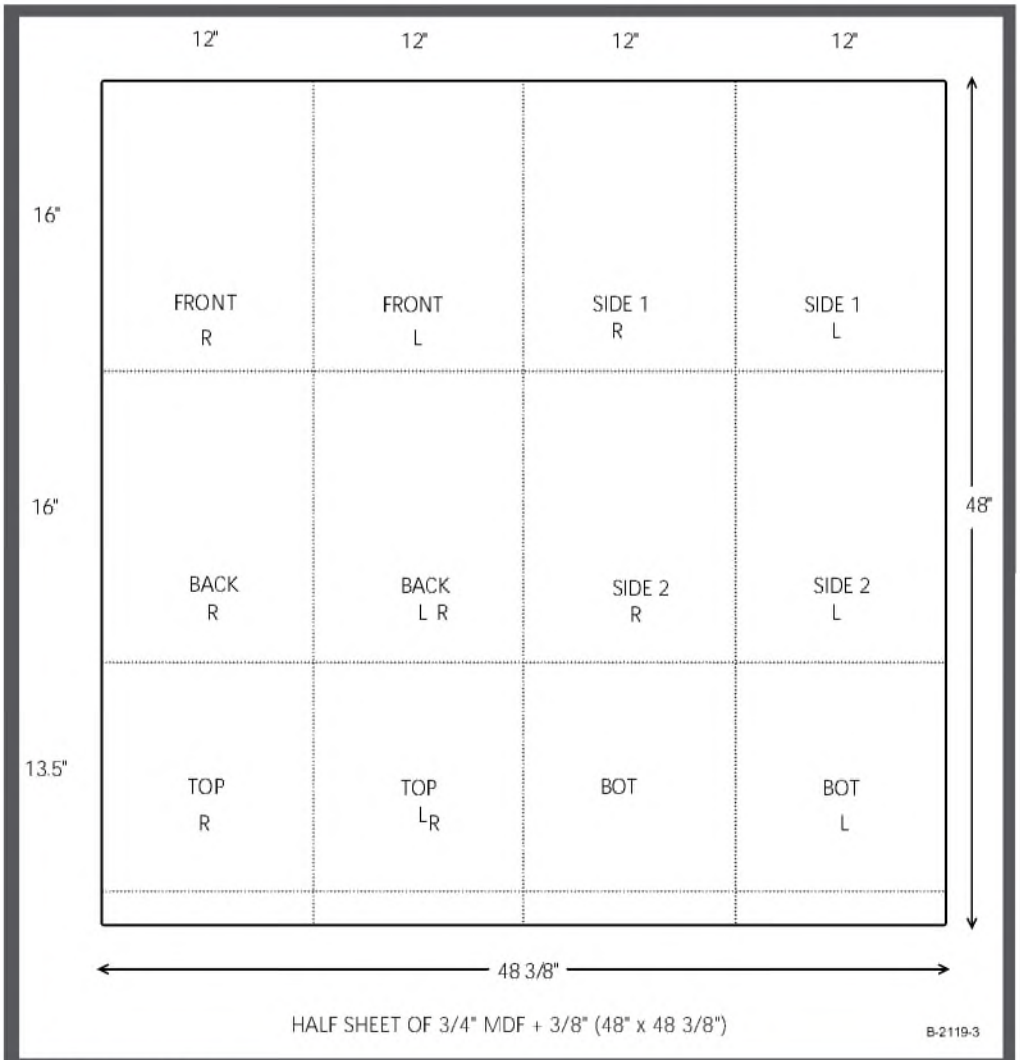

FIGURE 3: Cutting guide.

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pronged T-nuts might well damage the rim. I ordered a bag of 25 brass-threaded inserts, #8/32 size from McFeely's catalog, with stainless-steel screws to match. This is a more expensive option, but I found the result highly satisfying.

After carefully marking hole locations with the driver in place, I center-punched each location and drilled ¼″ holes at the eight locations. *Photo 5* shows one of the brass inserts installed. These may be driven in place with a straight blade screwdriver.

PHOTO 5: Brass insert installed in front panel.

Cutting the hole in the rear panel is done easily by boring 5/16″ holes at two corners and using a jigsaw to remove the stock. I strayed from Adire's suggested plans for the boxes by using the router to round the corners of the top and side edges of the front panel as well as the sides of the tops. Partly this was an aesthetic impulse and partly a conviction that smooth transitions at box edges are likely to be better for wave travel.

PHOTO 6: Assembled woofer and concentric tweeter just prior to installing the driver assembly.

ASSEMBLY

Assembling the cabinets went smoothly with generous amounts of Franklin Titebond® glue on all mating surfaces and especially in the biscuit slots. I used lots of bar and pipe clamps to compress parts joints, wiping excess glue with a damp rag. I used hot-melt glue on all the inner joints just to be sure there were no leaks. Sanding went quickly and I coated both boxes with primer-filler prior to two coats of paint, with a finish sanding after the first finish coat.

Installation of each crossover on the cabinet floor was a bit tricky but not really difficult. I opted to solder the cables to the drivers and to the input cup. The FAST-ON connectors were too large for those on the drivers, in any case. I found I had plenty of wire, cutting the leads for the input cup to 15″ and those to the drivers to 23″. I tinned the crossover ends of these wires for easy insertion into my compression connectors.

You will also need 24 ounces of fiberfill to stuff the two cabinets. I found mine at a local store selling sewing supplies. I chose a quilt insert, queen size, which had only a small strip left over. The 12 ounces fill the box snugly and the wires to the drivers keep the fiberfill from blocking the port (*Photo 6*). The 3″ diameter port can be cut from a short length of PVC pipe. If you're lucky your lumberyard or plumber may have a +4″ scrap they will donate to the project.

I packed up the two units, loaded them into my car, and drove them upcountry to Wolfeboro, on New Hampshire's Lake Winnipesaukee, meeting with Joe D'Appolito to have them measured, and with Dennis Colin who promised to give them some critical listening. Their efforts follow.

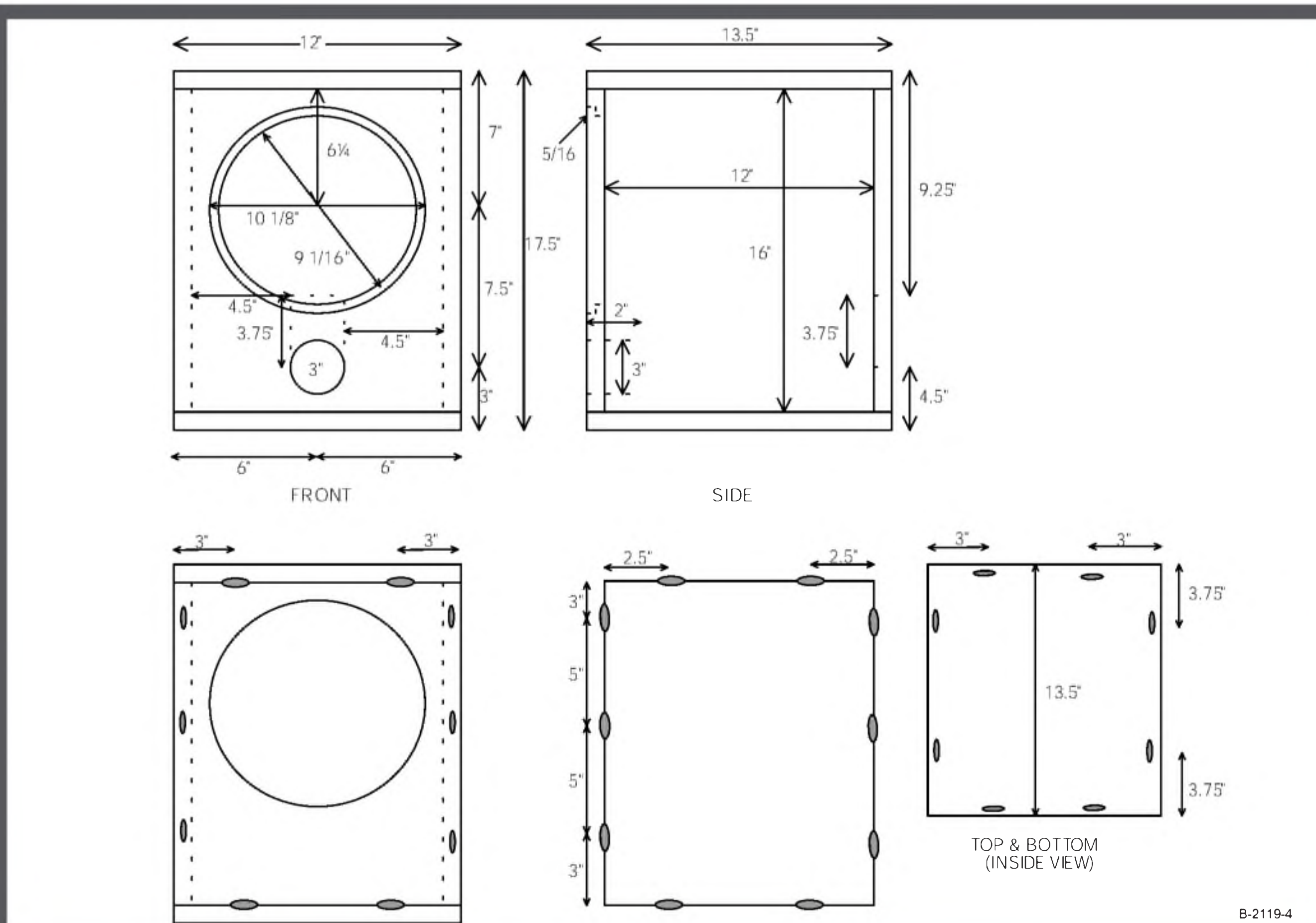

FIGURE 4: Diagram of box, including biscuit placement.

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CRITIQUE

Reviewed by Dennis Colin

I auditioned the speakers in Joe D'Appolito's listening room (Audio and Acoustics Ltd.).

SOURCE MATERIAL

1. Chesnokov: "Spaseniye sodelal," Turtle Creek Chorale, Timothy Seelig, cond., track 3, HDCD sampler, Reference Recording RR-905CD.
2. Hamlisch/Morita: "A Chorus Line," Turtle Creek Chorale/Dallas Women's Chorus, Timothy Seelig, cond., track 4, HDCD sampler, Reference Recording RR-905CD.
3. Jacintha, "Georgia on my Mind" from *Here's to Ben*, First Impressions Music, FIM XRCD 020.
4. "Carmen Fantasy" from *Percussion Fantasia*, Harold Farberman and the All Star Percussion Ensemble, First Impression Music, FIMCD 017 (an HDCD 24-bit recording).
5. Bizet-Shchedrin, "The Carmen Ballet," Orchestre Philharmonique de Monte Carlo, James DePriest, cond. Delos 3208.
6. Beethoven, Symphony No. 6, "The Pastoral," Hanover Band, Roy Goodman, cond., Nimus Records, NI5099.
7. Chopin, "The Nocturnes," No. 2 in D-flat major, Artur Rubenstein, piano, Musical Heritage Society 523870T.
8. Tannoy HiFi Series Sound Sampler, band 11, "Im Uomini, In Soldati," Mozart, Cecilia Bartoli, Wiener Kammerorchester, GyOrgy Fischer, cond.
9. Dvorak, Symphony No. 9, "From the New World," Chicago Symphony Orchestra, Sir George Solti, cond. London 410 116-2.
10. Berlioz, "Nuits d'ete," Frederica Von Stade, BSO, Seiji Ozawa, cond. CBS Master Works, MK 39098.
11. Dvorak, Piano Quartet in E-flat Major, OP. 87, 2nd movement, The Ames Quartet, Dorian-90125.

SONIC IMPRESSIONS

The Adire speakers, while generally pleasant sounding, did not to me qualify as high fidelity. In addition, at high SPL (≥95dB estimated) midrange and treble became edgy, most noticeable on horns, strings, and voices in chorus.

Dvorak Symphony No. 9 with Solti—Horns sounded good except at high SPL, although high overtones were somewhat congested. Image was well focused, but spaciousness sounded restricted.

Jacintha—Bass was good, sounded flat to the open E-string (41.2Hz). Imaging excellent. "S" sounds on voice were siblilant. Sax sounded excessively "buzzy."

Carmen Fantasy—Imaging good, very precise. Bell transients were very solid. High frequency tonality sounded "thin." Some overall "edginess."

Turtle Creek Chorale—Midrange on this most excellent recording sounded "peaky" (resonant). Highest overtones and breath sounds were colored with a sense of "non-smoothness." Sound became gritty at high SPL.

A Chorus Line—Bass sounded strong to 30Hz. Upper mids on horns sounded congested.

Other Recordings in General—Pipe organ bass was impressively deep, but upper-bass notes were "edgy" sounding. Violins, though somewhat colored, still sounded good at low SPL, but became unpleasantly harsh or strident at loud levels.

OVERALL CRITIQUE

These speakers seemed to be quite efficient, capable of high SPL, at least in the lower frequency ranges. I think they would serve well as public-address (PA) speakers: compared to the typical PA speakers that bands use, these would sound relatively high-fidelity, but only at SPLs moderate re rock-band levels (for example, with "easy listening" or "soft rock" lounge use). I would not recommend them for the serious music aficionado.

SONIC CHARACTERISTICS RATINGS

		1	2	3	4	5	6	7	8	9	10
Presence	DC						■				
Freedom from Distortion	DC						■				
Frequency Response Smoothness	DC					■					
L-M-H Balance	DC								■		
Treble Quality	DC					■					
Midrange Quality	DC						■				
Bass Quality	DC							■			
Bass Extension	DC								■		
Immediacy & Transient Response	DC								■		
Image Focus	DC									■	
Stereo Soundstage Realism	DC							■			
Ambience	DC						■				

A Note on Perspective Regarding this Scale
1 = worst rock band PA system you've heard
3 = boom box
5 = mass-produced stereo speakers
7 = just acceptable for "high fidelity"
9.5 = Joe D'Appolito's "THOR" speaker (*audioXpress* May 2002)
10 = virtually perfect, i.e., so good that the only difference from live music is from limitations of stereo or present multi-channel recording/playback processes, listening room acoustics, and so forth.

