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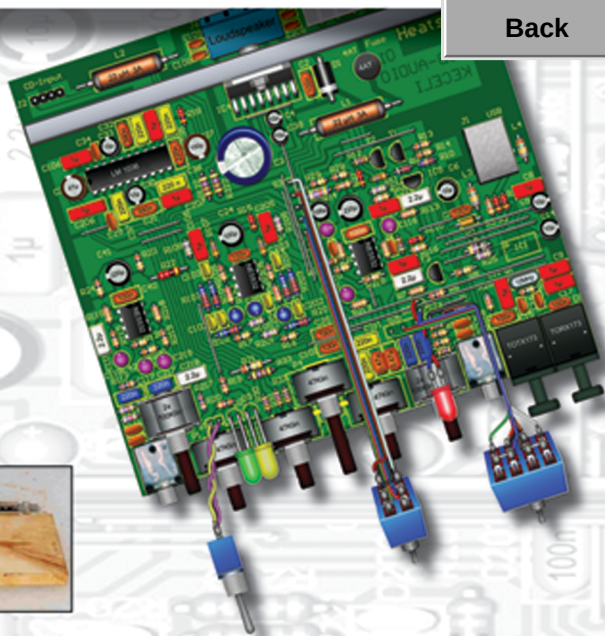
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The Wedgehorn

By Bill Fitzmaurice

After a number of requests to design a floor “wedge” style live sound stage monitor with higher output capability than his previous designs, this designer built a bigger—and better—monitor.

Monitors suffer more from dispersion issues than perhaps any other speaker, as the distance from the monitor to the listener is usually about 6'. Even a speaker with a reasonably wide 30° -6dB off-axis response has a very narrow listening zone at such short range, and a performer who moves even a foot to either side of his monitor's “sweet spot” can find himself unable to hear it. So when I started to design this box, my primary goal was a super-wide dispersion angle.

Another requirement was high output, but I wanted to keep the size of the box reasonable, and decided on a short straight horn that would limit the fc to 200Hz or so; but a properly tuned reflex rear chamber could give a response bump at 100Hz for adequate response within the desired passband.

Wide dispersion of the high frequencies critical for intelligibility on stage could be achieved with cross-firing tweeters. And by vertically arraying tweeter pairs, I could produce high sensitivity and a narrow HF vertical dispersion angle. A straight horn would not allow the tight horizontal packing of the tweeter arrays required to minimize combing and keep response flat, but in this application high fidelity reproduction would not be a concern.

The resulting Wedgehorn monitor (*Photo 1*) has an average sensitivity of 98dB/1W/1m from 100Hz to 12.5kHz. This is fairly average

PHOTO 2: Using a cutoff to set the blade angle.

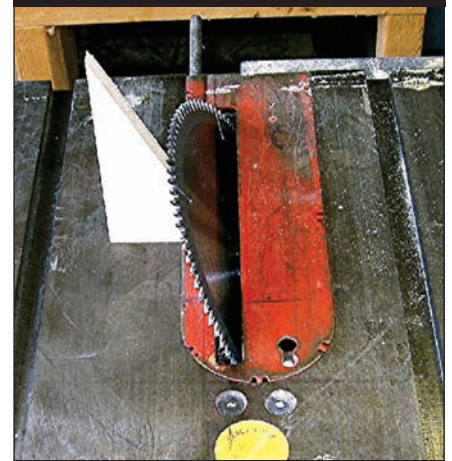


FIGURE 1: On-axis and 45° off-axis response.

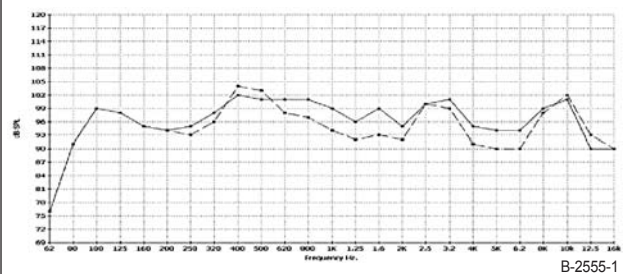


PHOTO 1: The Wedgehorn.

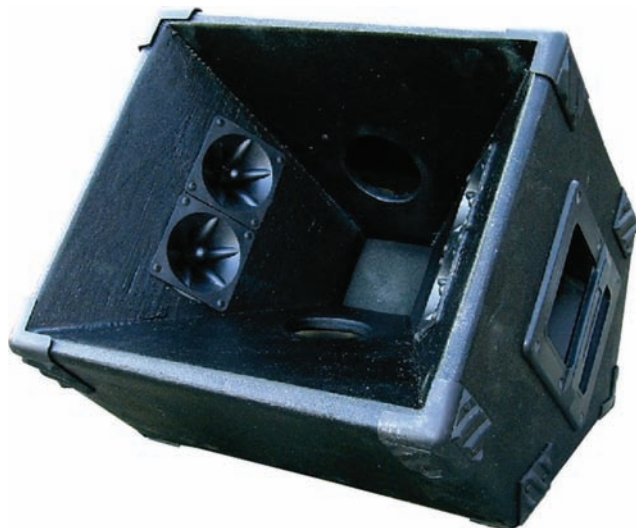


PHOTO 3: The assembled outer shell.



for a wedge monitor of this size, $16 \times 16 \times 14$ ". However, the 45° off-axis response never drops by more than 6dB, and in fact averages an exceptional

-3dB. There are even a few frequencies where off-axis sensitivity is higher than on-axis. Even at a range of 6' the "sweet spot" of this monitor is huge (Fig. 1).

FIGURE 2: Shell side dimensions.

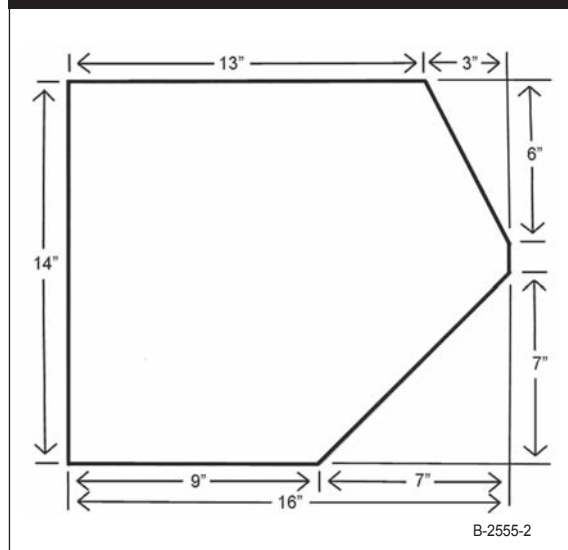


FIGURE 3: Cutaway side view.

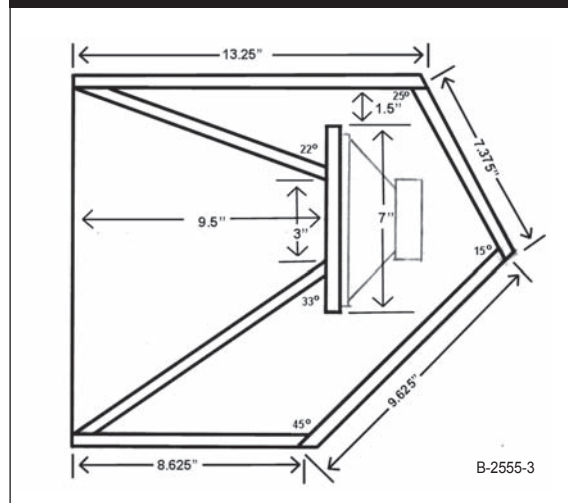
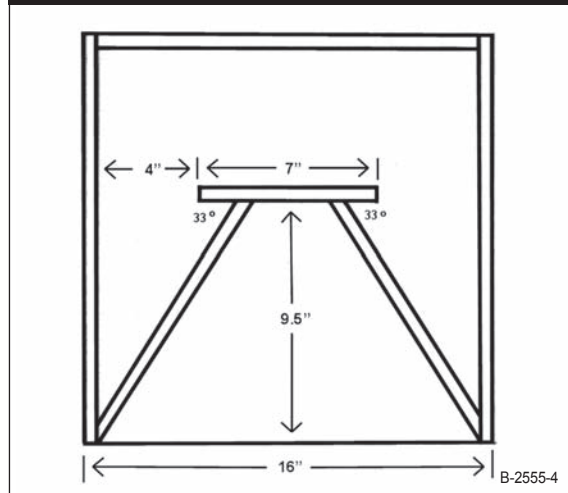


FIGURE 4: Cutaway top/bottom view.



The woofer I used is one developed for line-array use, the Eminence LA6-MB. I chose it for its 73Hz fs, 150W power handling, and 92dB sensitivity, a rare combination in a 6.5" driver. Normally you might need to use an eight to get these specs.

For tweeters I used four generic piezos, similar to the old CTS/Motorola KSN1005, widely available for about a dollar apiece. An alternative woofer is the Dayton PA165-8 (Parts Express #295-015). This is rated at 75W, which should be quite adequate for lounge and other low-to-medium level acts, and is definitely a bargain at about \$16.

CONSTRUCTION

The construction material is $\frac{1}{2}$ " plywood. Spruce or pine will do, but Baltic birch is much easier to work with and finishes with minimal sanding. It also doesn't add too much to the expense, as you can build two Wedge-horns from a single $5' \times 5'$ sheet. All joints are secured with $1\frac{1}{4}$ " drywall screws, piloted and countersunk, and polyurethane base construction adhesive, which expands as it cures to fill gaps.

You start constructing by cutting out the outer shell sides as shown in Fig. 2. Save the triangular cutoffs. On the sides draw the joints with the intersecting parts and also the locations of the internal horn pieces, as per Fig. 3. This will serve as a guide in assembling the horn later on. Fig. 3 also shows many of the angles to cut those parts for proper

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fit, as does *Fig. 4*.

Cut out the shell top, bottom, and two rear pieces per *Fig. 3*. Double-check the dimensions by measuring the layout on the sides, as variations in material thickness may affect the actual size. The top, bottom, and larger rear pieces are 15" wide; the smaller rear piece, removable for driver access, is 14.875" wide. Setting the table saw blade angle off vertical for the angled cuts is very easy using

PHOTO 4: View of the driver access opening.



FIGURE 5: Horn side dimensions.

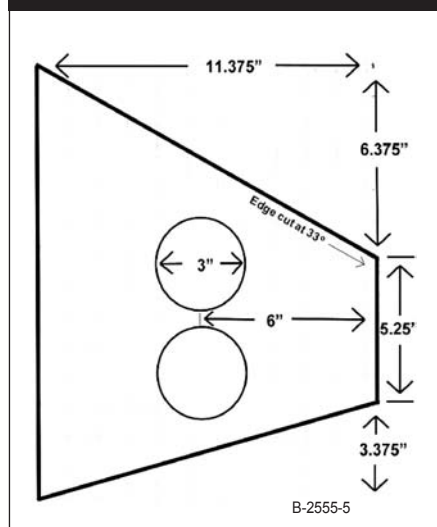
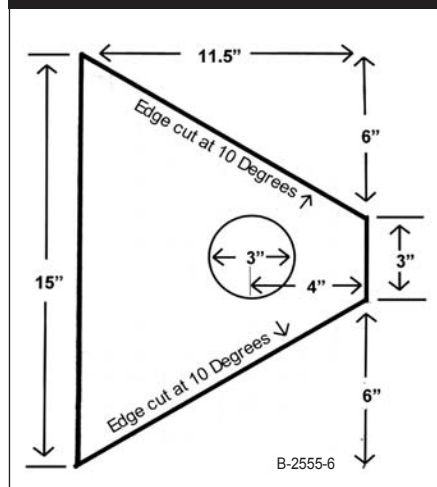


FIGURE 6: Horn top dimensions.



the saved triangular cutoffs as guides (*Photo 2*).

Assemble this box by first attaching the top, bottom, and larger rear panel to one side, then attaching the remaining side to the assembly. Frame the opening where the driver access panel will attach (*Photos 3 and 4*); you can use cutoffs from the top and bottom that are already cut at the correct angles. On the top draw the locations where the internal horn parts will go, as per *Fig. 4*.

Cut out the remaining parts, including a 7" x 7" baffle. Check *Figs. 3-7* for sizing and the angles of the various cuts. You need to make two horn sides (*Fig. 5*, which you'll note is shown upside down relative to the side view of *Fig. 3*), mirror-imaged with respect to the 33° angle cut where they attach to the baffle.

Before cutting each part use the layouts drawn on the exterior of the box as guides to assembling the various parts. When you cut the edges of the horn top and bottom at the indicated angles, the wider face of each part will be on the interior of the horn. Cut 3" diameter

holes in the parts for the ports and tweeters, preferably with a hole saw.

(Note that I did not cut these holes on the prototype until after assembling the box, because I didn't know until then

PHOTO 5: Determining tweeter locations.

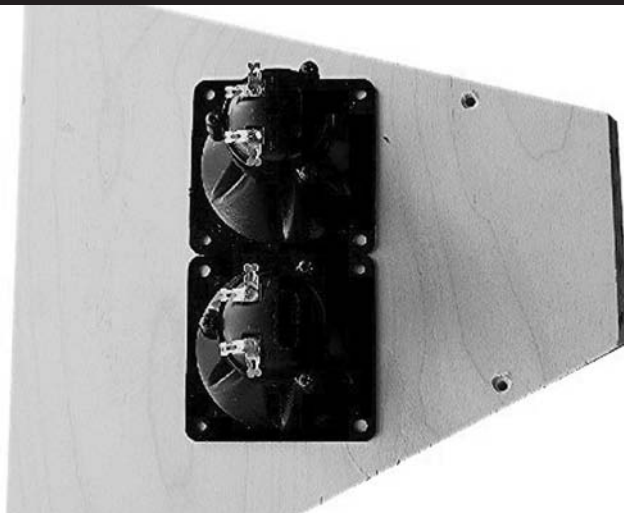


PHOTO 6: Horn top and bottom glued to the assembly jig.

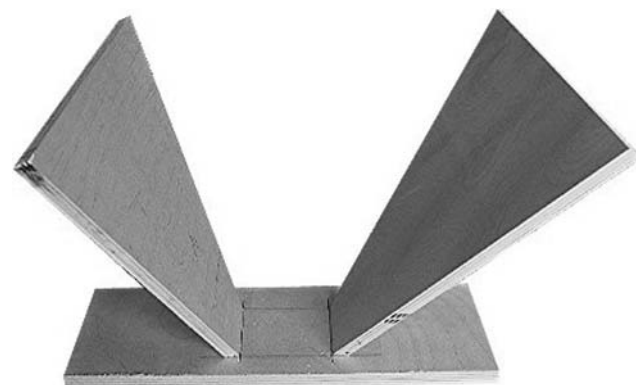


PHOTO 7: The assembled horn.

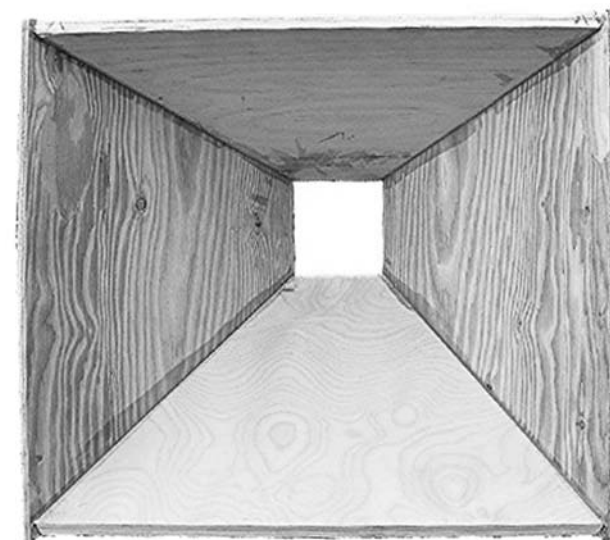


PHOTO 8: Checking alignment of driver bolts.

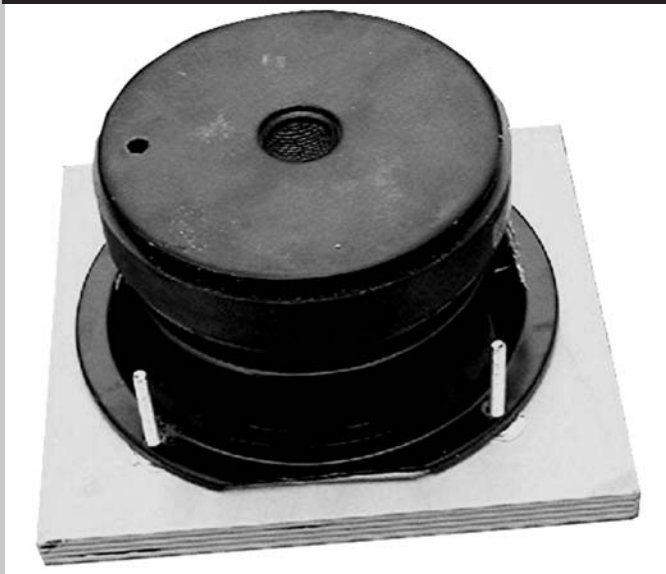


PHOTO 9: The baffle attached to the horn.



PHOTO 10: Trimming the horn mouth with a panel cutting jig.



PHOTO 11: The sides trimmed to the right trimmed.



PHOTO 12: The trimmed horn ready for installation.

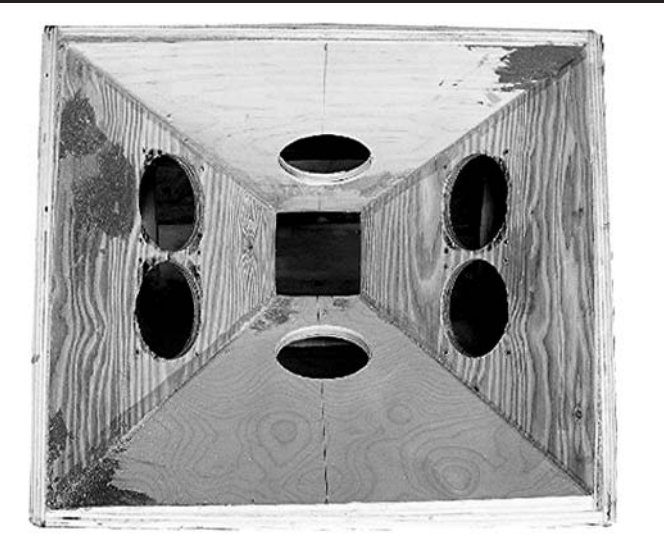
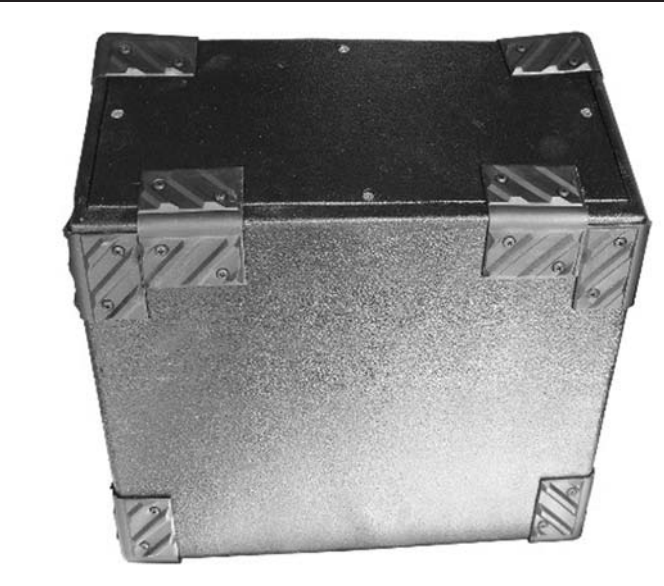


PHOTO 13: Protecting the box with plastic corners.



precisely where they would end up. Cutting them prior to assembling the box is much easier.) In the case of the tweeter holes, first draw a centerline on each horn side 6" from the baffle end. Place a pair of tweeters with their frames touching centered on this line, with the distance from their frames to the nearest edge equalized to determine the actual centers of the mounting holes, as in *Photo 5*.

ASSEMBLY

To assemble the horn, start with a piece of scrap plywood, onto which you draw a 3" x 3" square representing the horn throat. Using a small amount of hot melt glue, attach the horn top and bottom pieces to this jig (*Photo 6*). With the top and bottom secured, it's an easy job to then attach the horn sides and remove the finished assembly from the jig (*Photo 7*).

Now cut a 3" x 3" hole in the middle of the baffle. Use the driver to determine the mounting bolt hole locations,

drill the holes and insert 3/16" T-nuts, and then trial-fit the driver to be sure all is right (*Photo 8*). (For testing purposes I mounted the T-nuts on the driver side of the baffle, with the bolts coming through the baffle; insert the T-nuts from the opposite side of the baffle using 1" long attaching bolts.) Put the driver aside and attach the baffle to the horn assembly (*Photo 9*).

Now you can trim the mouth of the horn to fit into the shell, a very simple process with a table saw and panel-cutting jig (*Photo 10*). The horn sits atop the jig, mouth down. The jig slides

across the table saw top, and the blade set at vertical trims the horn sides to the correct angle (*Photo 11*). Don't try to cut the horn to its finished size in one pass. Instead, trim each of the four edges a little at a time, gradually reducing the size of the horn mouth until it just fits into the shell. Then attach it using plenty of adhesive to fill any gaps.

Fill all screw heads and defects in the project (I use automobile Bondo, which doesn't shrink and sets up fast), and when the glue and filler are set, sand everything smooth. Also put

FIGURE 7: Horn bottom dimensions.

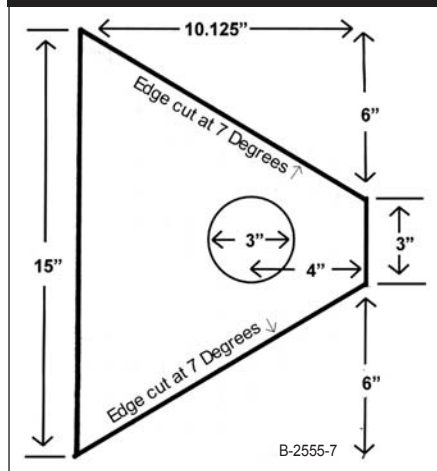
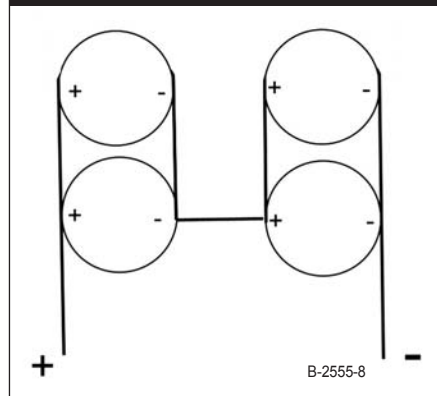


FIGURE 8: Series/parallel wiring of four tweeters.



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PHOTO 14: Dual phone jacks for daisy-chaining.



PHOTO 15: An insert handle for easy hauling.



Books on Electrostatics

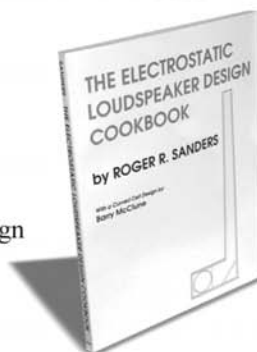
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by Roger R. Sanders

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a ½" radius chamfer on the exterior edges with either a router or sander, and round over the joints on the rear of the box (Photo 12). Temporarily screw the access panel into place and use a sander to round over where it meets the top. If you plan on using either handles or jack hardware that require cutting holes in the box, do it now. Be sure that you don't put a recessed handle where it will smack into the tweeters.

FINISHING TOUCHES

The next step is applying a finish. Carpet is an attractive and durable option, but it isn't easy to apply and is relatively expensive. I tried a product called DuraTex for the first time with this project (available from Acry-Tech at 800-771-6001) and am very pleased with the result. Intended as a speaker finish, this water-based urethane acrylic goes on with a standard paint roller, drying quickly with a lightly textured finish that's very durable and easily recoated if you ding it up. It doesn't cost much more than paint, coverage is quite good, and you can finish a cabinet of this size in about 15 minutes exclusive of drying time. Using a small trim roller, you can reach inside the box to cover those areas visible through the ports.