TEST REPORT

TESTING THE ADIRE HE10.1 COAXIAL LOUDSPEAKER KIT

By Joseph D'Appolito

According to Adire, the HE10.1 uses a proprietary 10″ coaxial driver with a custom-designed ten-element crossover. The woofer is the Eminence Beta 10CX; a 10″ accordion edged paper cone unit with a 2″ diameter voice coil. To this driver Adire adds a 90° conical horn, which extends from the rear to the apex of the cone, so that it doesn't block any of the woofer's radiating surface. The rear of the pole piece is threaded to receive a 1″ compression tweeter.

Adire claims that their custom mounting system physically aligns this tweeter to the woofer within less than 40µs. Efficiency is stated to be 95dB SPL at 2.83V.

I ran a series of impedance, frequency response, and distortion tests on the HE10.1. *Figure 1* is a plot of system impedance magnitude. At low frequencies the plot displays the double-peaked curve typical of vented systems. The impedance minimum of 8.76Ω at 52.4Hz indicates the vented-box tuning frequency. Impedance phase angles range from +48° to −47°.

FREQUENCY RESPONSE

Figure 2 shows the full-range frequency response of one HE10.1. This is a combination of the far-field quasi-anechoic measurement above 300Hz taken at 1.25m on the tweeter centerline combined with a ground-plane response below 300Hz[1]. The response data is ⅙ octave smoothed. In the octave between 500Hz and 1kHz, response sensitivity averages 93dB SPL/2.83V/1m. This is about 2dB less than Adire claims. Response rises to 95dB at 180Hz and is down −3dB relative to 1kHz at 70Hz.

Above 1kHz you can see rather wild response variations of 10dB peak-to-peak. I suspect that these variations are diffraction effects originating at the horn mouth/woofer cone interface.

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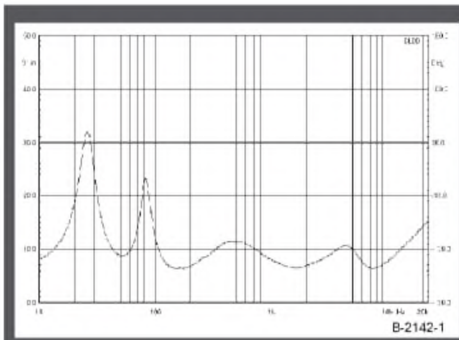


FIGURE 1: Adire impedance plot.

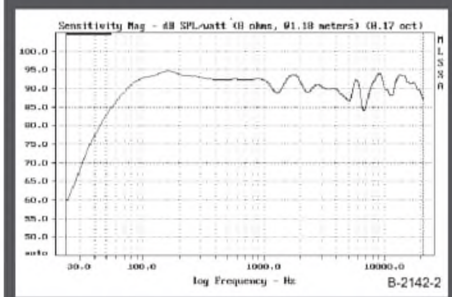


FIGURE 2: Adire full-range frequency response.

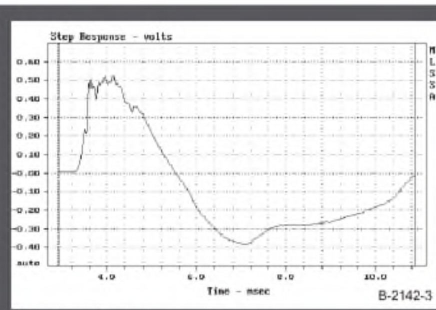


FIGURE 3: Adire step response.

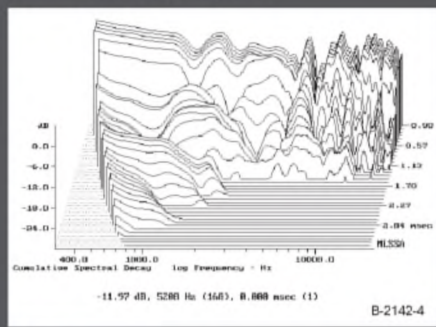


FIGURE 4: Adire cumulative spectral decay.

WOOFER/TWEETER TIMING

Figure 3 shows the HE10.1 step response. It is obtained by a numerical integration of the system impulse response. The ideal step response should be a single rapid rise followed by a smooth decay through the 0.00 level.

HE10.1 step response is very close to ideal. There is, however, a slower than expected initial rise. Detailed examination of the impulse response and energy-time plot (not shown) reveals that the woofer is actually arriving at the test microphone slightly before the tweeter. This result is similar to that described in my review of the Tannoy S8LR speaker, which also uses a coaxial driver[2].

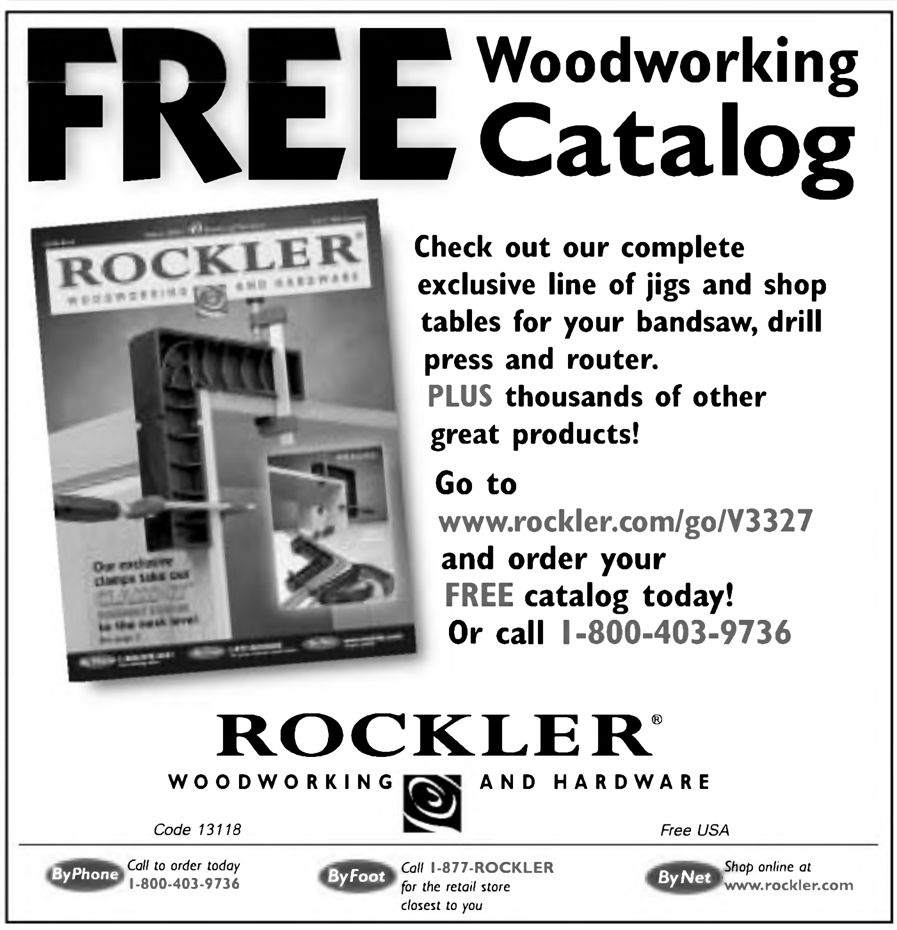
The ragged top of the step response is caused by response variations above 2kHz. Still, this is one of the best step responses I have seen in any of the speakers tested for *audioXpress*.

CUMULATIVE SPECTRAL DECAY

The HE10.1 cumulative spectral decay (CSD) response is presented in *Fig. 4*. This waterfall plot shows the frequency content of the system response following a sharp impulsive input at time zero. On the CSD plot, frequency increases from left to right, and time moves forward from the rear. Each slice represents a 0.1ms increment of time. The total vertical scale covers a dynamic 30dB range.

Ideally the response should decay to zero instantaneously. Inertia and stored energy that take a finite amount of time to die away, however, characterize real loudspeakers. A prominent ridge parallel to the time axis would indicate the presence of a strong system resonance.

The first time slice in *Fig. 4* (0.00ms) represents the system frequency response. Decay response above 3kHz falls uniformly by 30dB in 1.6ms. This is a somewhat longer decay time than I usually see with good dome tweeters.



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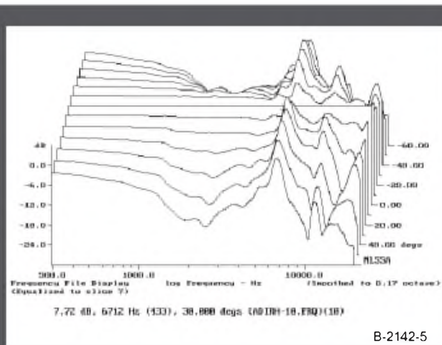

FIGURE 5: Adire horizontal polar response.

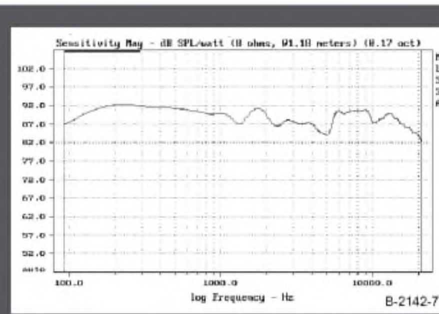

FIGURE 7: Average horizontal response ±30°.

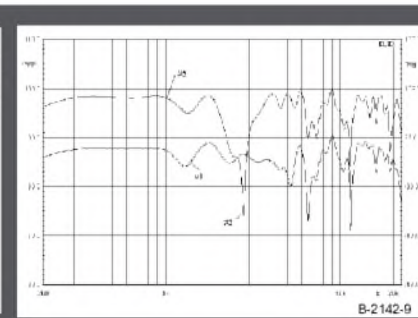

FIGURE 9: Comparing responses of HE10.1 samples #1 and #2 (offset +10dB).

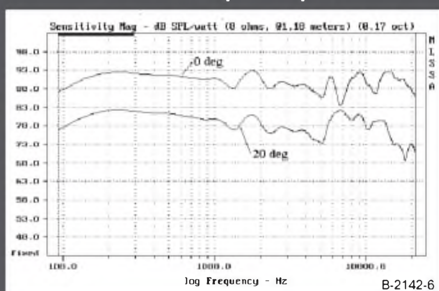

FIGURE 6: Response at 0 and 20° horizontal (20° offset –10dB).

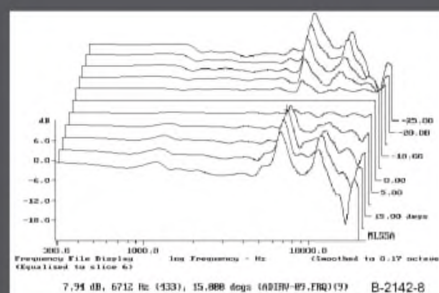

FIGURE 8: Adire vertical polar response.

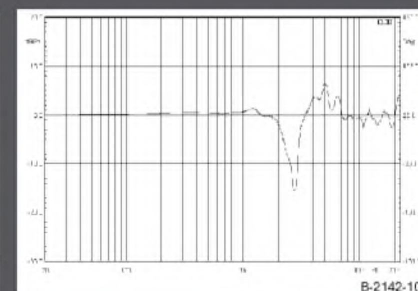

FIGURE 10: HE10.1 response difference (#2 minus #1).

Most of the response variation seen in *Fig. 2* persists in the decay response. Thus the high-frequency character of the HE10.1 is retained in the decay response. The low-frequency decay is fairly typical of vented loudspeakers.

HORIZONTAL POLAR RESPONSE

Horizontal polar response is examined in *Figs. 5–7. Figure 5* is a waterfall plot of horizontal polar response in 10° increments from 60° right (+60°) to 60° left (–60°) when facing the speaker. All off-axis plots are referenced to the on-axis response, which appears as a straight line at 0.00°. For this reason, the plotted curves show the change in response as you move off axis. For good stereo imaging the off-axis curves should be smooth replicas of the on-axis response with the possible exception of some tweeter rolloff at higher frequencies and larger off-axis angles.

Referring to *Fig. 5*, notice that the off-axis response beyond 10° peaks by 7–8dB relative to the on-axis at 7.7kHz. Above this frequency the spectral character of the off-axis response differs substantially from that of the on-axis response. This means that the speaker may sound different as you move off axis. The extent of this difference will be highly dependent on the spectral shape of later arrivals coming off the listening walls, floor, and ceiling.

The peaking in off-axis response of *Fig. 5* can be explained by examining *Fig. 6*. On-axis response dips at 7kHz while the response at 20° off axis peaks. When the two responses are differenced, you get a large peak around 7kHz.

The average response over a 60° horizontal window (±30°) in the forward direction is a good approximation of the way a speaker will sound in a typical listening environment. This response is plotted in *Fig. 7* and is a bit smoother than the on-axis first arrival response, but you still see peak-to-peak response variations of 6dB.

Figure 8 is the waterfall plot of vertical polar

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response. Responses are shown in 5° increments from 25° below (–25°) the tweeter axis to 25° above it. Change in off-axis response in the vertical direction is similar to horizontal off-axis response. This is a consequence of the circular symmetry of the coaxial driver.

HARMONIC DISTORTION

I ran harmonic distortion tests at an average level of 90dB SPL. Ideally, harmonic distortion tests should be run in an anechoic environment. In practice, it is important to minimize reflections at the microphone during these tests. Out-of-phase reflections can produce false readings by reducing the level of the fundamental while boosting the amplitude of a harmonic. In order to reduce the impact of reflections, I placed the microphone at 0.5m from the loudspeaker and response was gated to largely eliminate later reflections.