After the finish has cured, start applying protective corners. I like to use large plastic corners that are not only cheap but also can be trimmed where you don't want to have them wrap over an edge, as in Photo 13. They are also flexible enough to use over the corner formed by the upper and lower back pieces even though the angle formed is less than 90° (Photo 14).

Line the box as much as possible

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by Ronald Wagner

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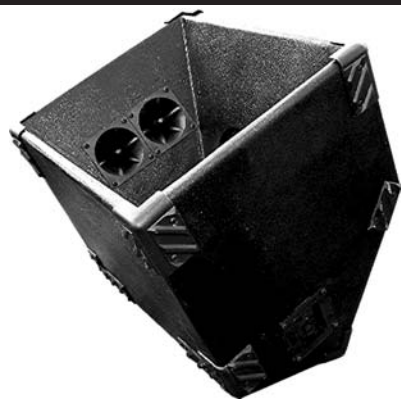
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with either polyester batting or acoustic foam to prevent internal reflections. Then install your drivers, starting with the tweeters. You may wire all the tweeters in parallel for maximum sensitivity, or series/parallel wire for higher power handling with 3dB less sensitivity (Fig. 8). Either way, keep the tweeters and woofer in phase.

Before mounting the woofer, install some type of protective grille on the baffle; I used 1/4" thick air conditioner filter foam on mine. Also double-gasket

PHOTO 16: Steep angle placement for close-in listening.



the woofer to prevent cone-slap against the baffle. Install jacks and handles, line the access cover with poly or foam and install the cover. Last, complete the installation of protective corners wherever you can (Photo 15).

The dual angles of the box rear allow you to place it on the floor in a shallow angle as shown in Photo 1, or at a steep angle as shown in Photo 16. Remember that while the nominal rating of the woofer is 150W, the box is tuned to 100Hz, so you should use either a high pass filter set at 100Hz or roll off the EQ of the monitor send below 100Hz to keep out potentially destructive bass frequencies. Most important, unless you have separate EQs, sends, and amplifiers for each monitor in your system, they must all be identical. Otherwise, you won't be able to get them to all sound the same and notching out feedback will be almost an impossibility. Luckily, you can construct even a stable of six Wedgehorns for about \$400 using the Dayton woofer, so having all identical monitors is an affordable luxury. *ax*



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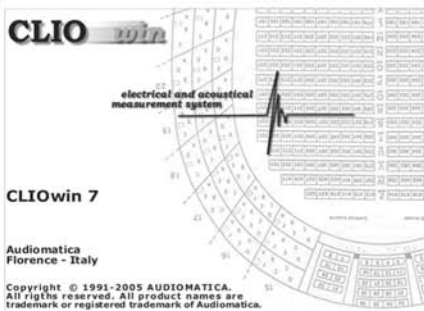
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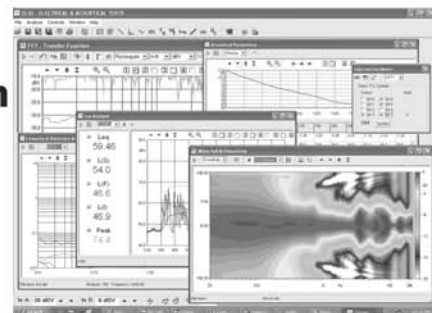
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Back

Starter Kits Series: All-JFET MM/MC Phono Preamp, Part 2

This flexible phono preamp design benefits from the author's 40 years of experience in the business.

By Erno Borbely

The EB-804/419 is a high quality, low-cost all-JFET DC-coupled MM/MC phono preamp with on-board all-FET regulators. The combina-

tion of low input noise and high gain allows you to use it with practically all pickups on the market. The EB-804/419 uses a two-amplifier approach instead

of the usual single amplifier. This allows you to optimize it for low noise, RIAA accuracy, high gain, and dynamic range. The block schematic is shown in *Fig. 4*.

You can use the two-amp configuration in three different ways to realize the RIAA function: all active, all passive, or hybrid, meaning combination of passive and active. Two of these are supported in the EB-804/419: the hybrid and the all passive.

In *Fig. 4A* the amp on the left is a high-gain amplifier with extremely low input noise and flat frequency response. You can use it with 20 or 40dB gain by changing the feedback resistor. The R18/C11 network between the two amplifiers provides the 75 μ s passive rolloff. The second amp provides a further amplification of 24dB at 1kHz and at the same time boosts the bass according to the RIAA characteristics actively through R33/R32/R31/C14.

FIGURE 4: Block schematic for EB-804/419.

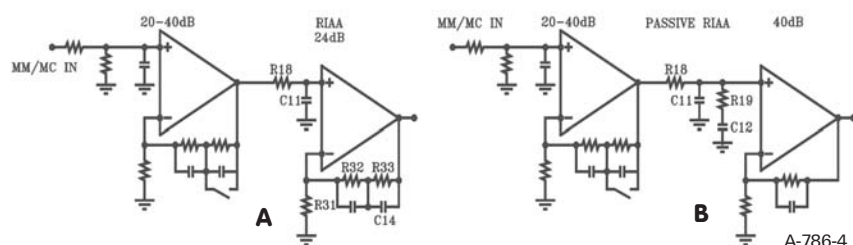
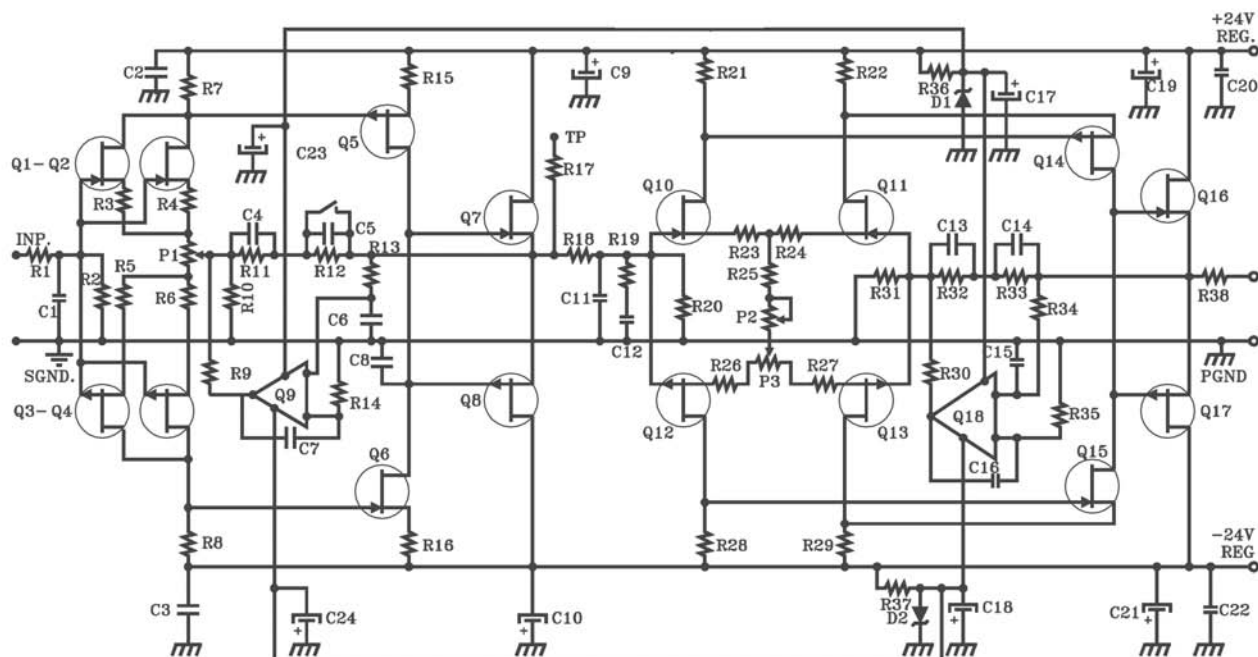


FIGURE 5: The EB-804/419 all-JFET MM/MC phono preamp.



A-786-5

For those of you who want to experiment with all-passive equalization I have included the components for Walt Jung's network N2^{6.7} in Fig. 4B. Here both amplifiers provide flat frequency response and all RIAA equalization is done passively between the two amplifiers by R18/C11/R19/C12. MM gain is 44dB and MC gain is 64dB for the circuit in Fig. 4A. The gain in Fig. 4B depends on the all-passive equalization network discussed later. The Starter kit is supplied with components for the circuit in Fig. 4A. You can order

the all-passive network separately from Borbely Audio.

Figure 5 shows the schematic of the EB-804/419. The input stage is essentially the same as the one in Fig. 3B, but I have added source resistors to each of the input JFETs in case these are needed for matching and/or adjusting the drain current. Because the DC gain of the circuit can be very high (MC application and/or all-passive equalization), I use a servo circuit instead of capacitive coupling to keep the offset close to 0V.

I calculated the equivalent noise re-

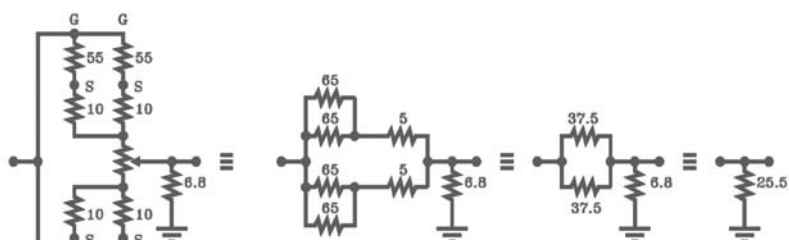
sistance of the input stage using the drawing in Fig. 6. The JFETs are represented by the 55Ω equivalent noise resistors in series with the 10Ω source resistors. These are connected to P1, which is a 10Ω trimpot. Finally, the center point of the trimpot goes to R10 = 6R8 feedback resistor.

Because the JFETs are connected in parallel AC-wise, the equivalent noise resistance can be calculated to 25.5Ω. This will produce 92nV over the audio bandwidth. If you use this preamp with a 50Ω MC pickup, you will have a total noise of $\sqrt{128^2 + 92^2} = 157.6\text{nV}$, which results in a signal-to-noise ratio of 70dB referred to 0.5mV.

The 50Ω pickup itself contributes 128nV—i.e., if the amp were noiseless, the signal-to-noise ratio would be 71.8dB re 0.5mV. This means that the amp contributes only 1.8dB to the noise. You could decrease this by reducing/eliminating some of the noise-producing resistors in the input circuits.

If you select the input JFETs very closely, you could eliminate the 10Ω source resistors. The close matching could also eliminate the offset trimpot.

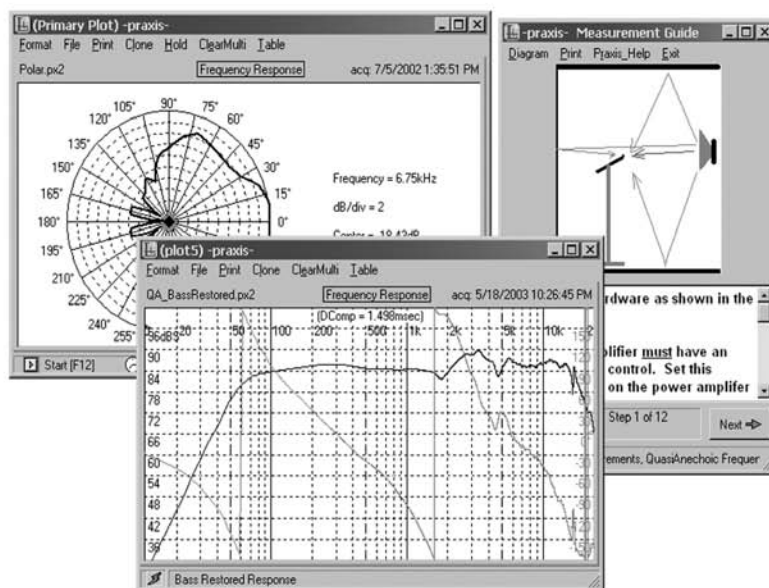
FIGURE 6: Calculating the equivalent noise resistance of the input stage.



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This would result in an equivalent noise resistance of 20.5Ω with a signal-to-noise ratio of 70.4dB, which means that the amp would contribute only about 0.4dB to the overall noise. For a 50Ω MC pickup this is probably the best you can achieve; however, for lower impedance/lower output MC pickups you will need to reduce the amp noise even further. (Calculate the signal-to-noise ratio for an MC pickup with 20Ω resistance!)

For MM the feedback resistor R10

is 75Ω, and the equivalent noise resistance is 93Ω. The equivalent short circuit input noise is 175nV. The total input noise with a 600Ω MM pickup is $\sqrt{(445^2 + 175^2)} = 478\text{nV}$, and the signal-to-noise ratio relative to 5mV is 80dB.

The second stage of the phono preamp uses the same topology as the Starter kit EB-604/410⁴. It provides the active bass boost of the RIAA characteristic through its feedback network. However, due to its high DC gain (in active eq.

mode the DC gain is 44dB!) a servo has been added. The servo amps are supplied with $\pm 10\text{V}$ from shunt regulators.

The all-FET phono preamp is a very sensitive amplifier and is capable of picking up small signals not only through its inputs, but also through vibration. It is, therefore, very important to make the whole amp as “dead” as possible for vibration by using rubber stand-offs or mounting the whole board on a Teflon plate, 6-8mm thick. And a mumetal box will certainly put the icing on the cake.

TYPICAL SPECIFICATIONS

Gain: 1st stage:	20 or 40dB
THD, 20dB gain, 3V/1kHz:	0.0033%
3V/10kHz:	0.005%
Gain: 2nd stage:	24dB
THD, 3V/1kHz:	0.003%
3V/10kHz:	0.007%
Max. output voltage:	approx. 9V RMS
Risetime	
(without RIAA network):	0.3/0.4μs
Freq. Response:	RIAA $\pm 0.2\text{dB}$
Equivalent input noise:	<100nV,
	20Hz-30kHz

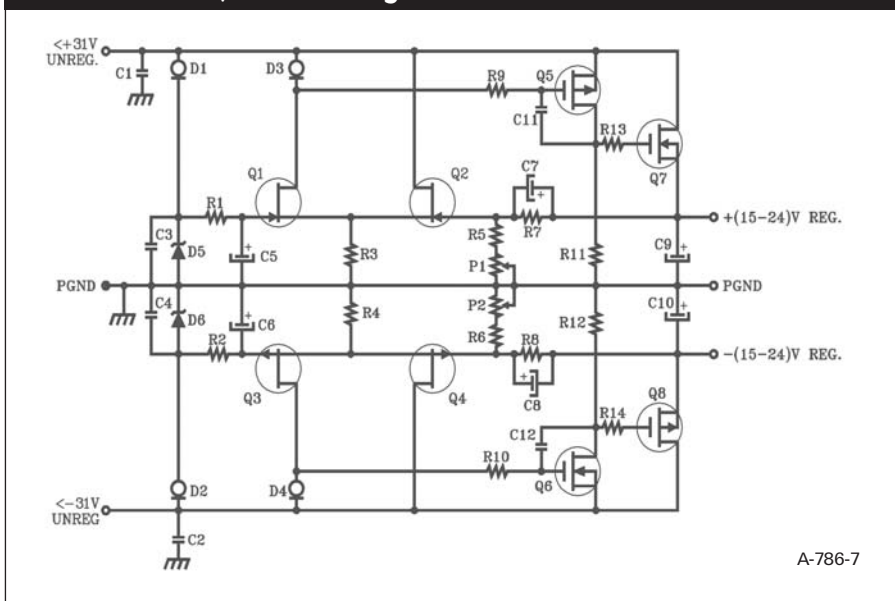
THE EB-704/418 ALL-FET ON-BOARD REGULATOR

The schematic of the on-board EB-704/418 all-FET regulators is shown in Fig. 7. The topology is very similar to

the EB-604/415 regulators used in the EB-604/410 line amp described in reference 4. However, I added Q7 and Q8 MOSFET source followers to be able to cope with the demand of the phono preamp (70mA). You can change output voltage between 15 and 25V with P1 and P2. If you use them with fixed 24V output, then you can short P1 and P2. Make R5 = R6 = 3k32.

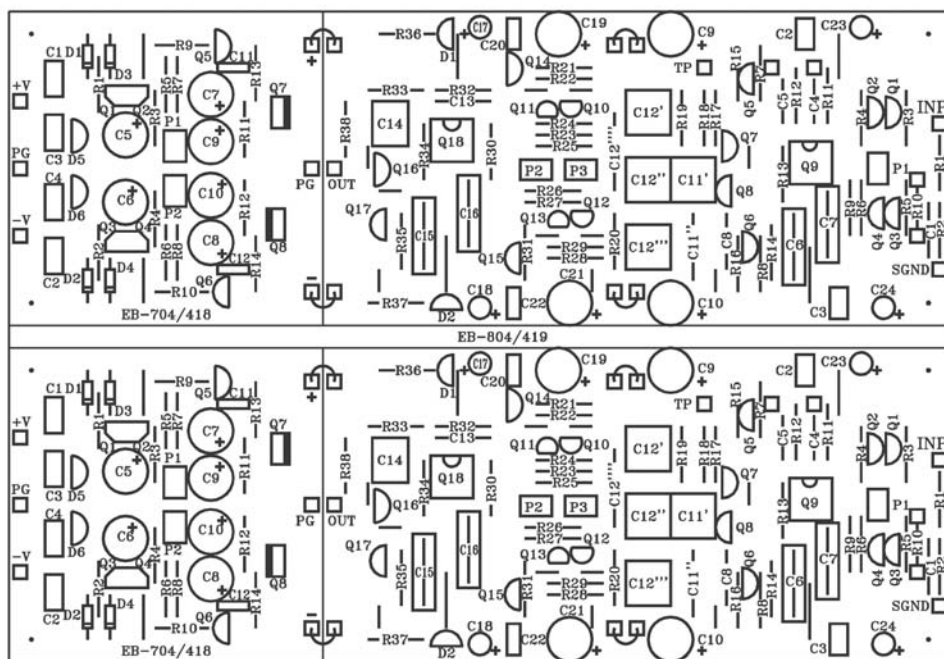
Minimum input/output voltage differential is 3V, but 4V is recommended. Maximum unregulated input voltage is $\pm 31\text{V}$, and you must heatsink Q7/Q8. The output noise of the regulators is $<5\mu\text{V}$ across the audio bandwidth. Recommended power supply is the EB-604/265. The stuffing guide for the EB-

FIGURE 7: EB-704/418 all-FET regulators.



A-786-7

FIGURE 8: Stuffing guide for MM/MC phono preamp EB-804/419 with EB-704/418 regulator.



A-786-8

804/419 phono preamp is shown in Fig. 8.

SETUP PROCEDURE

Start the assembly with the regulators, insert the solder pins and the jumpers, and then install the resistors, FETs, and finally the capacitors. Connect 332R/5W resistors between the +output and ground and the -output and ground of the regulators. Apply $\pm 29V$ unregulated DC to the regulators. Check the output voltage across the load resistors; it should be $24V, \pm 5\%$.

Next, begin the second stage of the

RIAA EQUALIZATION

The RIAA characteristic is defined by three time constants: $T_1 = 3180\mu s$, $T_2 = 318\mu s$, and $T_3 = 75\mu s$, corresponding to the crossover frequencies of 50, 500, and 2122Hz. A fourth time constant of $7950\mu s$ has been added by the IEC as an amendment to the RIAA characteristic; however, it has never been officially standardized by the RIAA. This time constant means a 6dB roll-off below 20Hz, and is meant to function as a rumble filter, reducing turntable/record related low-frequency disturbances. This feature is not included in the phono preamp described here.

The RIAA characteristic is shown in Fig. A with the asymptotes. It is specified in dB relative to 1kHz (0dB). It appears that the DC (or zero frequency) gain is 20dB (10 $\times$) higher than the gain at 1kHz. However, because of the interaction between the time constants, the actual DC gain is 9.898 $\times$ the gain at 1kHz. This means that in an ideal RIAA preamp the 1kHz gain is always 0.101 $\times$ DC gain (see reference 6: Walt Jung; *Op Amp Applications*, Chapter 6-1, Analog Devices, 2002, ISBN:0-916550-26-5), so specifying the gain at 1kHz also defines the gain for all other frequencies. ■

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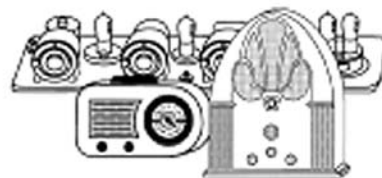
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phono preamp (R20 and onwards) by installing all solder pins, jumpers, resistors, JFETs, and capacitors. Put in the supply jumpers between the regulators and the second stage and short the input of the second stage (jumper across R20). Do not install Q18 just yet. Connect the $\pm 29V$ unregulated supply to the regulators. Measure the voltage drop across R22 (or R29) with a DVM and adjust it with P2 to 3V. Then check the offset voltage at the output and adjust it with P3 to 0V. Insert Q18 in the socket and recheck the offset; it should be less than a couple of mV after a few seconds.

Finally, assemble the input stage, except the RIAA components between the

two amps and Q9. Disconnect the supply jumpers between the regulators and the second stage and connect the regulators to the input stage with short wires. Short the +INP-pin of the input stage to SGND and check the voltage across R15 (or R16), which should be between 2.8V and 3.3V. Check the offset voltage of the input stage at the test-point TP and adjust it to zero with P1 (do this very carefully because the DC gain is very high). Install Q9 in the socket and recheck the offset, which should go down to a couple of mV in a few seconds.

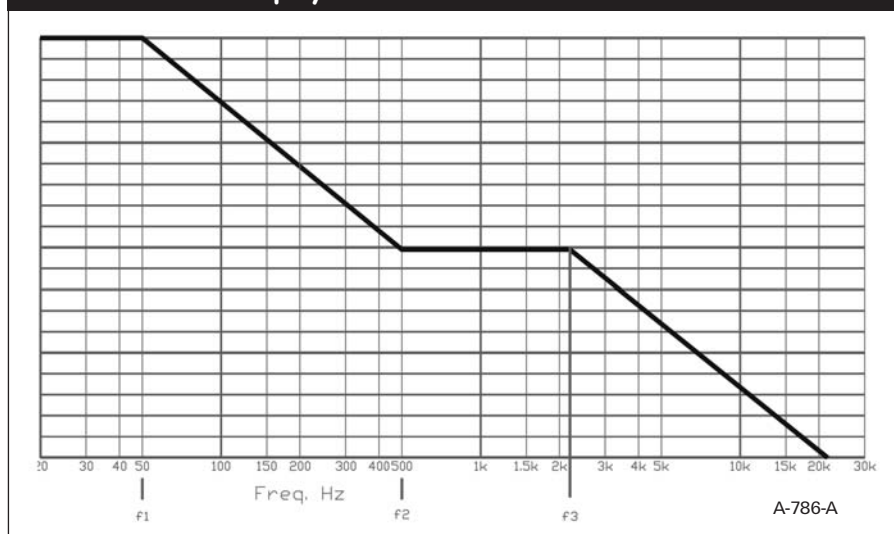
Remove the jumper from R20, install the RIAA components, and connect the

proper supply jumpers between the regulators and the second stage and between the second stage and the input stage. Leave the short at the +INP and switch on the supply voltage. Check the offset at the output, which, after a couple of minutes, should be a few mV. A certain short-term drift of the offset is normal—remember, you are dealing with a total DC-gain of 84dB!

If you have audio measurement equipment, including an inverse RIAA circuit⁸ connect it to the input of the phono preamp and sweep the audio generator from 20Hz to 20kHz. Monitor the output of the phono preamp with an audio mV-meter. The output voltage should be constant with a maximum tolerance of $\pm 0.2\text{dB}$. If you have a scope, connect it to the output and make sure that the circuit does not overload during the measurement.

The phono preamp is now ready to be connected to your system. Changing between MM and MC means replacing R10. For MM, R10 = 75R and for MC it is 6R8. For MM, R2 is 47k, and for MC you will need to connect the appropriate load resistor at the input. You can solder this resistor either directly across the input terminals of the PCB or across the input connector on the back panel. A shunt capacitor (C1) might also be necessary; consult the datasheet of your pickup. *ax*

FIGURE A: The RIAA playback characteristic.