Second and third harmonic distortions at 50Hz and 90dB SPL were 3.6% and 2.6%, respectively. This is a good result. Third- and higher-order distortions all fell below 1% above 80Hz, a very good result. Second harmonic distortion persisted above the 1% level until 200Hz.

INTERMODULATION DISTORTION

I measured intermodulation distortion next. In this test two frequencies are input to the speaker. Intermodulation distortion produces output frequencies that are not harmonically related to the input. These frequencies are much more audible and annoying than harmonic distortion. Let the symbols f_1 and f_2 represent the two frequencies used in the test. Then a second-order nonlinearity will produce intermods at frequencies of $f_1 \pm f_2$. A third-order nonlinearity generates intermods at $2f_1 \pm f_2$ and $f_1 \pm 2f_2$.

I examined woofer intermods first by inputting 400Hz and 550Hz signals at equal levels. These frequencies should appear predominantly in the woofer output. Total SPL with the two signals was adjusted to 90dB at 1m. Significant woofer IM products appeared at 950, 1350, 1500, and 1900Hz. However, the overall level was only 0.48%, a better than average result.

I measured tweeter intermods with a 9kHz and 10kHz input pair adjusted to produce an 87dB SPL at 1m. Because steady tones are used in the IM test, I thought it safer to use a lower power level to prevent possible tweeter damage. IM products were observed at 8, 11, 12, 18, and 19kHz. However, total distortion was only 0.084%, a very good result for tweeters.

The last IM test examines cross-intermodulation distortion between the woofer and tweeter using frequencies of 400Hz and 9kHz. Ideally, the crossover should prevent high-frequency energy from entering the woofer and low-frequency energy from entering the tweeter. IMD products appeared at 8600 and 9400Hz at a level of 0.07%. This is a fairly typical result and indicates good inter- driver isolation by the crossover.

SPEAKER MATCHING

All of the tests results reported so far were obtained from a single sample. Now you can look at how well the two speakers match in frequency response. *Figure 9* is a side-by-side plot of the two HE10.1s. The second sample is offset by +10dB for clarity.

Notice the deep notch in the response of the second unit. The notch is 24dB deep at 2800Hz. The average depth is about 12dB and it is an octave wide. This notch is in the critical presence region and should be quite noticeable. Above 4kHz the second sample shows peak-to-peak response variations of 15dB.

A frequency response plot of the difference between the two samples is shown in *Fig. 10.* The two HE10.1s match quite well up to 2kHz, but differ in the next octave by as much as 15dB.

AUTHOR'S COMMENT

The HE10.1 has a split personality. It has ex-

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cellent step response and low distortion combined with very poor frequency response. The HE10.1 would seem best suited to PA and other sound reinforcement applications. I would not recommend it for hi-fi music reproduction. ❖

REFERENCES

1. *audioXpress*, September 2001, p. 58.
2. J. D'Appolito, *Testing Loudspeakers*, Audio Amateur Corporation, Peterborough, NH, 1998.

A note on testing: The Adire HE10.1 was tested in the laboratories of Audio and Acoustics, Ltd. using the MLSSA and CLIO PC-based acoustic data acquisition and analysis systems. Acoustic data was measured with an ACO 7016 ¼″ laboratory grade condenser microphone and a custom-designed wideband, low-noise preamp. Polar response tests were performed with a computer-controlled OUTLINE turntable on loan from the Old Colony Division of Audio Amateur Corporation.

Manufacturer's response:

We appreciate the chance to have Ed, the founder of this venerable hobbyists' resource, build and review our high-efficiency HE10.1 kit. However, we are sorry that it appears the crossover installation and system review process were rather rushed and abbreviated, disallowing proper crossover assembly and driver phasing to be checked before the kit was evaluated. We received no support calls regarding this kit as suggested in the troubleshooting section of the instructions.

There are two small errors in the details listed for the kit. We list a 95dB sensitivity on the website and in the manual and the price is $299 for the pair, not $279. The kit plans now show a 4″ vent and the parts we've supplied for the last 12 months include this vent and the required polyfill; Ed ordered this kit shortly after it first became available over a year ago before these changes had been made.

In regards to Ed's choice to flush mount the woofer and round the cabinet edges, these are not as necessary with a speaker of this design as with others. The large midbass cone and embedded horn tweeter control directivity such that there is less signal to diffract off basket and cabinet edges. The additional steps taken by Ed certainly do not hurt, but they are not as necessary as in other designs.

We suggest an alternative to routing the driver and vent holes in the individually-cut panels. Cut the holes first, in the partial sheet of MDF, before cutting and separating the individual panels. This allows much easier clamping and routing. Of course, this does not apply to rounding the cabinet edges.

Ed also notes that printed plans were not automatically included in the box. For years we have reversed the typical method of not showing the design plans to the customer until after purchase; rather we make the complete plans available for inspection on our website before the customer makes their purchase decision. With a majority of our customers finding us and ordering through the Internet (including the builder in this review), we find this to work well in 99% of all cases. However, we are more than happy to print and include or mail instructions for any customers who request them.

We'd like to point out a design feature upon which Dr. D'Appolito failed to comment. The impedance shown in Fig. 1 *varies less than most loudspeakers, thus being a more benign load to amplifiers. In particular, the HE10.1 will retain its frequency response better with a wider range of amplifiers than loudspeakers with large impedance variations, especially with those amps having higher output impedances like single-ended and low- or zero-feedback amplifiers. Specifically tube-based amplification is a natural complement to the HE10.1 and is the usual combination. Flat impedance is of definite ben-*

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efit when used with most tube amps.

It appears that there may be a problem in the wiring of the second speaker's crossover. The frequency-response dip is akin to one caused by inverted phasing of the tweeter and noted in the troubleshooting section of the instructions, and is at a point consistent to what we would expect with a phase reversal of the tweeter. We were able to replicate the reviewers' experience when we intentionally mis-phased one tweeter in our listening room. No effort appears to have been made to compare the two speakers before evaluation, which might have caught this dip. We regularly help customers find and solve such problems when they arise. Just from the picture we can tell that the component connections appear to be correct in the one crossover shown, leaving the possibility of a reversed connection to the terminal strip.

There are a number of tests the builder can perform to check their wiring, most of which require no extra tools. We will be expanding the troubleshooting instructions to include these suggestions. The first test we suggest is to run the speakers in a normal listening setup with the same signal going to each (i.e. monaural), and compare audible output, ideally with a frequency sweep (test CD or computer). The image should be dead center unless there is a mismatch between speakers like the one noted. In the case of the pair reviewed here, the image would have pulled away from the affected speaker when the frequency was near that of the measured dip.

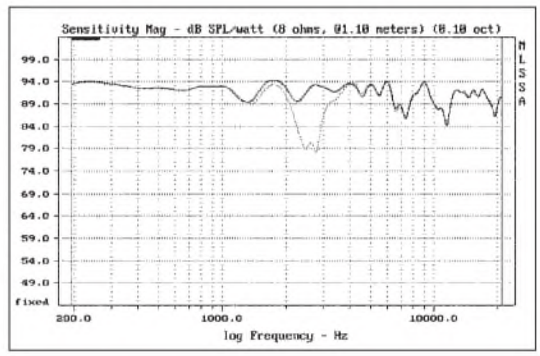
One of the speakers can be connected in reverse and the test repeated with the speakers facing each other, looking for consistent cancellation of the output. In the reviewed case, an increase of combined output would have been noted in the range of the dip. The DC resistance of the speakers can be measured with an ohmmeter (DVM, DMM, and so on) to make sure they are at least close to one another.

It is unfortunate that the reviewers' comments about timbre and frequency response were likely negatively influenced by a mistakenly reversed driver connection. It is an indication of good sound that despite this error, the sound was judged reasonably good. Judging by comments from other customers, a review in a UK publication, and visitors to our display booths, the reviewers would likely have had an even more favorable opinion of the sound if the error had been detected and fixed before the listening and measurements began. We hope to be in further contact with Ed to determine the problem with his second speaker. ❖

Dave & Dan
Adire Audio

Joe D'Appolito responds:

This frequency response plot shows the second Adire system as auditioned (dotted) and as corrected after reversing tweeter leads (solid). The crossover was wired correctly as indicated by the red dot on the tweeter terminals. Unfortunately, the terminals are mismarked. This is an Adire error. A DIY builder would have no way of knowing the tweeter was polarity-reversed.



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Bandwidth (10kOhm):	50	MHz
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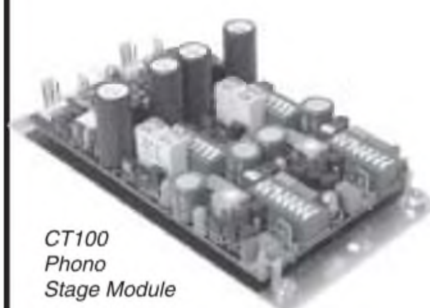
Attenuation accuracy:	±0.05	dB
Channel matching:	±0.05	dB
Mechanical life, min.	25,000	cycles



CT100
Phono
Stage Module

CT100 key specifications

Gain (selectable):	40 to 80	dB
RIAA eq. deviation:	± 0.05	dB
S/N ratio (40/80dB gain):	98/71	dB
THD:	0.0003	%
Output resistance:	0.1	ohm
Channel separation:	120	dB
Bandwidth:	2	MHz
PCB dimensions:	105 x 63	mm
	4.17 x 2.5	"

CT101 Line Stage Module
with a stereo CT1 attenuator added.

CT101 key specifications

Gain (selectable)	0, 6 or 12	dB
Bandwidth (at 0dB gain)	25	MHz
Slew rate (at 0dB gain)	500	V/uS
S/N ratio (IHF A)	112	dB
THD	0.0002	%
Output resistance	0.1	ohm
Channel matching	± 0.05	dB
PCB dimensions:	100 x 34	mm
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Product Review

Behringer DSP8024

Reviewed by Charles Hansen and Bill Fitzmaurice

Behringer Ultra-Curve PRO DSP8024 2-Channel Digital Graphic/Parametric Equalizer-Analyzer, Behringer Spezielle Studiotechnik GmbH, Hanns-Martin-Schleyer-Strasse 36-38, Willich-Münch-heide II, Germany, +49 (0) 21 54/92 06-0, Fax +49 (0) 21 54/92 06-30, www.behringer.com; list price $230 U.S.; dimensions: 3.5″ (89mm) H × 19″ (483mm) W × 12″ (305mm) D; net weight: 11 lbs (5kg); warranty 1 year; service available at Behringer USA, Edmonds, Wash.

The DSP8024 is a 24-bit digital audio processor, featuring a real-time analyzer with Auto-Q function for automatic room measurement and correction, a 31-band graphic equalizer, and three-band parametric equalizer. Additional functions include a peak limiter, an adjustable digital delay, a noise gate, and a feedback destroyer feature. Two analog line inputs and one microphone input are provided through XLR and stereo phone jacks. An optional AES8024 feature adds AES/EBU digital inputs/outputs to the DSP8024, but this was not provided with the review unit.

You can copy, compare, add, or subtract EQ and analyzer curves, and 100 user memory locations are available.

Three level meter references are provided: dBu (dB in reference to 1mW at 600Ω, equal to 0.775V RMS); dBV (dB relative to 1V peak-to-peak); and DIG-MAX referenced to maximum output level. If overload occurs, either from excessive analog signal levels or due to digital signal processing limitations, the green LED above the IN/OUT switch turns red.

The 36-page user's manual is extremely well written, with useful illustrations, examples, and connection diagrams for every application.

PHOTO 1: Front view of unit.

PHOTO 2: Rear view of unit.

TABLE 1
MEASURED PERFORMANCE

PARAMETER	MANUFACTURER'S RATING	MEASURED RESULTS
Analog input impedance:	50k balanced 25k unbalanced	49k5 balanced 24k9 unbalanced
Max analog input level:	+21dBu balanced/unbalanced	8.7V RMS (+21dBu)
Mike input impedance:	2k balanced	1k97 balanced
Mike operating level:	-60dBu to 0dBu	
Max mike input level:	+1dBu	0.87V RMS (+1dBu)
CMRR:	40dB typ., >55dB at 1kHz	
Output impedance:	60Ω balanced 30Ω unbalanced	98Ω balanced 48Ω unbalanced
Max output level:	+16dBu balanced/unbalanced	4.64V RMS (+15.5dBu)
Frequency response:	20Hz – 20kHz, +0/–0.5dB	20Hz – 20kHz, +0/–0.2dB
Signal to noise ratio:	103dB unweighted, 22–22kHz	Below noise floor
THD+N:	0.004%, 1kHz +4dBu	0.0039%, 1kHz +4dBu
IMD - CCIF (19+20kHz):	N/S	<0.0032%
Crosstalk:	<–103dB, 22–22kHz	Below noise floor
AES/EBU digital input impedance:	10k balanced, 3–10Vpp	(Not provided)
AES/EBU digital output impedance:	100Ω balanced, 5Vpp	(Not provided)
Graphic equalizer:	+16dB to –16dB, 0.5dB steps	verified
Parametric equalizer:	+16dB to –48dB, 0.5dB steps, 1/60 to 2 octaves bandwidth	verified
Feedback destroyer:	Down to –48dB, 1/60 to 12/60 octaves bandwidth	Not tested
Digital delay:	0.1ms to 2.5s, each channel	Not tested
Level meter:	60dB/s RMS, one sample peak, 20dB/s decay	
Noise gate:	Threshold -44dB to -96dB, 1dB steps	Not tested
Limiter:	Threshold 0dB to -36dB, 1dB steps, 500 to 5000ms	Not tested
Power requirements:	30W maximum	
Lithium battery life:	3 years typ.	

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INSIDE THE EQUALIZER

The Behringer DSP8024 has a black painted steel chassis and 3mm thick aluminum front panel. The unit is designed to be rack-mounted, but you can easily remove the rack supports for shelf mounting. Four adhesive rubber feet are included for this purpose. "BEHRINGER" is spelled out in the cooling louvers on the top cover.