DESIGN PROCEDURE

The design procedure for the hybrid circuit in Fig. 4A is relatively simple:

1.) 75 μs passive network: choose an appropriate value for R18, which should be as low as possible because it influences the noise in the second stage, but high enough so that the input stage can drive it at high frequencies. If you use op amps for the two amps, the value should be between 600 Ω and several k Ω , depending on the drive capability of the op amps. I use R18 = 750 Ω for the discrete JFET input circuit used in the EB-804/419 because it is easy to make the 75 μs time constant with a C11 = 75 $\mu\text{F}/750 = 0.1\mu\text{F}$ capacitor. Because resistors are available with many more values than caps, you can also start

with the cap and calculate the necessary resistor. If you want to use a 47nF resistor, R18 = 75 $\mu\text{s}/47\text{nF} = 1.6\text{k}$. Naturally, you can also use two capacitors in parallel to make a convenient value.

2.) 318 and 3180 μs feedback network: choose a practical value for R33, which determines the 3180 μs time constant. Because I wanted to use the same cap as for the 75 μs , I calculated the resistor from R33 = 3180 $\mu\text{s}/0.1\mu\text{F} = 31\text{k}$ 8 (closest practical value is 31k6). Next calculate R31 from the formula that gives the DC (zero frequency) gain. The 1kHz gain is 0.101 $\times$ DC gain, or the DC gain is 9.898 $\times$ the 1kHz gain. I want a 1kHz gain of 24dB, which is 15.85 $\times$, so the DC gain will be 9.898 $\times$ 15.85 = 156.88 $\times$. R1 = (9.898 $\times$ R3)/(9 $\times$ DC gain) = 222 Ω (closest value is 221R). Finally, calculate R2 from (R3/9)-R1 = 3290

(closest value: 3k32).

For the all-passive equalization in Fig. 4B I used Walt Jung's network N2⁷ with the following component values:

Theoretical:	Closest fit:
R18 = 7k29	7k32
R19 = 1k06	1k05
C11 = 0.3 μF	0.3 μF
C12 = 0.1029 μF	0.1 μF + 3nF

All network components should be precision ones: resistors 1% or better and caps 2% or better. The Starter kit EB-804/419 is delivered with 0.1% Dale CMF-55-143 non-magnetic resistors and 1 and 2% polypropylene and polystyrene capacitors. Using Walt's inverse RIAA network⁸ both networks show better than $\pm 0.2\text{dB}$ accuracy across the audio range. ■

Acknowledgements

Many thanks to Walt Jung for letting me use his passive RIAA network in the phono preamp and for his valuable comments and suggestions regarding this article.

The Starter Kits EB-804/419 and EB-704/418 (available from Borbely Audio, Angerstr. 9, 86836 Obermeitingen, Germany. +49/8232/903616, sales@borbelyaudio.com) are the intellectual property of Erno Borbely/Borbely Audio. Commercial use or duplication in any form is not authorized without a license agreement.

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4. Erno Borbely, "Starter Kits, Part I: EB-604/410 All-JFET Line Amp," audioXpress, March 2005, p. 9.
5. Erno Borbely, "The All-FET Line Amp" audioXpress, May 2002, p. 28.
6. Walt Jung, Op Amp Applications, Chapter 6-1, Analog Devices, 2002, ISBN 0-916550-26-5.
7. Walt Jung, "Topology Considerations for RIAA Phono Preamplifiers," AES Preprint 1719, 67th Convention, 1980 Oct. 31/Nov. 3 New York. (http://home.comcast.net/~walt-jung/wsb/PDFs/Topology_Considerations_for_RIAA_Phono_Preamps.pdf)
8. Walt Jung and Stanley Lipshitz, "A High Accuracy Inverse RIAA Network," The Audio Amateur, 1/80, p. 22.

PARTS LIST

PHONO PREAMP EB-804/419

Resistors, Trimpots

R1	Short for MC 10R for MM
R2	47k5 for MM See spec for MC
R3, R4, R5, R6	10R
R7, R8, R11	681R
R9	2K21
R10	6R8 for MC 75R for MM
R12	Optional for passive eq.
R13, R14, R20, R34, R35	1M
R15, R16, R22, R29	332R
R17, R25, R38	47R5
R18	750R
R19	See passive eq.
R21, R28	1k5
R23, R24	100R
R26, R27	75R
R30	100k
R31	221R
R32	3k32
R33	31k6
R36, R37	1k2
P1	10R COPAL
P2	200R COPAL
P3	50R COPAL

Capacitors

C1, C8	100pF, 160V, PS
C2, C3, C20, C22	0.1µF, 100V, PP
C4, C13	33pF, 160V, PS
C5	Appl. Dependent
C6, C7, C15, C16	0.22µF, 250V, PP
C9, C10, C19, C21	47µF, 35V
C11, C14	0.1µF, 100V, 1%, ERO PP
C12	See passive eq.
C17, C18, C23, C24	100µF, 25V, ROE EKO

FETs, Diodes

Q1, Q2	K170GR (Idss: 3.5-4mA)
Q3, Q4	J74GR (Idss: 3.5-4mA)
Q5, Q14	J74V (Idss: >10mA)

Q6, Q15	K170V (Idss: >10mA)
Q7, Q16	K170BL (Idss: 8-10mA)
Q8, Q17	J74 (Idss: 8-10mA)
Q10, Q11	K170BL/V*
Q12, Q13	J74BL/V**
Q9, Q18	LF411CN
D1, D2	LM4040DIZ-10

* Dual JFET K389BL/V can be used for Q10-Q11

** Dual JFET J109BL/V can be used for Q12-Q13

Miscellaneous

40 × 1mm solder pins
PCB: EB-804/419

REGULATORS EB-704/418

Resistors, Trimpots

R1, R2, R5, R6	3K09
R3, R4	1K82
R7, R8	8K25
R9, R10, R13, R14	100R
R11, R12	10K
P1, P2	5K COPAL

Capacitors

C1, C2, C3, C4	0.1µF, 100V, PP
C5, C6	220µF, 16V
C7, C8, C9, C10	47µF, 35V
C11, C12	33pF, 400V, MICA

FETs, Diodes

Q1, Q2	K170BL/V* (Matched, Idss: >9mA)
Q3, Q4	J74BL/V** (Matched, Idss: >9mA)
Q5	J148
Q6	K982
Q7	K2013
Q8	J313
D1, D2	E202 (2mA)
D3, D4	E102 (1mA)
D5, D6	LM329DZ (6.9V ref.)

* Dual JFET K389BL/V can be used for Q1-Q2

** Dual JFET J109BL/V can be used for Q3-Q4

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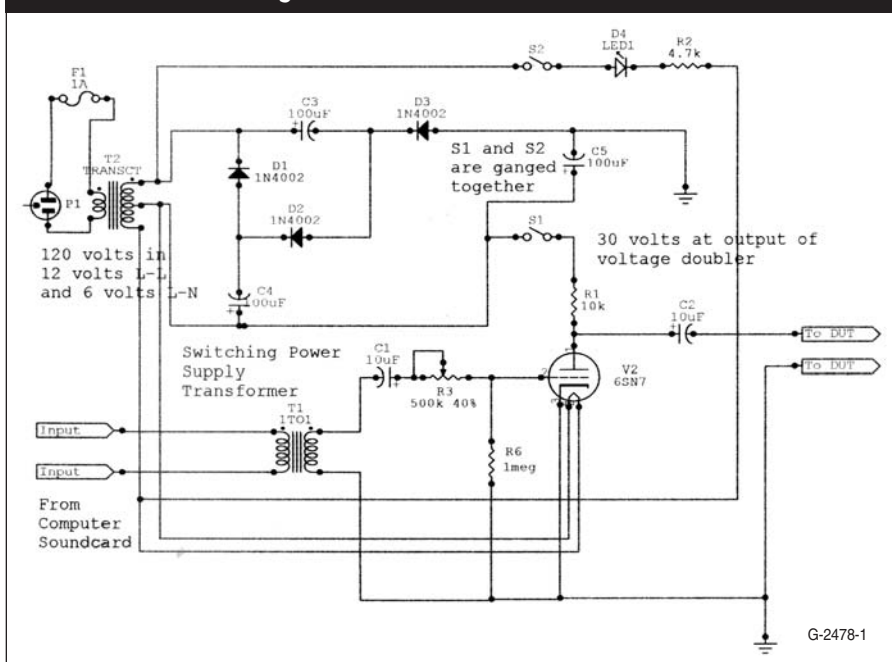
Build this neat safety device to connect the audio output of your computer with vacuum tube equipment.

By Frank Simonsen

PHOTO 1: The "Isolator" showing power cord.



FIGURE 1: Schematic Diagram.



I downloaded and purchased this software and installed it on my desktop computer; the price is very reasonable. It allows you to generate sine, square, triangular, sawtooth, impulse, white noise, and pink noise, and can output in mono or stereo and up to 16 different test tones on each channel. You can set each frequency independently and sweep them in a linear or log fashion. You can set the output level in dB, and the frequency goes up to 20kHz.

The output of the sound card is low impedance and solid-state. I remember an unfortunate experience in which I was conducting tests on a piece of tube gear with a solid-state signal generator and inevitably the output transistor was fried. Luckily, it was an easy-to-obtain 2N3903, and I quickly replaced it. I wouldn't want to have this experience with an expensive sound card or an even more expensive laptop computer.

DESIGN GOALS AND CIRCUIT OPERATION

I needed to design an interface device with completely isolated input and output. I thought about using solid-state devices, but I figured that the electrical fragility of the devices precluded their use in this project. I settled on the 6SN7 because it is easy to obtain and it is a triode, which was fine because I don't need large amounts of gain. The tube is rugged and can work on a low voltage such as 30V. I originally intended to power the device with batteries, but I needed to put it in a small case. The 600mA that the heater requires is not conducive to small batteries, so I settled on a line-powered device (Photo 1).

FIGURE 2: 1.25MHz sweep.

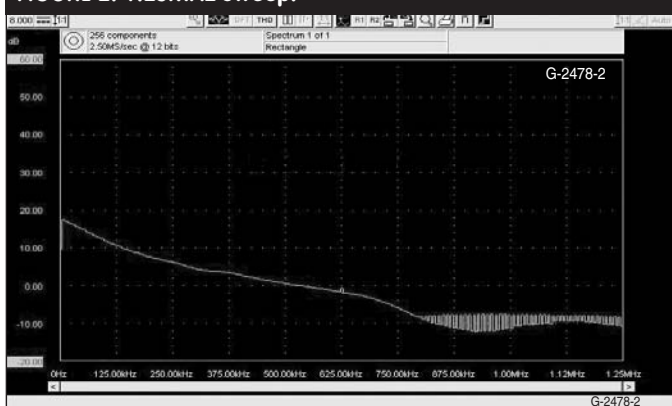


FIGURE 4: 1kHz sine wave before symmetry adjustment.

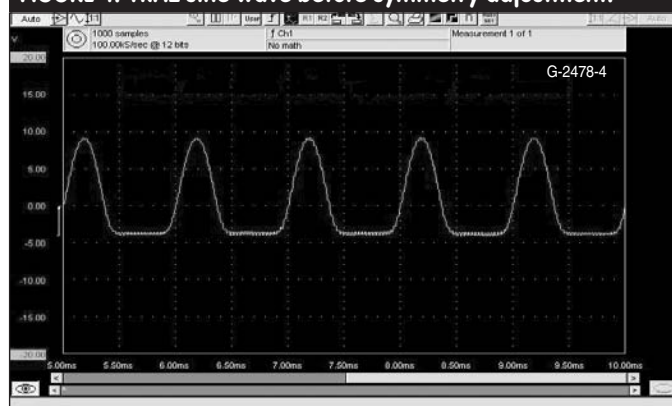


FIGURE 3: 125kHz sweep.

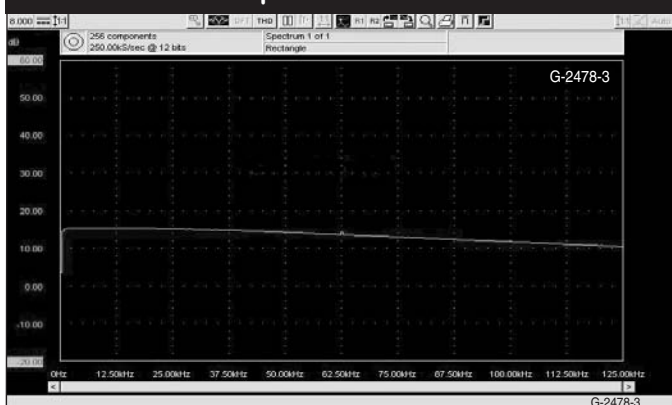
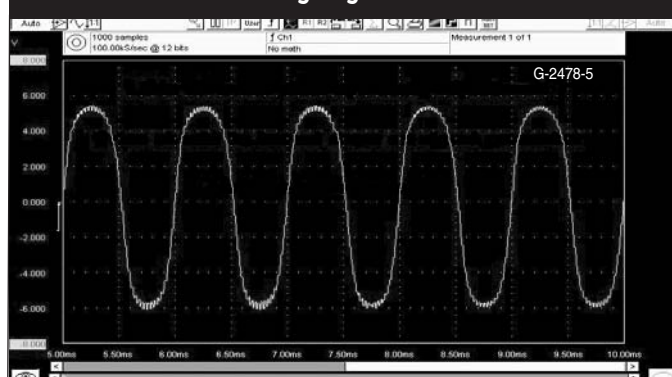
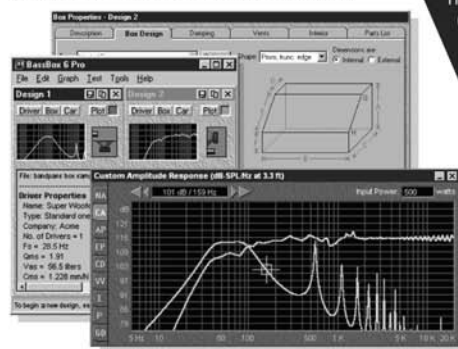


FIGURE 5: 1kHz sine wave after symmetry adjustment. Drive should be turned down on signal generator for cleaner waveform.



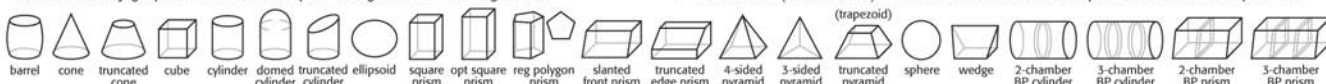
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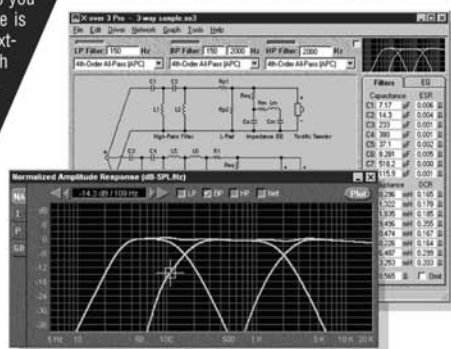
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FIGURE 6: 25kHz sweep.



PHOTO 2: Inside view of the Isolator.

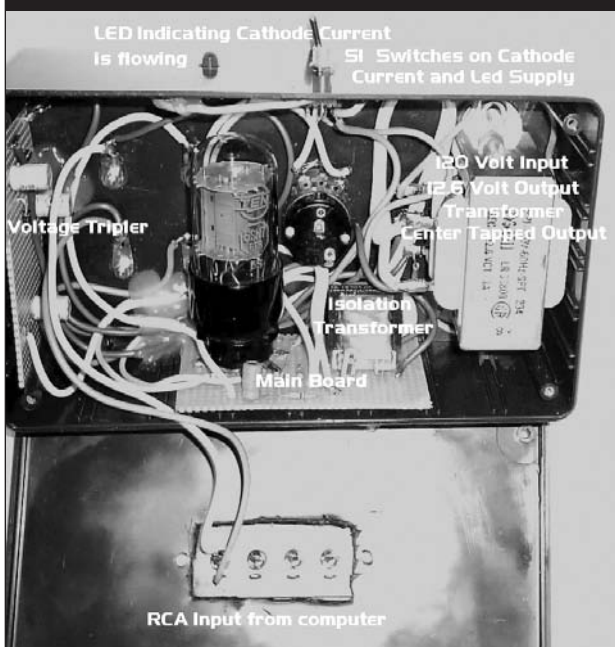


PHOTO 3: Back of device showing RCA jack input.



I wished to isolate the electronics from the line, so I settled on a 12V center-tapped transformer to power both the heater and the voltage tripler, which supplies the plate supply. The power for the LED also comes from the transformer. I supplied the heater from one side of the transformer output and the tripler from the other. The LED is supplied by the full 12V. You could use a 6V transformer here, but you would need to change the limiting resistor for the LED to a smaller value. I just used a 12V transformer, which I had in my parts box.

The circuit (*Fig. 1*) is a very conventional common cathode circuit and the grid is biased at 0V through a 1M Ω resistor. The voltage gain is about 5. The plate resistor is 10k Ω and the output signal is taken out through a 10 μ F electrolytic capacitor that should be voltage rated

as high as possible, at least 50V. The output impedance is less than 10k Ω .

The input circuit is isolated through a 1 to 1 ratio switching power supply transformer. The input impedance of the device I used is about 250 Ω at 1kHz. With one side grounded, the other side is attached to another 10 μ F electrolytic capacitor. The signal is taken through the capacitor and a 500k Ω potentiometer, which is used as an input waveform symmetry adjustment. With careful adjustment of this control and the level control of the NCH program, you should obtain an excellent output waveform.

Apply the heater current as soon as you plug the unit in. This gives the heater time to warm up before the plate voltage is applied. The LED power is applied at the same time as the plate voltage, indicating when the plate supply is on. The 6V RMS voltage is applied to the tripler, and each capacitor charges up to its peak value. The tripled voltage is around 25V DC.

My RMS voltage was a little higher than 6V, so the tripler put out about 30V. The difference is caused by the loading on the power transformer. My transformer was fairly lightly loaded, even while supplying the heater current of 600mA, so the output voltage is a little higher than rated.

TESTING AND DEVICE PERFORMANCE

I did some frequency response testing on this circuit. From the measurement graphs (*Figs. 2-6*), you will notice that the response is poor at the extreme end of the audio spectrum (such as below 30Hz) but is flat up to 25kHz. The response up to 125kHz is not bad, dropping only about 5dB in 125kHz. The response from low audio to 800kHz drops about 27dB. This shows that the device is best used in audio testing. The graphs also show the difference that adjusting the waveform symmetry control makes on a sine wave.

CONSTRUCTION

I constructed the two main circuits on perfboard. I attached the tube socket to the board with the wires that were used to make connections to the actual pins and some hot melt glue. I also glued the boards in place to the inside of the box with hot melt glue (*Photo 2*).

One of the advantages of using hot

melt glue is that you can cut it out if you need to modify. The interconnecting wires were neatly held in place with a bit of hot melt glue. I attached the audio power transformer to the box with machine screws. I replaced the input and output connections with "banana" type jack connectors.

I designated the balanced input with two terminals of the same color and the unbalanced output connectors with red and black. The four RCA type connectors of which I used only one were mounted on the rear of the project box (Photo 3). The whole project is housed in a blue project box available at your local electronics store. The 110V cord comes into the box through a hole drilled in the side (Photo 4).

Take precautions to tie an Underwriters knot to make sure it doesn't

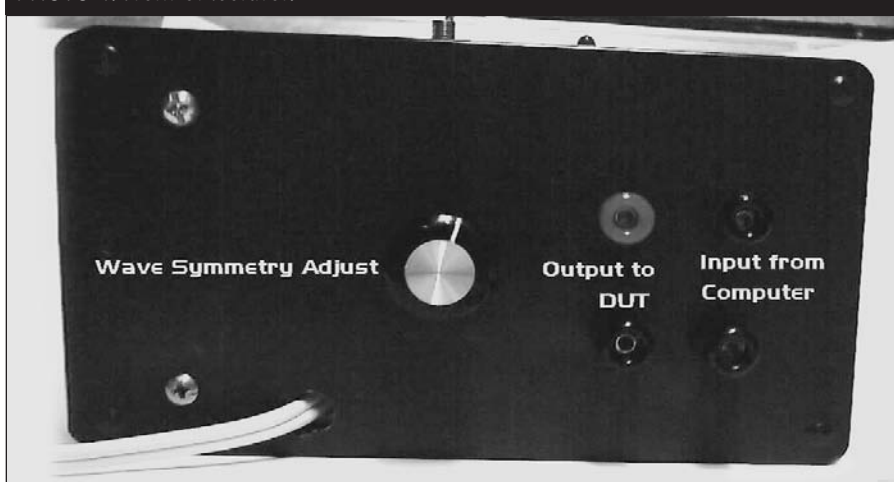
slip out when tugged on from outside the box. Work on the unit only when it is unplugged. Keep in mind that the heater current is on immediately when you plug the unit in. *ax*

Frank Simonsen is a certified electronics technician working in industrial electronics. He has been interested in audio electronics and particularly tube electronics for many years. He is also a ham radio operator and a collector of antique radios.

SOURCES

All of the parts except the tube and socket should be available from your local electronics store or Digi-Key. You can purchase the tube and socket from Antique Electronic Supply in Tempe, Ariz.

PHOTO 4: Front of Isolator.



PARTS LIST

Item	Quantity	Reference	Part
1	3	C1, C2, C3	100µF
2	2	C4, C5	10µF
3	3	D1, D2, D3	1N4002
4	1	D4	LED 1
5	1	F1	3A
6	1	J1	AC IN
7	1	R1	10K
8	1	R2	4K7
9	1	R3	1M
10	2	S1A, B	DPDT
11	1	T1	Transformer 1/1
12	1	T2	Transformer 120V/12V CT
13	1	V1	6SN7G
14	1	P1	500K POT

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Electrostatic Loudspeaker Basics, Part 2

By Matthew Lattis

The author continues his detailed look at ESLs, comparing basic theory with test results.

AMPLIFIER LOADING

This brief, initial discussion of the load presented by a transformer and speaker covers the case of a transformer with an amplifier connected directly to the primary and a speaker connected directly to the secondary. Refer to *Fig. 18's* bottom pane for a typical impedance/phase plot of an ESL load measured at the transformer primary. At low frequencies the primary inductance of the transformer is the dominant factor influencing impedance, and most amplifiers have little trouble in this region. As the frequency increases, the capacitive reactance of the speaker begins to take a more prominent role in the final impedance of the system, and the electrical phase swings strongly capacitive in this region.

Luckily, the impedance is still relatively high at these frequencies, and most amplifiers tolerate this kind of load as well. At high frequencies things become ugly as the leakage inductance of the transformer and the speaker load produce a series resonance and the impedance plummets. At this point the impedance is basically determined by whatever wire resistance is in the primary plus the secondary's reflected wire resistance. At the typically high frequencies involved, the demands for power (with music) are small, but some amplifiers are still very unhappy when presented with this type of load.

As a general rule, transformers with the highest step-up ratios are more problematic because the capacitance on the secondary of the transformer is multiplied by the step-up ratio squared when it is referred to the primary (e.g., 500pF on the secondary of a 1:50 transformer is 1.25μF when reflected to the

primary). The leakage inductance is also normally higher with higher turns ratios, which causes the series resonance at high frequencies to occur at a lower frequency. Good transformer design and implementation can help to lighten the load for the partnering amplifier, though, and I will discuss that a little later. For a more thorough treatment of equivalent circuits and transformer testing, Ron Wagner's *Electrostatic Loudspeaker Design and Construction* is a good resource.

Figures 18-23 present a variety of typical transformers and wiring configurations with no load, a 165pF load, and a 1060pF load. Electrical phase is the higher trace at 10Hz in each graph. The approximate capacitance of an ESL can be computed with equation 3

$$C = (0.224KA)/d \quad (3)$$

where

C = capacitance in picofarads

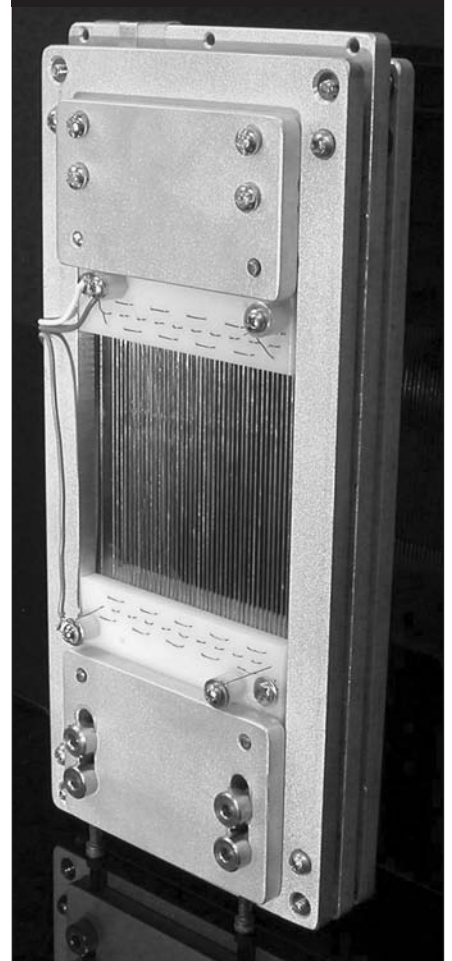
K = dielectric constant of the material between the plates (air = 1)

A = area of one plate in square inches

d = distance between plates in inches

The first transformer I will look at is a clone of the MagneTek Triad S-142A (I used a clone because the S-142A was discontinued before I started working with ESLs). Since this device was designed for use as an output transformer in tube amplifiers, it is connected in reverse when used with ESLs (the primary is used as the secondary). This model presents a few wiring options using the full primary as a secondary and various secondary taps as the primary. I tested the following configurations:

PHOTO 3: Finished unit.