Photo 1 shows the front panel of the Behringer DSP8024, with its 240 × 64 backlit LCD display. The four larger switches on the left control the equalizer (EQ), the real-time analyzer (RTA), signal path IN/OUT switch, and a Setup key to access menus. The four, smaller vertically oriented switches are softkeys, whose functions change depending on the operating mode. They line up with corresponding pictograms on the display. Four cursor control keys are located in a diamond pattern to the right of the display.

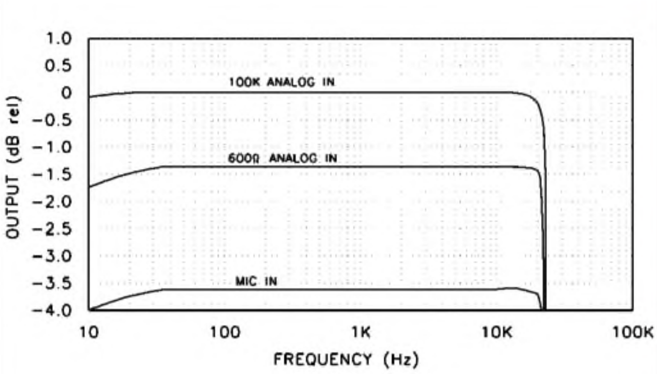


FIGURE 1: Frequency response.

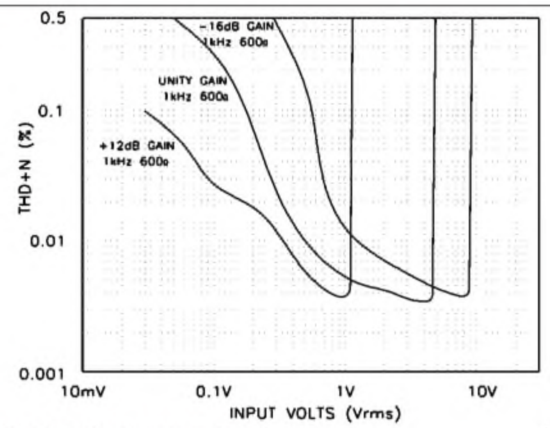


FIGURE 3: THD+N versus input.

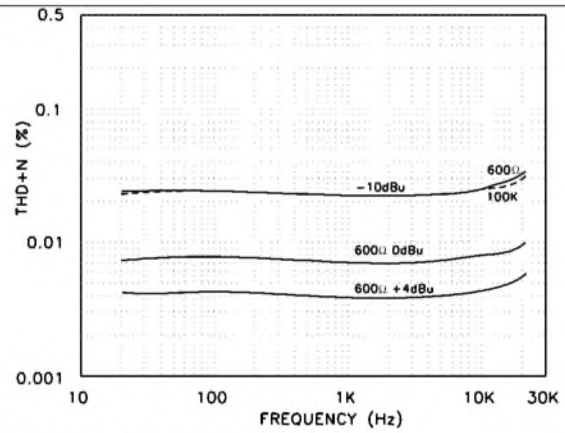


FIGURE 2: THD+N versus frequency.

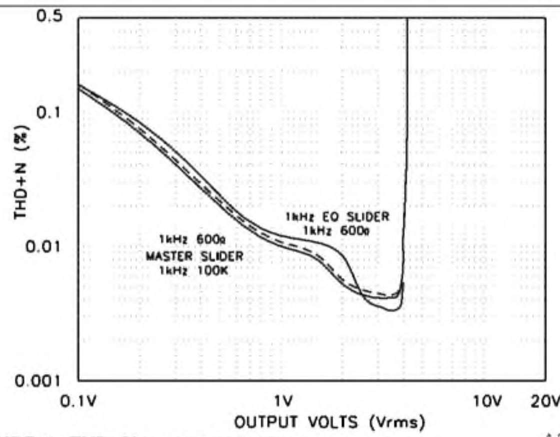
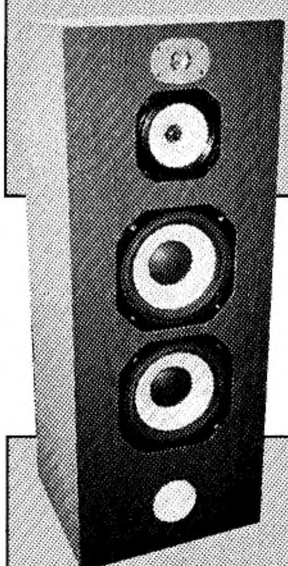


FIGURE 4: THD+N versus output.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The rear panel (*Photo 2*) has the IEC power receptacle, with the power switch just above it. The unit is furnished with a heavy power cord. A line fuse is located in a drawer in the IEC receptacle. The third pin of the AC receptacle is connected to the chassis.

To the right of the IEC are a number of connectors. A blanking plate covers the cutouts for the AES/EBU digital input/output jacks on the review unit. Just below this plate are MIDI out, through, and input DIN connectors. Next are stereo pairs of analog output phone jacks and gold male XLR jacks. To their left are stereo pairs of analog input phone jacks and gold female XLR jacks. Finally, there is a gold female XLR mike connector that also provides +15V phantom power.

Photo 3 shows the interior of the DSP8024. With the eight cover screws and the cover removed, the side and bottom plates are interlocked with tab-in-slot construction that wiggles around quite a bit. The cover provides a fair amount of rigidity, so the unit is solid with the cover in place. You can con-

CRITIQUE: BEHRINGER DIGITAL 8024

By Bill Fitzmaurice

Not so long ago, if you wanted to have a graphic EQ, an RTA, an auto feedback controller, a limiter/noise gate, and a DDL for loudspeaker management, it would have required a rack full of processors. Now, thanks to the digital revolution, you can get all of those toys combined in a single piece of gear, at a price less than any one of those separates might have cost only ten years ago.

The generic term for a processor that combines all of those elements is LMS, for Loudspeaker Management System. One such unit is the Behringer Ultra-Curve Pro DSP8024. Behringer is a German company that engineers its products with typical German attention to quality and detail, but avoids Mercedes-like pricing by having its factory in China. With a "street" price of less than $400, the 8024 offers both versatility and value.

When Ed Dell asked me if I'd like to review the DSP8024 for *audioXpress*, it was serendipitous to say the least, since I've owned a DSP8024 for about a year now. My experience with the 8024 has been almost totally positive, and I wouldn't hesitate to recommend it to anyone looking to upgrade his or her sound system.

While intended primarily as a tool for professional sound reinforcement and studio duty, the DSP8024's capabilities may well make it a worthwhile addition to most home stereo systems as well. Why? Because the RTA and EQ features of this two-rack space box can correct the sonic deficiencies inherent in practically any room/speaker combination.

WHAT IT CAN DO

First, you may use the 8024 as a stereo graphic EQ. It does that job exceedingly well, far better than analog designs, as its digital filters reduce the overlap between EQ bands to negligible. I find the EQ to be very natural sounding, adding no texture of its own to the sonic palette.

Claimed S/N ratio is 103dB unweighted, and I have found no reason to doubt that spec. Even with high frequencies boosted to the max, there is no self-noise added, as is the case with analog circuitry. In addition to its dual ⅓-octave EQs, the 8024 also offers a pair of three-band shelving filters with user adjustable corner frequencies, and a pair of three-band parametric filters. Whatever EQ chore you want to accomplish, this rig will do it and do it well.

Next is the RTA [Real Time Analyzer]. When that function is engaged, the unit's LCD screen displays a graphic representation of the signal passing through the unit, broken down into ⅓-octave bands. You may select the displayed signal from the stereo program input, an external microphone, or onboard generators capable of producing pink noise, white noise, and sine waves. In RTA mode the 8024 can measure everything from speaker response curves to room resonance nodes with ½dB resolution.

One drawback, however, is that while the unit will show you the frequency content of a speaker's output, it cannot measure the output level. If you wish to determine a speaker's sensitivity as well as its frequency response, you'll need a separate dB meter.

Perhaps the most useful function, especially for home stereos, is the "auto-Q." Hook the 8024 up to your system to play pink noise through your stereo, and it will use the microphone input [Behringer offers a reasonably priced and surprisingly accurate mike for the purpose] to measure the system/room response. The unit then automatically adjusts the graphic EQ for flat response. I use my 8024 in my recording studio for just this purpose, and the difference it makes is quite dramatic, even with accurate speakers in a non-resonant room.

The 8024 is even more useful in live sound-reinforcement applications. Auto-Q will appreciably clean up a PA system, especially in the typically poor acoustic environments that most clubs tend to have. Once you've used the auto-Q to get the room/system response flat, you can tweak the individual EQ bands as necessary to fine-tune to your personal preference [since the 8024 will set response flat to 20Hz, it's also a good idea to roll off mains response below 60Hz and monitors below 120Hz to protect your speakers and preserve amp headroom].

Having done that, you next engage the Feedback Destroyer function, which uses the parametric filters to "search out and destroy" microphone feedback. Then you set the output threshold of the limiter, adjustable from −36 to 0dB. This will protect your speakers, and your audience's ears, by limiting how much signal can go into your power amps.

Got a noisy PA? Set the noise gate threshold to allow the music through when you're playing a song, but stop the noise when you're in between tunes. If you don't run your PA in stereo, you can split the 8024's two channels, using one to control mains, the other monitors. If you have a really big PA system—and I'm talking "Woodstock" big here—the 8024 has a built-in delay line to adjust the feed to speakers flown over the audience. The only feature lacking is an active crossover, which you probably already have in your rack anyway, and the 8024 costs about a hundred bucks less than LMS processors that include one.

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The beautiful glass epoxy PC board is the picture of digital convergence, looking as though it would be just as much at home in a personal computer. Most of the parts are surface-mount types, including resistors and non-electrolytic caps. The PC board connects to the display and front-panel switches via three ribbon cables.

TOPOLOGY

A schematic was not furnished with the unit, but the manual has a detailed block diagram. Each analog signal is input to an NJM4580 dual op amp connected as a servo-balanced amplifier.

The right input is dedicated, while the left input can select either the left line signal or the mike input. Another 4580 boosts the mike input by +20dB. The StereoLink function can form the two channels into a stereo pair, even if unrelated.

The analog stereo signals are then input to an AKM AK5392 24-bit 48kHz analog-digital converter (ADC). The digital output goes to a pair of TI TMS57002 DSP chips, which are very popular in musical synthesizer effects and computer gaming boards. These DSP chips perform all the gain control, digital filtering, equalization and limiting functions, as well as the digital delay. An Intel 80C31-12 microcontroller running Behringer software stored in a large EPROM handles func-

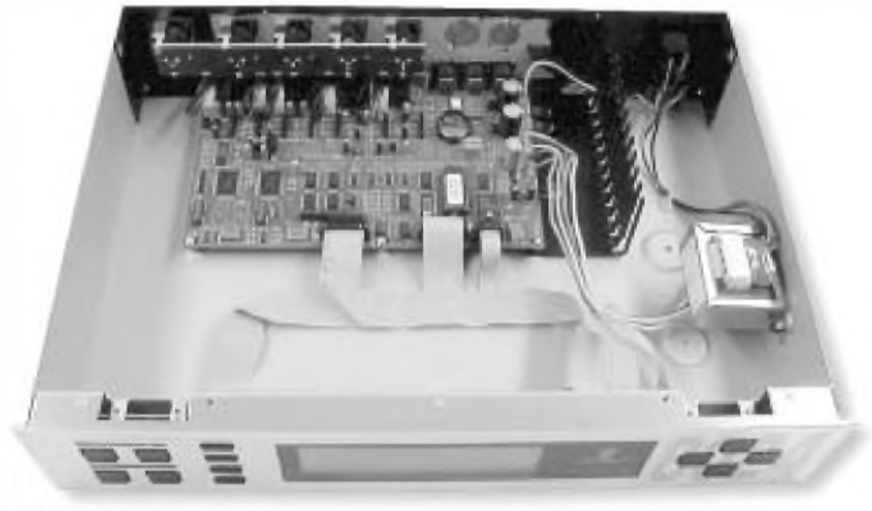

PHOTO 3: Interior view.

OPERATION

The controls of the 8024 are typical of today's processor-controlled gear in that you use pushbuttons and the LCD display to access its parameter controls. There are no sliders or rotary pots—in fact, no knobs at all—and unlike analog gear, there is very little about controlling this unit that is intuitive. I figured out how to use the controls with little difficulty, but then I already owned a similarly operated digital console.

If this is your first CPU effects box, getting used to the menu scrolling process could be daunting. There is a comprehensive 50-page owner's manual, but even getting through that may require the aid of a 12-year-old computer wiz. Unfortunately, this situation is pretty much true with any gear that squeezes as many functions as this one does into such a small package.

However, once you set everything the way you want it, you can put everything into memory and store it, with 100 memory locations available. This is most valuable for live-sound work, because you can store the settings for a venue and recall them when you go back for a return engagement, instead of having to reprogram from scratch. The 8024 is MIDI controllable if you're into that, and you may also use its MIDI interface to integrate the 8024 with a computer for both remote control and remote display.

For home use you might consider many of the 8024 features to be unnecessary, which is probably true if the auto-Q function is likely all you'd want. But if you want to buy a processor that only offers digital EQ and RTA functions, you'll likely end up spending just as much. When I bought my 8024 I shopped around for pure RTA/EQ units, found there are very few on the market, and none of them offer a better performance and price value than the 8024. While you may not need its live performance features, you're getting them essentially for free.

As to spending about four hundred bucks on an EQ for home stereo, consider this. You can spend thousands on a set of high-end speakers that may give response within 2dB of flat, or you can use auto-Q to achieve near perfect response from even modestly priced speakers, while compensating for room acoustics at the same time. Purists may recoil at the thought of using an RTA/EQ in their system, but the reality of the situation is that many studios today use RTA/EQs, and there is a good chance that a recently produced CD was engineered with an RTA/EQ in the signal chain. Mine was. ❖

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tion switching and display control. Lots of high-speed CMOS glue logic is evident on the board.