Common - 4Ω:144 ratio —*Fig. 18*
8Ω - 16Ω 1:76 ratio —*Fig. 19*
4Ω - 8Ω 1:100 ratio —*Fig. 20*

Next, two toroidal models from Plitron are shown. The PAT-4133-ES is a 1:50 unit whose results are shown in *Fig. 21*. The PAT-4134-ES has a 1:75 turns ratio and is shown in *Fig. 22*. The final transformer considered in these tests is the Tranex 2-0404, which has a 1:150 turns ratio—*Fig. 23*.

A quick survey of the test results shows that the modern Plitron units provide the most extended frequency response of all the transformers tested

and are an easier load to drive when similar turns ratios are involved. When compared to the S-142A clone wired for a 1:44 ratio, the PAT-4133-ES has significantly higher impedance at high frequencies and also has a 1.1dB advantage due to its 1:50 turns ratio. In the lowest pane of Fig. 18, you can see the impedance minimum at ~18kHz and the abrupt change in electrical phase in the same region which indicate the resonance formed by the S-142A's leakage inductance and the speaker capacitance. This resonance produces a low-pass filter that limits the high-frequency response of the system.

No sign of the Plitron PAT-4133-ES's resonance is visible on its plot with the same load (a resonance is still there, of course, but it is ultrasonic and, therefore, outside the range of the hardware used). With the 1060pF load the impedance of the 1:75 Plitron PAT-4134-ES is inconsequentially lower at 20kHz than the S-142A wired for 1:44, but the Plitron unit still has a bandwidth advantage. Though the phase is just starting to swing upward near 20kHz with the heaviest loading of the PAT-4134-ES,

the actual resonance cannot be seen on this plot. The 1:75 ratio provided by the Plitron unit gives it a 4.6dB output advantage over the 1:44 of the S-142A (equivalent to nearly tripling amplifier power). When you compare the 1:75 Plitron to the S-142A wired for 1:76 with the heaviest loading, the Plitron's resonance occurs over an octave higher, and it has a moderate impedance advantage at high frequencies.

LIGHTENING THE LOAD

You can use two simple methods to make an ESL load less demanding. Neither approach will make the speaker easy to drive, but *easier* is possible without much effort and can make a significant difference if your amplifier is borderline. Both methods involve placing resistors in the circuit, so there are no detrimental phase effects.

Option 1: By dividing the speaker into smaller areas and using resistors between the transformer's secondary and the individual segments, you can produce low-pass filters that can be used to adjust frequency balance and to prevent the full capacitance of the speaker from being reflected to the

primary at frequencies higher than the crossover point. This resistance is referred to as Res in the following treatment. It is Res/2 in the schematic because each resistor sees the capacitance formed from the stator-to-diaphragm. You should use plate-to-plate capacitance with Res or plate-to-diaphragm capacitance with Res/2 when calculating crossover points.

The low-pass slope is 6dB/octave with the -3dB point occurring where the capacitive reactance of the ESL segment is equal to the value of Res. The Quad ESL-57 and ESL-63 were some of the best-known units to use this technique (the 63 also used a rather elaborate time delay circuit with ring-shaped segments in the central portion of the speaker to emulate a point source). You can use equation 3 to calculate capacitance, while equation 4 defines capacitive reactance

$$X_c = 1/(6.283fC) \quad (4)$$

X_c = capacitive reactance in ohms

f = frequency in hertz

C = capacitance in farads

Option 2: Placing a resistor in series

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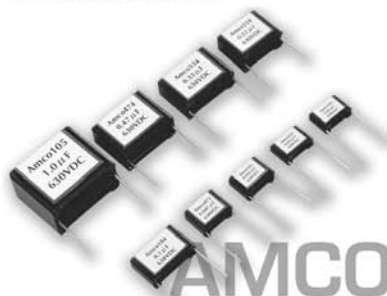
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with the transformer's primary also has several benefits and is highly recommended by Menno van der Veen, the designer of the Plitron ESL transformers. You can easily tune the Q of the series resonance formed by the speaker capacitance and transformer leakage inductance with this resistor to eliminate ringing in the speaker/transformer system. If necessary, you can also

decrease the output at high frequencies with this resistor. Additionally, you can sometimes use this extra resistance to stabilize an amplifier that is having difficulties driving an ESL load.

The following treatments of ESL transformer theory were graciously supplied by Menno van der Veen. As stated earlier, transformer theory is also covered in Ron Wagner's *Electro-*

static Loudspeaker Design and Construction (please keep in mind that loads can be reflected to the primary or secondary side for analysis).

Figure 24 shows the basic components I have been discussing.

Rep is a tuning resistor in series with primary

Res is a tuning resistor in series with secondary

FIGURE 18: MagneTek Triad S-142A clone 1:44.

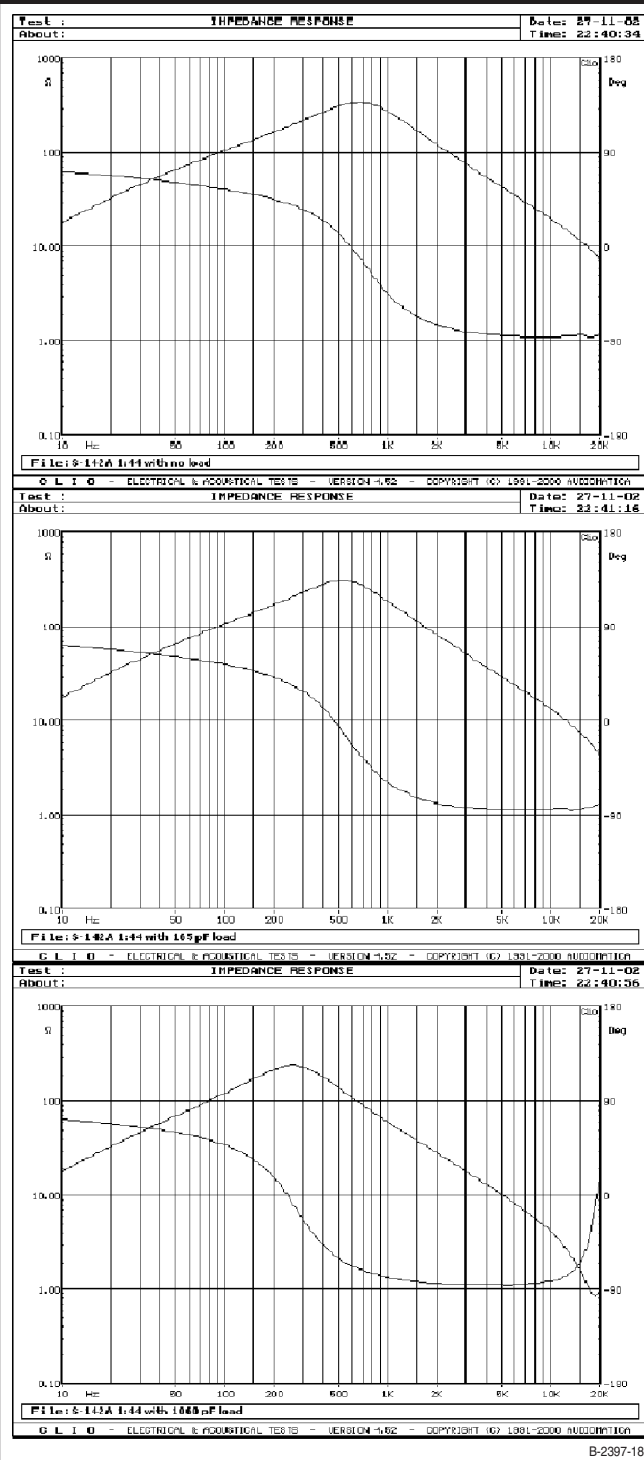
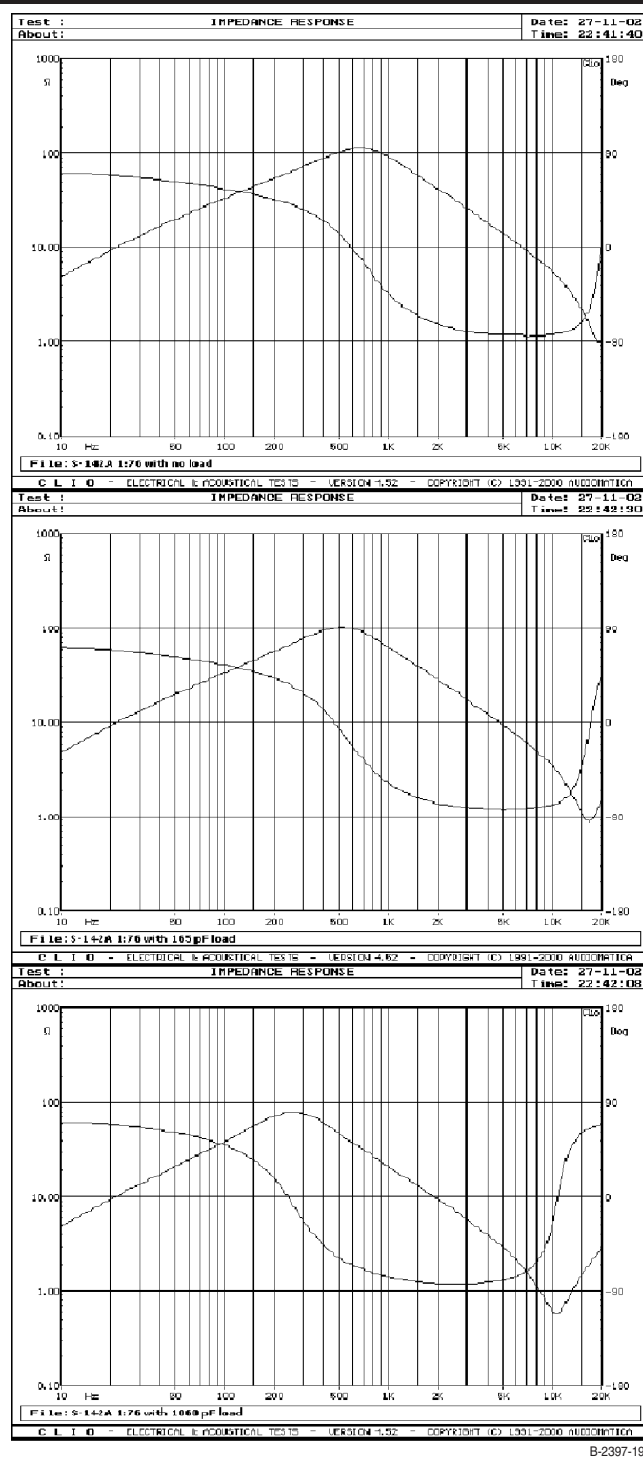


FIGURE 19: MagneTek Triad S-142A clone 1:76.



Ces is the capacitance of the electrostatic speaker from plate-to-plate

If you omit Res to simplify the analysis, at high frequencies you are left with the equivalent circuit shown in Fig. 25 and covered in equations 5, 6, and 7. All of the relevant primary elements are reflected to the secondary side in this analysis.