Two Alliance 1MB × 4 DRAM chips and a Windbond 32K × 8 SRAM chip handle memory requirements. A lithium backup battery maintains the RAM memory when power is turned off. A Dallas DS1210 nonvolatile controller monitors the battery status and write-protects the RAM contents. The unit always returns to its last used functions when turned back on.

Once processed, the analog signals are restored by a Cirrus Logic CS4390 24-bit, 48kHz stereo digital-analog converter (DAC). The DSP8024 has adjustable system sampling rates including 32kHz (AES/EBU only), 44.1kHz, and 48kHz. The default analog signal sampling rate is 48kHz. Digital de-emphasis is provided for 32kHz (AES/EBU only), 44.1kHz, and 48kHz.

Finally, the analog signals are connected to the output jacks through their own 4580 servo balanced op-amps circuits. As with the inputs, the output amplifiers maintain the same gain whether balanced or unbalanced output connections are used.

MEASUREMENTS

The review unit did not have the optional AES/EBU digital interface, so testing is limited to the analog inputs and outputs at 48kHz. I found that there was no change in gain going from balanced to unbalanced inputs or outputs. You would normally expect 6dB more gain through the balanced connections, but the DSP8024 servo-balanced output stage detects the type of signal and adjusts the gain accordingly.

I ran both channels at 0.5V RMS in, 2V RMS out for one hour into 600Ω. The DSP8024 preserves normal polarity. The tips of the phone jacks and pin 2 of the XLRs are wired "hot." You can use a standard mono phone plug as an unbalanced input. The input impedance measured 24k9 unbalanced and 49k5 balanced, independent of volume setting. The output impedances for both channels measured 48Ω unbalanced and 98Ω balanced at 1kHz.

The DSP8024 showed unity gain when the equalizer and master sliders were all at 0dB. Hum and noise (+16dB gain setting, input shorted) measured 0.18mV, with a DC offset of 0.27mV. Viewing the analog output on an oscilloscope showed only random noise. Relays mute the output during startup and shutdown, and bypass the entire electronics section when you select the OUT mode.

The frequency response for the DSP8024 is shown in *Fig. 1*. I made these measurements at a volume setting corresponding to 2V RMS output with a 0.5V RMS test signal (12dB gain), with 0dBr defined as 2V RMS at 1kHz into 100k. It measured +0/–0.2dB from 20Hz to 20kHz.

With a 600Ω load,

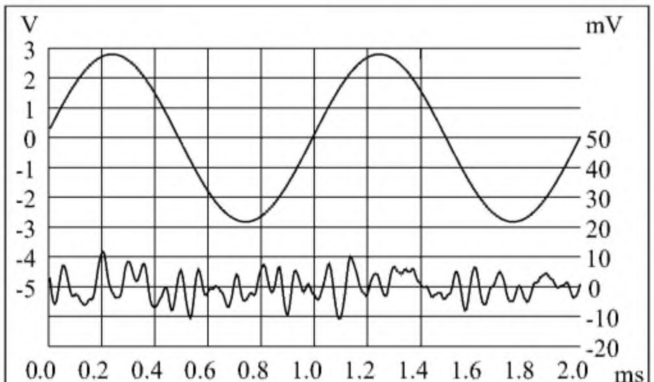

FIGURE 5: Residual distortion.

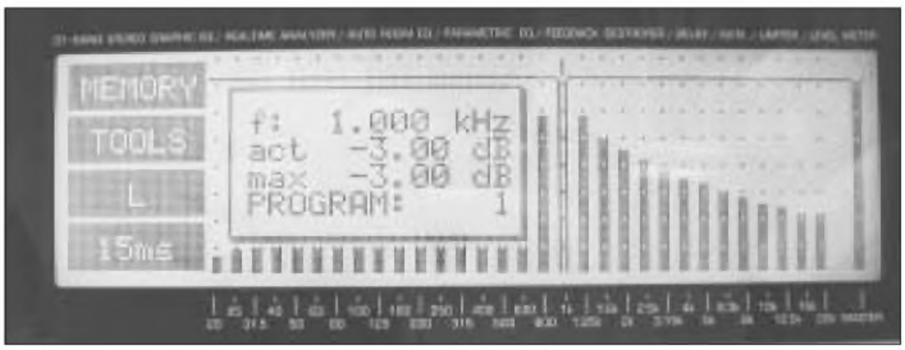

PHOTO 4: ⅓ octave RTA screen shot.

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the response was down –1.4dB with a slight bit more droop at the low end, possibly due to coupling capacitors in the analog output stages. The mike input showed the same flat response. Its output was actually at –14.9dBr, so I shifted the curve up to –3.7dB to keep it on the graph. HF response rolls off rapidly above 22kHz, where the LP digital filter kicks in.

The ⅓ octave RTA display of my 0.0025% THD 1kHz sine wave test signal is shown in *Photo 4*. The fundamental is –3dB, with the two adjacent bars (800Hz and 1.25kHz) showing –14.5dB. Crosstalk performance was impeccable, being near the noise floor until 20kHz, where it increased to –90dB.

The DSP8024 provides a master gain range of ±16dB. Volume control tracking between channels was perfect.

When I started measuring distortion, I found the DSP8024 had a somewhat limited range of input/output level combinations where the distortion was below 0.01%. The input voltage clipping point was 8.7V RMS (+21dBu), beyond which the DSP8024 goes into hard "brick wall" clipping. For any combination of volume setting and input signal level, the output clipping point was always limited to 4.64V RMS.

You must take maximum advantage of the input level overhead to keep the distortion low. Low-level analog sources or mikes with low output will tend to produce more output distortion. The least distortion occurs just below where the red digital overload indicator activates.

Operating the DSP8024 at the –10dBV consumer reference level will limit the dynamic range much more than the pro-audio +4dBu reference level. The DIGMAX reference level represents the true maximum output level (0dB peak, –3dB RMS). In all cases, the red overload LED signals the start of digital clipping. You should avoid this at all times because it is not harmonic distortion, but rather harsh and objectionable noise.

Figure 2 shows the THD+N versus frequency. I engaged the test-set 22kHz low-pass filter to limit the out-of-band noise. The top curve is with a 0.65V RMS input level and +10dBu volume setting, 100k and 600Ω loads.

Next, I intentionally set the input level to 2V RMS to obtain lower distortion. The middle curve is 0dBu into 600Ω. The bottom curve is at +4dBu with a 600Ω load.

Figure 3 shows THD+N versus input voltage, plotting a 1kHz signal into 600Ω loads for +12dB, unity gain, and –16dB volume settings. Here you can see the relatively high distortion when input signals are at lower levels. You can also see that output clipping limits the amount of input signal that can be applied.

Figure 4 shows THD+N versus output voltage into 100k and 600Ω loads, using a 1kHz 0.65V RMS input signal. I varied the volume settings to increase the output signal rather than increasing the input signal. Output clipping limits the amount of gain that can be applied.

There was very little difference in performance whether I used the master volume slider or the 1kHz EQ slider for gain changes. When I switched the DSP8024 out of the loop, sending the input signal directly to the output connector via the unit's bypass relays, the THD+N dropped from 0.0042% to 0.0035% (the test set residual THD level is 0.0025%).

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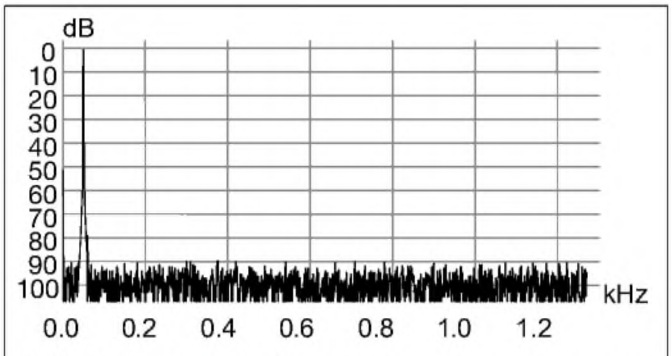

FIGURE 6: Spectrum of 50Hz sine wave.

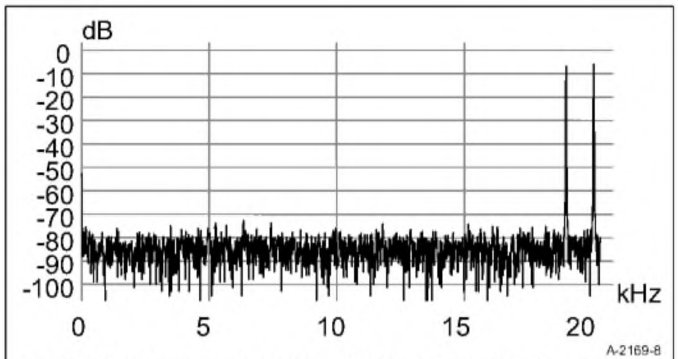

FIGURE 8: Spectrum of 19kHz + 20kHz intermodulation signal.

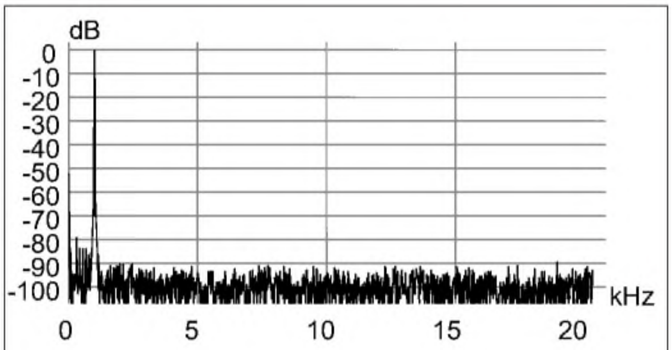

FIGURE 7: Spectrum of 1kHz sine wave.

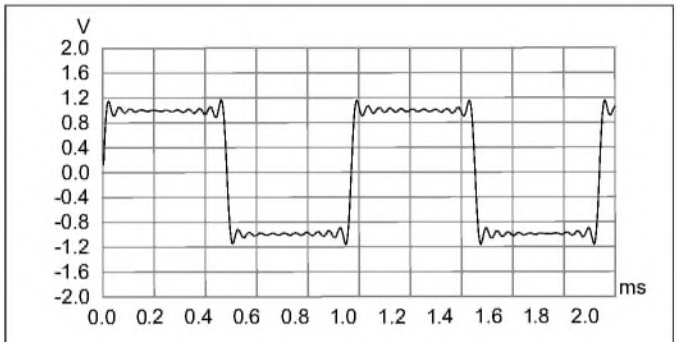

FIGURE 9: 1kHz square-wave response.

The distortion waveform for 2V RMS into 600Ω at 1kHz is shown in *Fig. 5.* The upper waveform is the amplifier output signal, and the lower waveform is the monitor output (after the THD test-set notch filter), not to scale. This distortion residual signal shows just a bit of high-frequency noise, which is of no significance since THD+N at this point is just 0.0039%. As the input level is reduced this noise increases rapidly. Since data is theoretically processed at 24-bit 48kHz, this suggests either the input ADC or (more likely) the output DAC may not have true 24-bit performance.

The spectrum of a 50Hz sine wave at 2V RMS into 600Ω is shown in *Fig. 6*, from zero to 1.3kHz. The THD+N measured 0.0042%, with no obvious harmonics present. The only peak above the noise floor is at 60Hz, and this is almost –80dB down. I expanded the spectrum to 20.8kHz using a 1kHz test sine wave (*Fig. 7*) with similar results.

Figure 8 shows the output spectrum when the DSP8024 reproduced a combined 19kHz + 20kHz intermodulation distortion (IMD) signal at 11Vp-p into 600Ω. The 1kHz, 18kHz, and 21kHz products are lost in the noise floor of my test equipment. Repeating the test with a multi-tone IMD signal (9kHz + 10.05kHz + 20kHz, not shown) produced similar results.

SQUARE-WAVE TESTS

The 2Vp-p square wave into 600Ω at 1kHz (*Fig. 9*) exhibits the Gibbs phenomenon ringing associated with the steep digital filters used in the DSP section of the DSP8024. For the same reason, the 10kHz square wave (not shown) was rounded over into nearly a sine-wave shape. A 40Hz square wave (also not shown) had very little tilt at 100k load, and only slightly more tilt with a 600Ω load. During sine testing, as the sine-wave output level increases beyond the initial clipping point, there was an increased amount of this Gibbs phenomenon ringing.

Manufacturer's response:

The ULTRA-CURVE DSP8024 represents digital mainframe technology at its best. Some remarkable engineering went into the design of the unit. The impressive result is an all-in-one professional equalizing solution for live, studio, and even home stereo system applications—yet it retails at a price that's

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more consumer electronics than typically pro audio oriented.

The ULTRA-CURVE's digital 24-bit dual-DSP mainframe architecture is based on two extremely powerful, high-speed DSPs, first-class 24-bit A/D and D/A converters from either CIRRUS LOGIC® or CRYSTAL®, ensuring impressive specs that were nicely underscored by the review's meticulous test results.

With its broad range of functions and outstanding audio quality, the ULTRA-CURVE PRO DSP8024 is ideally suited for demanding users and applications. Left to mention is the relay-controlled hard bypass with auto bypass function that guarantees uninterrupted operation in case of power failure. No matter what your application, the ULTRA-CURVE PRO puts you in total command.

For example, Scott Schenk, monitor engineer for Dwight Yoakam, Smashmouth, Third Eye Blind, and others, likes the DSP8024 because it provides him with perfect control over individual signals. For Scott, the equalizer is also top-notch for in-ears, parametric and third-octave equalization, while the unit's limiter and delay enable him to line up his musicians' in-ears with monitor speakers.

In order to keep up with the fast pace of technological progress, the 8024 features an open architecture for easy software updates. Free Windows® editor software and a new firmware release v. 1.3 is downloadable from the BEHRINGER website.

For those who prefer a more purist equalization approach, the TUBE ULTRA-Q T1951 2×4-band parametric tube equalizer with 12AX7 vacuum tubes and BEHRINGER's trademark ULTRA-TUBE circuitry technology may be the solution. BEHRINGER's range of equalizers currently embraces four parametric and graphic tube and solid-state equalizers. ❖

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Thanks very much for the wonderful resources you've made available to all of us interested audio amateurs. I've been a subscriber, off and on, to one or another of your publications almost since their inception many years ago.

Though I haven't built as many projects as I've wanted, the ones I have followed to fruition—or that have served as inspirations for my own explorations—have been priceless. Always a good read, I look forward to each and every issue.

I noted with great interest your own project article, describing construction of Joe D'Appolito's THOR project speakers (Sept. '02 *aX*). I am seriously considering building a pair myself and was wondering what kind of performance character they now exhibit with a bit more break-in time. I note that you mentioned at the time of writing their treble seemed a bit prominent to you. Has this tamed down somewhat?

I appreciate any sort of analysis or characterization you might have to offer, before I commit to what is a sizable purchase of drivers and parts.

Steve Zettel
Libby, Mont.

I am using a stereo Zen amp for each channel, left and right. That means that 10W is being fed to the tweeter and another 10 to the two woofers. The break-in has not changed the character of the speakers. I've simply cut the treble control on the preamp to 11:45 and boosted the bass to 12:15, which seems about right. One of these days I'll calculate what kind of resistor I need to pad the tweeter signal slightly and set the tone controls to 12—or zero.—Ed

I have been suitably impressed by your efforts in constructing a pair of THORs, and by your comments about their performance. Much credit is due to you for taking so much trouble in their construction, and they look very nice, too.

I also note that you said you have tried them with some Zen amps, which makes me wonder whether they might just be satisfactory with perhaps a Son of Zen (SOZ) variant, and I would be extremely grateful if you could answer the following points.

1. What is the output of the Zen amps you used, without bridging, which you said you may try later? Is it merely the 10W per channel of the "original" Zen?
2. What is the approximate size of the room you use them in?
3. Did you find this single Zen amp power adequate, or did you later find that bridging was necessary (or a different higher powered amp) in order to achieve realistic sound levels?
4. If a single Zen (10W) was not enough, could you guess (without fear of any later blame!) at a minimum output

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necessary for a single-ended SS amp such as a SOZ?

5. In your opinion, is the THOR design a good partner for these low-powered, single-ended SS amps, or should I keep on looking elsewhere for some speakers?

Bob Kenyon
Bob.kenyon@virgin.net

Edward T. Dell responds:

1. Output is 10W per channel. I use one amp to drive each speaker—one channel to the tweeter and the other to the two woofer/mids. I haven't bothered to try the bridged.
2. My room is 11'W × 15'D × 7'3" high, with a 4' door on the left side wall at the rear and a 7' opening into another room at the back, right.
3. The two, 2-channel Zens seem more than adequate with the level control on my Adcom preamp at 12 o'clock.
4. Since I don't find the Zen pair inadequate, I haven't had to guess about power.
5. I can't speculate about what SE amps in general might sound like with the THORs. Sorry. I think if you used four reasonably powered monoblocks, a clean 6–8W, with the THORs, you are likely to be quite satisfied with the levels.

I did an experiment in the '60s with monitoring source material from FM broadcasts and LPs over several hours. Only very rarely did my instruments show anything on the meters above 2W. How clean the signal is, is far more important than its power level.

SQUARING THE CIRCLE

For the ingenious construction of the tractrix horn (Sept. *aX*, p. 28), some readers who do not want to hang their horns from the ceiling might consider constructing a rectangular rather than a circular dam for the concrete to aid mounting in a more conventional way.

I learned my electronic engineering on tubes and spent 20 years of my career designing aircraft computers using the whole range of solid-state devices. The more music I listen to through tube amplifiers and horn loudspeakers, the more I am convinced that "the shortest distance between two points is a vacuum" and that "three legged switches" cannot compete.

I have enjoyed all the articles in the new combined magazine. My fears that tube interests would be suppressed have proven unfounded. Thank you.

Alan Sanders
York, England

Robert Roggeveen responds:

Thank you for your constructive comment. The project as described here (Photo 1) examined prototypes in their most pure form. Hence, I extended the mouth's diameter beyond its calculated frequency cutoff by only 2" or less. Indeed, by aligning the horn's mouth to the same plane as a wall surface, the flange is extended, and this lowers the cutoff frequency of the horn. I did not want to prove that yet.

Further, there is a high degree of stability in the axisymmetrical design. By adding a flange of significant size, stability of the concrete mouth terminus is reduced. By adding "corner wings" to square the mouth, the stability is further reduced. So it is not without risk of breaking that you extend and rectangularize the circular concrete mouth. Certainly, do not mount the completed horn by the flange alone, because the screws anchoring the plywood to the concrete will not support the forces the horn's weight brings to bear.

You can integrate a square or rectangular flange to the circular terminus of the mouth with concrete at the same time you build up the horn. This might become very heavy, though, and is not advised. Alternatively, you may extend the flange with 1" marine plywood cut to size as needed. Choose dimen-

PHOTO 1: The author's axisymmetrical horn design.

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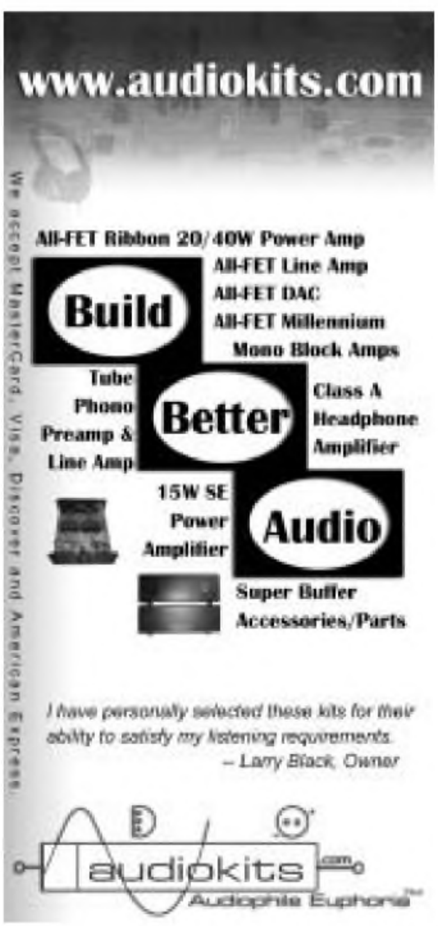

sions of the board so that at least 3″ of wood remain between the circle and the rectangle edges. To anchor the flange to the concrete, use the same principles as you would with the driver mounting plate.

Because the concrete mouth terminus will have a slight angle, about 10°, with the flange, mount the screws at the same angle. Use 2½″ screws drawn one-third in at 3″ intervals. Pre-drill the holes into the now circular wooden dam. The paper horn mold still needs a flat paper base disk larger than the diameter of the circle in the wooden flange by about 1″. You should glue this ½″ overlap to the wood flange to keep moisture from seeping out once the concrete is built up onto the mold. Use the bonding agent to smear on the 1″ thick circular edge of the flange and screws before applying concrete.

You may also choose to square the driver mounting plate. Use fir stripping instead of a paper dam, and paint the strips with some crankcase oil for easy dismantling. Making a back chamber is much easier this way, something I found out when trying different drivers on the 30″ diameter horn.

I made an interface plate from ¾″ plywood to mount a 15″ EV TRXB triaxial speaker on the big horn. That plate has a 9″ diameter throat and a squared circumference for easy mounting of a 1.5ft³ back chamber. This arrangement sounds great with a monoblock Leslie 147 tube amplifier. The –3dB point is at about 100Hz.

In the future I may report more formally on the results of my testing of various drivers on different concrete horns, and how I made an extension to the 30″ horn's 9⅞″ throat. Happy building and listening.

BATTERY TUBE CIRCUITS

I recently tried Mr. Lisle's battery tube hi-fi amplifier circuit (*GA* 3/97, p. 38). I didn't have one of the battery tubes mentioned, so I tried a small-signal triode. I figured it might work like in his "A Beginner's Push-Pull or Single-Ended Amp" (January 2002), which used a 6SN7.

I think most of the common small-signal triode tubes have a higher plate dissipation than the battery power pentodes. I had several 6C4s (half of a 12AU7) on hand, so I used the single-ended schematic according to the *GA* article with battery bias. It worked really well.

I also didn't have an interstage transformer, so I used a small step-down power transformer with a 120V primary and 24V secondary, a 5 to 1 ratio. I used the 24V secondary as the signal input and connected the 120V primary to the grid. I don't think it made the most ideal interstage transformer, but it worked well.

I also tried two 6C4s in push-pull. This time I used the schematic from the *audioXpress* article. I kept the battery bias instead of cathode bias as mentioned in the article. I just connected it to the center tap of the input transformer and didn't ground it. It also sounded great.

Again, I didn't use a standard input transformer. Instead, I had another one lying around and used it. I didn't have any power transformers with a center tap to use.

The secondary (what is normally connected to the speaker) was connected to the input signal. The primary (the side of the transformer normally connected to the plates of the tubes with the high voltage connected to the center tap) was the input to the grids of each tube in the push-pull circuit with the negative bias voltage connected to the red center tap. It's a 6000Ω 30W transformer with a common and 8Ω secondary. I didn't do the math to figure out how much it stepped up the input voltage. The push-pull circuit with the output transformer connected to the input sounded noticeably better than the single-ended circuit with the power transformer as its input.

I really like the all-battery power-supply approach to building an amplifier. It's a lot simpler to work with than a power transformer and the associated circuitry to go with it. I used thirteen 9V batteries for the high voltage on the 6C4(s) (that was all I had at the time), two AAAs for the bias, and eight AAs for the filaments. The filament voltage dropped slowly but noticeably with AAs. It might be better with eight D batteries or a small filament transformer instead.

This might seem like a lot of batteries, but it's not too bad. Occasionally, batteries go on sale for ninety-nine cents for a 9V battery around here, so it's easy to stock up.

Anyway, I would like to thank Mr. Lisle for bringing these fascinating and easy-to-build circuits to the attention of

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your readers. I look forward to more battery tube circuits and would like to suggest a battery line stage for CD and a battery phono stage for LPs.

Thanks for your time. Keep up the great work.

Shawn Shaffer
Lexington, N.C.

Larry Lisle responds:

Thank you so much for your kind letter! Your experimenting is what "Do It Yourself" audio is all about: going beyond the conventional theory and simulations, using what you have, combining old ideas with new ones to see how they work and having fun! Great job!

I have some ideas in mind, but not a line or phono stage project at the moment. I've had good luck with a 1U5 in either triode or pentode mode using either a 10MΩ resistor from grid to ground or a 1½V battery and 470kΩ resistor for bias.

CABINET CARPENTRY

As a woodworker and speaker builder (see www.audua.com), I was surprised to note that I found myself disagreeing with Bill Fitzmaurice on more than one occasion while reading his article "It's not just a Speaker—It's Furniture" (Aug. '02, p. 22):

1. I have a jointer and I first pass the board through the jointer crown up. I think that's faster and better than using a planer, which won't do any real length-wise flattening. Admittedly, people may not have a jointer, but it is worth noting. You certainly get a better glue joint.
2. I don't think biscuits are designed for urethane glues. They work best by absorbing moisture (yellow glue) and expanding then hardening. Urethane won't soak them adequately—it will expand itself and your biscuit joint becomes a weaker glue joint. A look through people's experiences in the Internet forums seems to agree with my thoughts.

   I used dovetail joints on my subwoofer, but rabbet or butt joints, which I mainly use, are great for smaller speakers. With plain butt joints on the sides you have long grain to long grain and the glue joint is very strong, especially combined with internal bracing and the cube shape. You can easily fashion rabbets with a router and bit.
3. I think it's important to cut and recess the driver holes before you assemble the pieces. This lets you heavily chamfer the inner edges of the woofer holes—which should cut down very early reflections. It also lets you insert screw keepers into the driver screw holes comfortably. A slight chamfer of the driver edges during sanding is sonically irrelevant and can be esthetically pleasing.
4. I think using solid hardwoods for front and back is a mistake for two reasons. First, if you consider the change in size of wood due to moisture variation, then the back/front hardwoods will be stressing the joints. Second, hardwood has some undesirable sonic properties—it is higher Q than MDF and can resonate. Most of the resonances from a speaker emit from the front. For these reasons, it's important to use

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MDF in the front and back.

I like an MDF + thin (⅛″ or less) hardwood sandwich, and I think you get the best of both worlds that way. The front/back need to be inset (via rabbets or other joins) to make the MDF invisible.

5. For bracing I again worry about expansion and try to use hardwood braces with the grain parallel to top/bottom and sides.
6. I think Mr. Fitzmaurice's finishing discussion was excellent.

Mark Zachmann
Marietta, Ga.

Bill Fitzmaurice responds:

First, while I also have a jointer, it has only a 5″ capacity, so using it to flatten an 8″ wide board is out of the question. Jointers are most often used to true the edge of a board, not the face. In the article I used a router to true the edge, as readers are about ten times more likely to either own or be able to borrow a router than a jointer.

Urethane glues don't have the water content that aliphatics do, so biscuits won't expand as much when used with urethanes. On the other hand, they don't need to, because the urethane itself expands more than enough to secure the joint, and expands throughout the joint, eliminating the need for additional caulking.

The purpose of biscuits is identical to that of dovetails, rabbets, tongue-and-groove, and all the variations on those, which is to add an additional plane of material to the joint to transform it from a two-dimensional to a three-dimensional structure. The advantage of biscuits over the other methods is ease of implementation. As to the strength of this particular combination, I've been using hardwoods/biscuits/urethanes for three years and have yet to suffer a joint failure.

The question of expansion/contraction-induced joint shear doesn't apply to the front/side joints, because the grain direction is the same on both sides of the joint. Shear is potentially a problem where the front joins the top and bottom, as the grains there are at 90° angles to each other. However, because I neither use nor recommend drivers larger than 8″ for home hi-fi woofers, the dimensions of the boxes I build are small enough to preclude joint shear.

For the same reason, the higher Q of hardwood versus MDF is not problematic, nor is bracing a concern. Reader Zachmann's concerns are quite valid with respect to boxes large enough for drivers of 10″ or more, but then the cabinet size required pretty much precludes using solid hardwoods anyway. My subs are veneered MDF.

Finally, as to cutting driver holes before assembly, if you want to chamfer the driver holes on the baffle interior, that's fine. Personally, I don't take that step, nor do I recess my drivers. I've even been known to put grilles on my cabinets. Heresy, you say? Maybe.

I personally don't believe that going to great lengths to obtain perfect response necessarily translates to better sound in your living room. Why? As the owner of a recording studio, I know that the only way you can duplicate what the engineer put onto a CD is to use identical speakers to those that the project was mixed with, mounted in the same position in a room identically laid out as the studio—including the mixing console and every other piece of equipment and furniture.

The potential for diffractive and reflective distortions from any speaker pale in comparison to the diffractions and reflections off perhaps hundreds of knobs and sliders on a console. Add in the acoustic peculiarities of your listening room, and a 2dB diffractive glitch in your speaker at 4kHz doesn't seem quite so critical anymore.

AVOIDING AIRSICKNESS

Bravo to Mr. G. R. Koonce for that wonderful explanation regarding the properties of Doppler distortion in the Aug. issue (Letters, "Doppler Distortion," p. 60). I have also done experiments with single driver and two-way systems and found the same results he mentioned.

When the heavy bass passages from the pipe organ start on the Philips album #412619-2 "Saint-Saens Symphony No. 3" (track 2), the distortion which is affecting the delicate sound of the violins is very, very evident. It almost has the same effect as mild airsickness or seasickness to the inner ear—at least that is the best I can explain the sensation. It is as though something unnatural is occurring and the message being sent to the brain is confused and the brain is trying to make constant connections to remedy the situation, which, of course, in this case, it cannot. Some of the lower notes from the organ on this album produce motions in the woofer that you can almost count, some of which are below 24Hz, and are only audible on the better low-frequency drivers which are installed in a properly tuned enclosure!

By the way, for anyone who wants to witness this effect firsthand, this album is a great test tool and it will really give you a true overall picture of how well your speaker system can handle heavy bass passages and will quickly reveal any Doppler distortion (frequency modulation) that should not be there! I agree with Mr. Koonce that the best way to avoid this problem is with good three-way systems, to which I converted all of mine. So, thank you, Mr. Koonce, for your well-thought-out and informative explanation, which I'm sure will be of great benefit to a lot of readers.

Rick Spencer
Clovis, Calif.

G R Koonce responds.

I thank Mr. Spencer for his kind comments on my discussion of Doppler distortion. His description of the effects of Doppler distortion is interesting and informative. I will have to add the Philips album #412619-2 to my testing tools.

I agree completely with Mr. Spencer that Doppler distortion is alive and well in this day of high-displacement drivers. The use of physically large woofers in a three-way—or greater—system or of limiting the woofer's displacement by employing a subwoofer are recommended ways to avoid the problem. As Mr. Klipsch pointed out on numerous occasions, horn loading of the drivers is also an excellent way to avoid Doppler distortion.

PERFECT SQUARE WAVES

Congratulations on an excellent article and a superlatively designed amplifier ("6B4G Stereo 90 Power Amp," Aug. '02, p. 6). Your 6B4 push-pull parallel cathode-follower output stage, 6L6GC ultralinear driver stage, and creative plate voltage parameters for the 6L6 and 6B4 make this the best technical/practical cathode-follower amplifier design of all time, in my opinion.

The low impedance associated with your amplifier and my 100W triode amplifier (*GA* 3/00) are the only two amplifiers, to my knowledge, that provide "textbook" perfect squarewaves.

Again, I want to compliment you on the excellent, creative design of your amplifier.

Joseph Norwood Still
Bel Air, Md.

Michael Burrows responds.

Thank you for your most complimentary letter! It's always nice to read a positive letter for a change.

The high- and low-frequency square-wave response took me totally by surprise, as I hadn't expected it. Because the signal must travel through a low-tech filament transformer before reaching the output transformer, I thought the HF response would drop rapidly above 5kHz.

I must give the Lundahl Transformer Co. a lot of the credit for the excellent square-wave response. They somehow came up with a magic mix of steel and winding technique.

Thanks again for your kind comments. ❖

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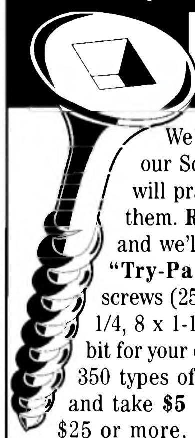

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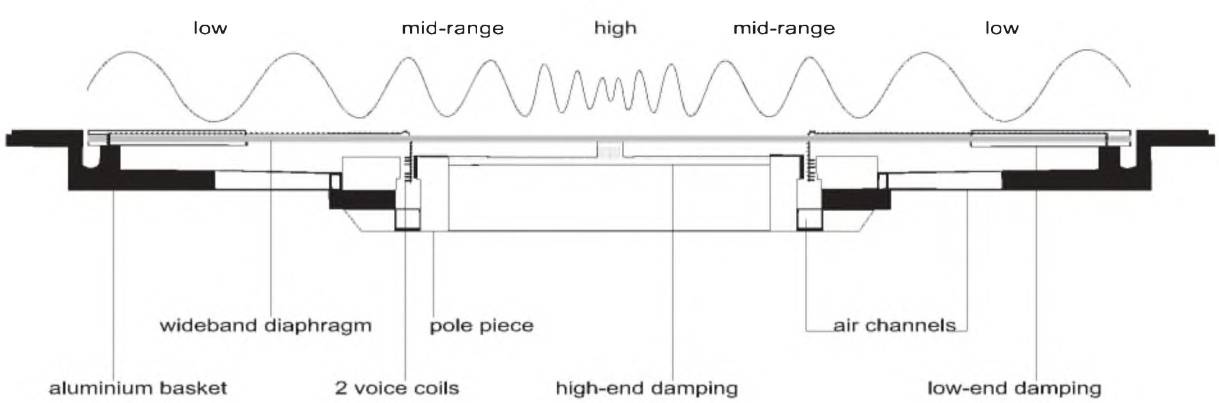

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Volume Control

from page 11

80dB range. In operation, the volume control characteristic feels natural and precise.

The output of A1-a (after D1) is biased and scaled to produce –6V at minimum volume and 0V at maximum volume.

When using a "wired remote" pot, switched by S2, there was concern that an open pot, cable, or connection would result in a default to maximum volume: the pot wiper voltage fed to A1-a pin 3 is normally 0V (for –80dB) to 44V (0dB). But an open pot would increase this to +6V, resulting in +40dB gain and toasted tweeters (at least!). Diode D1 limits the output fed to R5, limiting pot default volume to about +1dB (above maximum).

But at Ed Dell's suggestion, I added a circuit to default volume to maximum attenuation (Q1, R15, R16, R17). A voltage greater than 4.60V at A1-a pin 3 immediately shuts down the audio gain to about –104dB, as shown in *Fig. 3* and *Table 1*.

Switch S2 greatly increases the Spousal Acceptance Factor—for example, wife can instantly flip switch and mute excessive volume set by audio hubby on his concealable remote volume box!

A1-b is an inverting summing "amplifier" ("gain" from A1-a = 0.412 at +25°C). With P2 ("maximum gain" pot) centered, and P1 (volume) at maximum CW (clockwise) rotation, the 0V fed to R5 results in 0V also at A1-b output (pin 7). This (with balance pot PB centered; only one of six shown) feeds the VCA control pin 11, a 0V signal, which results in an audio gain of 0dB.

RT1 is a linear +3500ppm/°C compensation resistor that causes non-zero (attenuation control) voltages out of A1-b (pin 7) to have this temperature coefficient, which is the same that the VCAs need for essentially zero drift. Analog Devices suggests the model PT 146 (1.00k ±1% @ +25°C) from Precision Resistor Co., Largo, Fla. The area code on the AD data sheet has been changed; the correct phone number is (727) 541-5771, ask for Arlene.

The output of A1-b feeds six resistors (RE1–6), one for each channel, to the corresponding VCA (1–6) in *Fig. 1B.* These resistors, together with RF (1–6) from the balance pots PB (1–6), supply the control voltages to the VCAs. The balance pots are supplied ±6V (@ +25°C), proportional to absolute temperature courtesy of RT2 and A2 (a, b), *Fig. 1A.*

Note: The circuitry could have been simplified by first combining the volume and balance signals, then temperature compensating with one TC resistor.

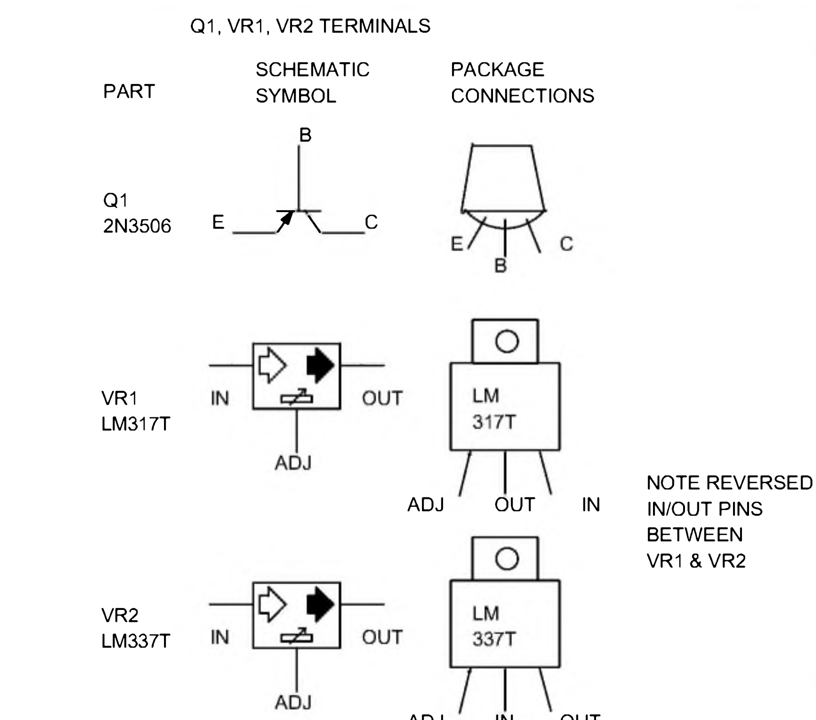

FIGURE 4: Q1, VR1, VR2 terminals.

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However, Precision Resistor Co. usually stocks only the 1.00kΩ value, and this would have required more drive current to the VCA control inputs, using the PT 146 as a shunt element. In addition, a series/shunt resistive compensator would lower the effective tempco.

RF (1–6) sets the balance controls' range (±5dB with 196kΩ). Should you desire more range (up to about ±20dB), select the closest 1% standard value to 973kΩ/B, where ±B is the desired balance range in dB.

CALCULATING VALUES

Calibrating dB attenuation versus volume control position is simple due to the precise and linear 20dB/V relation regarding pot P1 voltage fed to A1-a pin 3. If a = "gain" in dB (negative here), and V_P is the pot output voltage, then

$$a = 20\,V_P - 80, \text{ and } V_P = (a + 80)/20$$

So with a voltmeter measuring V_P, you can make panel markings corresponding to any desired dB values. After I did this, I checked attenuation values with sine wave levels down to 80dB attenuation. Results agreed well within the thickness of my panel marking lines (all six channels).

Regarding the balance and maximum gain controls, these pots are essentially unloaded (as opposed to the volume control). Therefore, if desired, you can make panel markings (as I did) by measuring either wiper-to-end resis-

TABLE 4
PARTS LIST

REFERENCE	DESCRIPTION	MFR/PN	DIST./PN	PRICE
A1, A2	Dual op amp 8-DIP	TI, TL082CP	Newark, TL082CP	$1.40
BR1	Bridge rect. 100V, 1.5A	Diodes, Inc.	Digi-Key, KBP01G	$1.16
CA1–6, CB1–6	Cap, 47pF. 100V	Panasonic, ECU-S2ZA470JCA	Digi-Key, P4845	$4.56
C1, CC1–6	Cap, 10µF, 16V	Panasonic, ECE-A1CKG100	Digi-Key, P910	$2.24
C2–C5	Cap, 1000µF. 25V	Panasonic, EEU-FC1E1025	Digi-Key, P10279	$5.92
D1	Diode	NTE, 1N4148	Newark, 1N4148	$0.42
F1	Fuse, 0.5A FB, 3AG	Littelfuse	Digi-Key, F112	$0.42
J1, JA1–6, JB1–6	Phono jack		Newark, 44N936	$5.20
LED1	LED, color of your choice			
P1, P2, PB1–6	Pot, 10kΩ LIN., 2W	Precision, RV4NAYSD103A	Digi-Key, RV4N103C	$44.96
Q1	Transistor, PNP	Fairchild	Digi-Key, 2N3906	$0.21
RC1–6	Res, 5%, 120Ω, ¼W	Yageo	Digi-Key, 120 QBK	$1.68
R10, R12	Res, 5%, 220Ω, ¼W	Yageo	Digi-Key, 220 QBK	$1.40*
R11, R13	Res, 5%, 1.8k, ¼W	Yageo	Digi-Key, 1.8K QBK	$1.40*
R14	Res, 5%, 3.3k, ¼W	Yageo	Digi-Key, 3.3K QBK	$1.40*
R17	Res, 5%, 6.8K	Yageo	Digi-Key, 6.8K QBK	$1.40*
RD1–6	Res, 5%, 22k, ¼W	Yageo	Digi-Key, 22K QBK	$1.68
R15	Res, 1%, 1.00k, ¼W	Yageo	Digi-Key, 1.00K XBK	$2.70*
R7, R16	Res, 1%, 2.00K	Yageo	Digi-Key, 2.00K XBK	$2.70*
R5	Res, 1%, 2.43k, ¼W	Yageo	Digi-Key, 2.43K XBK	$2.70*
RE1–6	Res, 1%, 4.99k, ¼W	Yageo	Digi-Key, 4.99K XBK	$3.24
R1, R2, R8, R9	Res, 1%, 10.0k, ¼W	Yageo	Digi-Key, 10.0K XBK	$2.70*
RA1–6, RB1–6	Res, 1%, 15.0k, ¼W	Yageo	Digi-Key, 15.0K XBK	$6.48
R6	Res, 1%, 32.4k, ¼W	Yageo	Digi-Key, 32.4K XBK	$2.70*
R4	Res, 1%, 100k, ¼W	Yageo	Digi-Key, 100K XBK	$2.70*
RF1–6	Res, 1%, 196k, ¼W	Yageo	Digi-Key, 196K XBK	$3.24
R3	Res, 1%, 200k, ¼W	Yageo	Digi-Key, 200K XBK	$2.70*
RT1, RT2	Res, 1.00k, 1% +3500ppm/°C	Precision Resistor Co. PT146		$14.00
S1, S2	Toggle switch, SPDT	Alco/Tyco, A101P3YZQ	Newark, 46F2996	$9.78
T1	Transformer, 24VCT, 0.25A	SPC XBD-424	Newark, 44N3631	$10.19
TP1, TP2	Trimpot, 12 turn, 200Ω	Bourns, 3266W-1-201	Newark, 44F3528	$6.58
VCA1–6	Audio VCA	Analog Devices, SSM2018T	Newark, SSM2018TP	$49.14
VR1	Adj. pos. volt. reg.	ON Semi LM317T	Newark, LM317T	$0.70
VR2	Adj. neg. volt. reg.	ON Semi LM337T	Newark, LM337T	$0.86
	Knob, ¼" shaft, 22.9mm		Digi-Key, 8560K	$5.76
	Knob, ¼" shaft, 17.8mm (7)	Keystone	Digi-Key, 8559K	$35.42
	Box, 10″ × 6″ × 3.5″	Bud, CU-2110B	Newark, 91F697	$22.90
	DIP socket, 16 pin (6)	SPC ICD-16-2T	Newark, 46N2852	$0.72
	DIP socket, 8 pin (2)	SPC ICD-8-2T	Newark, 46N2850	$0.16
	Fuse holder, 3AG	Littelfuse, 342001	Digi-Key, F002	$3.08
	Heatsink (for VR1, VR2) TO-220 (2)	Aavid, 575102B00000	Digi-Key, HS116	$1.02
	Power cord, 2 cond., polar. 9′	Volex, 17109-B1-9	Newark, 02F5264	$2.33
	Board, grommet, feet, wire			
			Total	$272.65

*Minimum quantity five

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tance (before connecting pots) or wiper voltage in-circuit; dB values are very nearly linearly proportional to both, with 0dB at mid-rotation (0V at wiper).

I recommend these calibrated panel markings; multichannel recordings differ "markedly" (sorry about that) in their optimum front/rear gain settings, also considering individual listening preferences. Panel notations allow you to record optimum balance (and overall level) settings for any given disc.

CONSTRUCTION RECOMMENDATIONS

1. Do not use a 3-wire power cord to AC-ground the chassis, unless none of your audio equipment is so grounded; ground-loop hum may result. For safety, you can ground one piece of equipment (probably the power amp if a multi-channel unit is used).
2. If you use a solid copper ground-plane board (as I did), you can mount insulated parts (IC sockets, regulators, filter caps) on a piece of wood glued to the copper plane. I used balsa wood, sticking such leads into it (carefully avoiding depth that could short to ground), then securing with a drop of Krazy Glue adhesive.
3. You could use solderless breadboards ("proto boards"). I've used them to 100MHz. The maximum audio gain here is only +17dB. Capacitance between adjacent proto-board strips is only about 3pF. However, I would dedicate one board to the VCAs, spreading them across the board, and bypass each VCA supply voltage with a 10µF, 16V cap to ground.
4. For audio jack in/out wiring, I simply used unshielded wire point-to-point. Interwiring capacitance is only 0.3pF (26MΩ @ 20kHz; with 1kΩ audio sources, 20kHz crosstalk is only –88dB).
5. I used rainbow-ribbon cable to connect the eight pots. *Table 2* shows the legend I used. Because all six balance pots have common end connection, only 13 wires were needed. Of course, since all pots carry only DC control voltages, crosstalk with these wires is not an issue.

Ed Dell tells me that if readers exhibit sufficient interest, Old Colony may supply a PC board. Send an e-mail to custserv@audioXpress.com.

USAGE

This mulitchannel volume/balance controller is an inexpensive device allowing an SACD or DVD-A source to drive up to six power amplifiers, while maintaining the outstanding transparency and resolution of this source material.

While lacking bass management, even the inexpensive SACD players have this, as well as many subwoofers. Operating in pure Class A analog mode, with the simplest possible audio path, this versatile and voltage-controllable unit will allow you to enjoy the dramatically realistic surround capabilities of these relatively new formats, with up to six channels of basic power amp/speaker combinations.

Table 3 shows the performance summary; *Table 4* is the parts list. ❖

REFERENCES

1. Analog Devices says -3500ppm/°C. This is close enough.
2. For best accuracy, you should select R1 and R2 to equal half the resistance of pot P1, within 1%.

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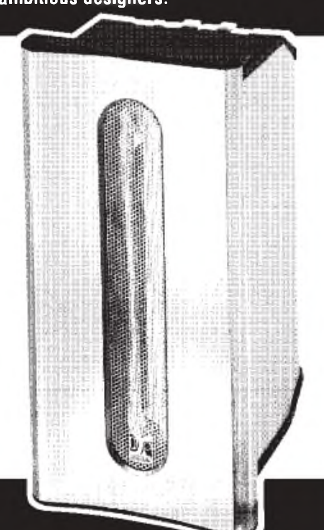
*PL-160 is sold with 2 x 9 Ohms diaphragm.



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Acoustic Diffraction

(from p. 19)

loudspeakers can often image better than larger systems.

Compared to an enclosure with no edge treatment, a 4″ radiused edge reduced diffraction ripples from an untreated enclosure by up to 2dB. These ripples occurred between 1–5kHz. There were variations of less than 0.5dB above 5kHz. Again, 45° beveled edges were not as effective as radiuses, but a dual-bevel design was nearly as good as a 4″ radius.

Earlier, I pointed out that a ¾″ radius isn't going to help reduce diffraction very much. However, a 1″ radius did reduce diffraction by 1–2dB between 2–5kHz. So, there exists some benefit in using a ¾″ radius on a cabinet edge.

Implementing edge treatments into a cabinet design can be challenging, so you must weigh the benefits against the effort required. A ¾″ radius router bit is pretty easy to use if you have a router table. I have a 1½″ radius router bit, but it is a little scary to use. The dual-bevel design isn't that difficult for the average woodworker to build. The 4″ radius could be accomplished with a custom router bit, specialty plywood shapes, laminates, or custom cardboard. This would certainly be the realm of the expert woodworker.

Finally, integrating the grille frame with a stepped front baffle can eliminate diffraction caused by the frame. *Photo 11* shows a recent design that uses a 1½″ radius roundover bit to shape the grille frame and the cabinet front edge. The only modest drawback to this approach is the need to flush-mount the drivers. This tends to limit your choice of tweeters, and there is some additional diffraction caused by the mid-driver being recessed.

I have also built a system that has a grille frame with a 22° bevel that is integrated with a stepped front baffle. The edge of the cabinet sides was beveled with a 45° angle, so the design was very much like the dual-bevel edge that was tested in this study.

This study only scratches the surface of the subject. Could more be done to reduce or minimize cabinet edge diffraction? I limited the edge treatments to what would be considered practical, but perhaps even larger radiuses could be implemented.

Of course, the most important question yet to be answered is how much diffraction takes away from the listening experience. Do loudspeaker systems with less edge diffraction sound better or image better than others? A double-blind study comparing a low-diffraction system versus a high-diffraction version might provide some answers. ❖

REFERENCES

1. Joseph D'Appolito, *Testing Loudspeakers*, First Edition, 1998, Audio Amateur Press, Chapter 4: Acoustical Testing of Single Drivers, p. 59.

2. Vance Dickason, *The Loudspeaker Design Cookbook*, Sixth Edition, 2000, Audio Amateur Press, Chapter Five: Cabinet Construction: Shape and Damping, p. 99.

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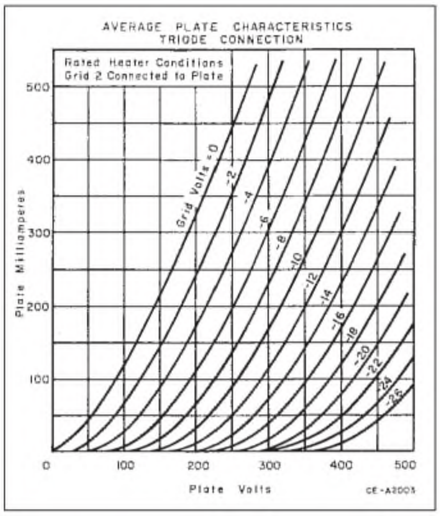

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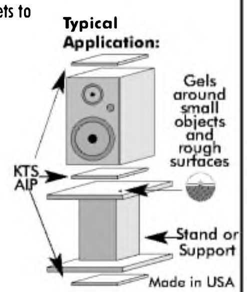

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After reading articles pertaining to vacuum tubes in *audioXpress*, I recall a tube type that many audio amplifier designers seem to have overlooked. It is the 8417 beam power pentode, which came on the scene rather late in the tube era and probably explains its not being widely used.

The 8417 can deliver more power in Class A, AB1 (conventional push-pull or ultralinear), or triode-connected than most of the types popular in the tube period. However, the 8417 is most outstanding as a triode, having an amplification factor of about 16—making it very easy to drive—and plate resistance in the order of 700Ω. Triode-connected, with 400V plate supply, it will deliver 25W in class AB1 with a 5000Ω plate-to-plate load, or about 30W 3000Ω plate-to-plate.

I have used the 8417 with success triode connected as a power amplifier. I caution anyone who uses it as a triode to connect a 1k resistor in series with the screens to prevent RF oscillation.

The accompanying 8417 manufacturer's data sheets are from pp. 465-6 of the Sylvania Receiving Tubes Technical Manual. ❖

J. L. Markwalter
Port Charlotte, Fla.

AUDIO POWER AMPLIFIER or VOLTAGE REGULATOR | **8417**

Beam Power Pentode

Construction ....Octal T-12
Base ....Octal 6 Pin, B6-22
Basing..............................7S
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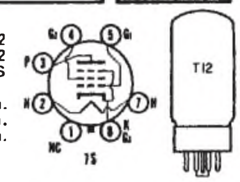
Maximum Diameter .... 1.562 In.
Maximum Seated Height ... 3.875 In.
Maximum Overall Height .. 4.500 In.



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Heater Voltage	6.3 Volts
Heater Current	1600 Ma
Maximum Heater-Cathode Voltage	
Heater Negative with Respect to Cathode	
Total DC and Peak	200 Volts
Heater Positive with Respect to Cathode	
DC	100 Volts
Total DC and Peak	200 Volts
DIRECT INTERELECTRODE CAPACITANCES	
Grid No. 1 to Plate	0.9 Pf
Input	22 Pf
Output	9.0 Pf
RATINGS (Design Maximum Rating System)	
Plate Voltage (Max.)	660 Volts
Grid No. 2 Voltage (Max.)	500 Volts
Plate Dissipation (Max.)(1)	35 Watts
Grid No. 2 Dissipation (Max.)(2)	5 Watts
Cathode Current (Max.)	200 Ma
Grid No. 1 Circuit Resistance	
Fixed Bias (Max.)	0.1 Megohm
Cathode Bias (Max.)	0.25 Megohm
CHARACTERISTICS AND TYPICAL OPERATION	
Plate Voltage	300 Volts
Grid No. 2 Voltage	300 Volts
Grid No. 1 Voltage	-12 Volts
Plate Current	100 Ma
Grid No. 2 Current	5.5 Ma
Transconductance	23,000 μmhos
Plate Resistance	16,000 Ohms
Amplification Factor (Triode Connected)	16.5
Grid Voltage for Ib = 1 Ma	-37 Volts

Class AB1 Ultra-Linear Push-Pull(3)

	Values for 2 Tubes
Plate Supply Voltage	445 Volts
Grid No. 1 Voltage	-25 Volts
Peak AF Grid to Grid Voltage	45 Volts
Zero Signal Plate Current	146 Ma
Maximum Load (Plate to Plate)	3500 Ohms
Total Harmonic Distortion	2.5 Percent
Maximum Signal Power Output	70 Watts

Class AB1 Pentode Connected

	Values for 2 Tubes	
Plate Supply Voltage	400	560 Volts
Grid No. 2 Supply Voltage	275	300 Volts
Grid No. 1 Voltage	-13	-15 Volts
Peak AF Grid to Grid Voltage	24	29 Volts
Zero Signal Plate Current	150	124 Ma
Maximum Signal Plate Current	294	290 Ma
Zero Signal Screen Current	4.4	3.6 Ma
Maximum Signal Screen Current	34	39 Ma
Effective Load (Plate to Plate)	2800	4200 Ohms
Total Harmonic Distortion	2.5	2.5 Percent
Maximum Signal Power Output	65	100 Watts

NOTES:
(1) It is essential to maintain free circulation of air around the tube for proper cooling.
(2) Grid No. 2 dissipation may reach 8 watts during intervals of maximum speech and music signals.
(3) Screen tapped at 40% of primary turns. Plate current includes screen current.

AVERAGE PLATE CHARACTERISTICS