Lss is the leakage inductance of the transformer in henries

Cis is the secondary winding capacitance of the transformer in farads

Ces is the capacitance of the electrostatic speaker from plate-to-plate in farads

Rt is a combined resistance reflected to the secondary and is defined in equation 5

$$R_t = (N_s/N_p)^2(Z_{out} + R_{ep} + R_{ip}) + R_{is} \quad (5)$$

Ns = number of turns in the transformer's secondary winding

Np = number of turns in the transformer's primary winding

Zout = output impedance of the amplifier in ohms

Rep = tuning resistor in series with

FIGURE 20: MagneTek Triad S-142A clone 1:100.

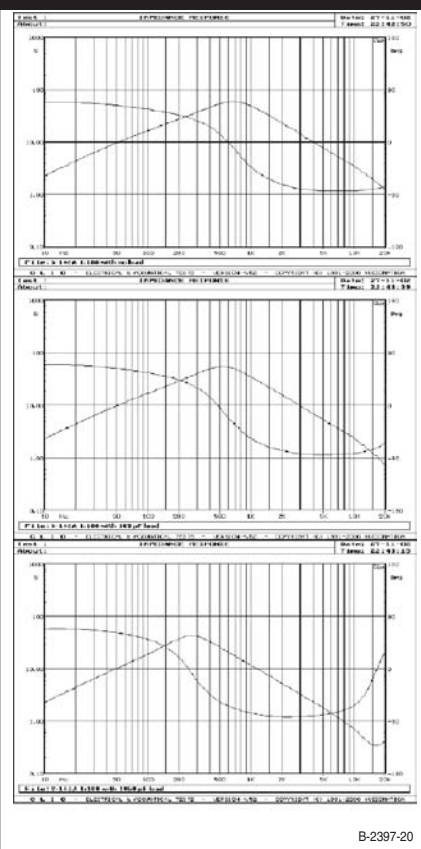
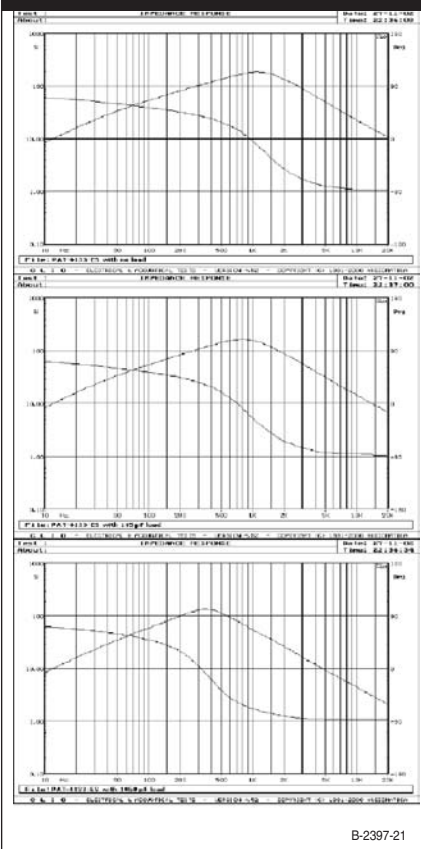


FIGURE 21: Plitron PAT-4133-ES 1:50.



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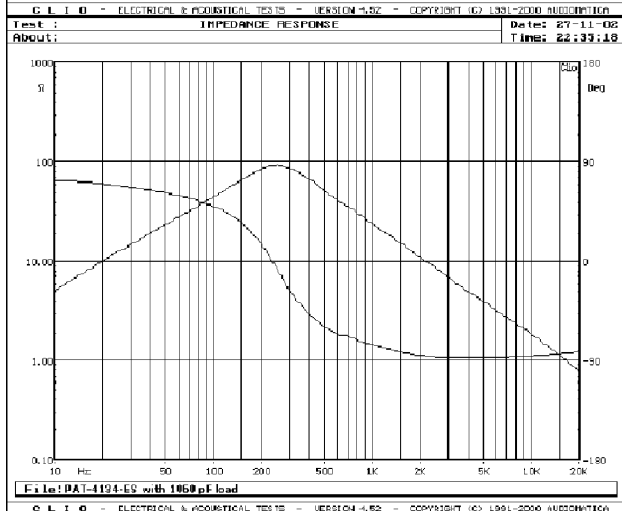
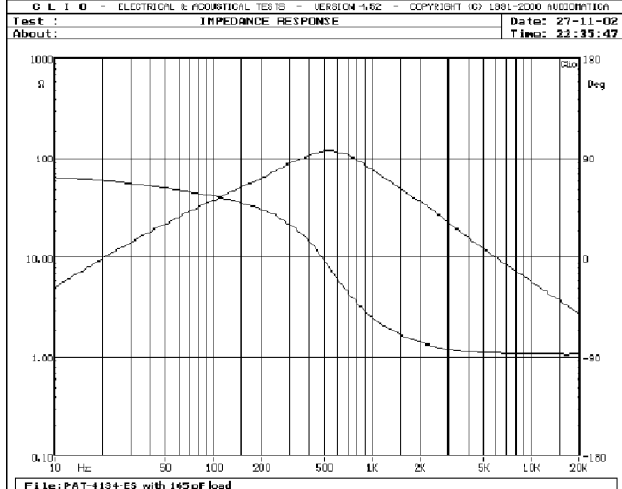
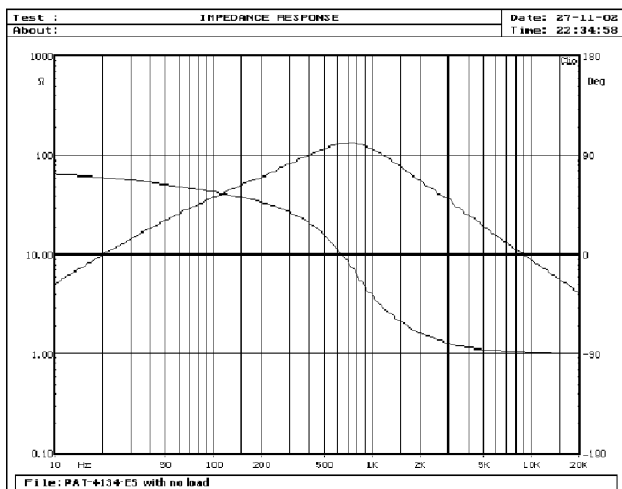
Z56548 Reproduction of the Z565 output transformer as used on the ST35 and SCA35 amplifiers, except that the output taps are 4 and 8 ohms

A470S reproduction of the Dynaco A470 output transformer as used on the Dynaco (tm) ST70 and MkIV amplifiers

A431S a reproduction of the Dynaco A431 output transformer as used on the MkII and MkIII amplifiers and Sunn guitar/bass amplifiers.

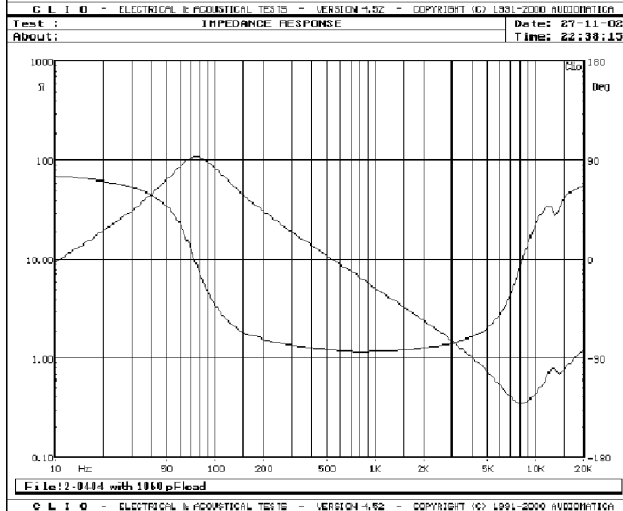
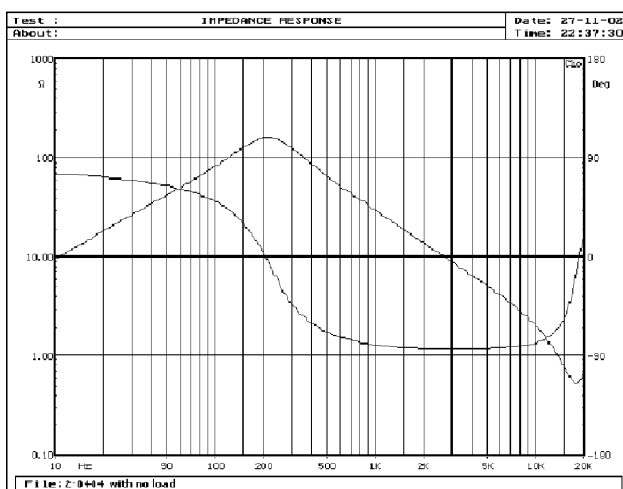
Other stuff we're working on: A420 (6600 ohm 30W) and A442 (4300 ohm 60W with tertiary screen winding)..

FIGURE 22: Plitron PAT-4134-ES 1:75.



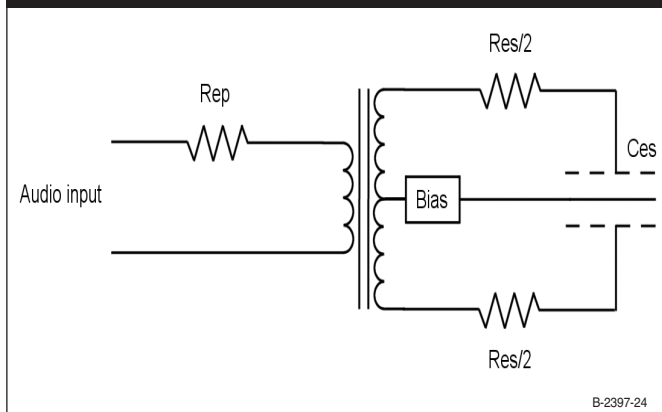
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FIGURE 23: Tranex 2-0404 1:150.



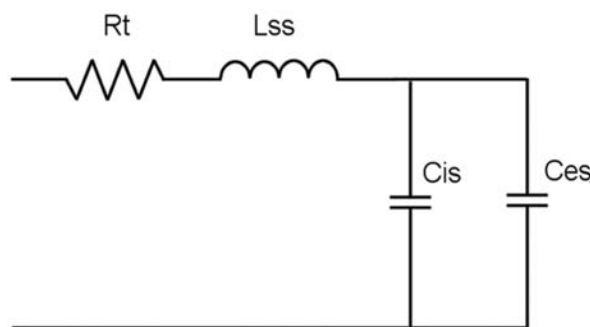
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FIGURE 24: Basic ESL/transformer configuration.



B-2397-24

FIGURE 25: High frequency equivalent circuit.



B-2397-25

primary, value in ohms

Rip = wire resistance of the transformer's primary in ohms

Ris = wire resistance of the transformer's secondary in ohms

The actual number of turns in the primary and secondary are not necessary; the ratio is all that is required in the calculation.

Equation 6 defines the resonant frequency of the low-pass filter formed by these components.

$$f = 1/(6.283(Lss(Cis + Ces))^{1/2}) \quad (6)$$

f = frequency in hertz

capacitance is in farads and inductance is in henries

Equation 7 defines the Q of the circuit

$$Q = (1/Rt)(Lss/(Cis+Ces))^{1/2} \quad (7)$$

For the best high-frequency extension with minimum phase shift and ringing, set the Q at 0.577. You could increase the Rep beyond this point to try to stabilize the partnering amplifier or to decrease high-frequency output.

The following points were also conveyed in correspondence with Menno van der Veen.

1. He suggested a maximum DC offset of 3mV from the amplifier to ensure that the transformer has adequate magnetic headroom during operation. As little as 10mV of offset can saturate the core.
2. At both the high-frequency series

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resonance and at very low frequencies, R_t is the major factor influencing the total impedance.

3. The use of R_{ep} produces better DC offset behavior because part of the DC will be dropped across the resistor in series with the primary.

To demonstrate the benefits of using R_{ep} , I conducted the following test using an inexpensive 45W/channel receiver that was known to be slightly unstable into electrostatic loads. I used a 100MHz

Tektronix TDS 340A oscilloscope to gather the data presented in the graphs that follow. *Figure 26* shows a 2kHz 1V peak-to-peak square wave at the output of the receiver with no load. *Figure 27* shows the input and output of a PAT-4134-ES driven with the same signal while the secondary was connected directly to a 1200pF ESL. The transformer's output trace has been rescaled to compensate for the 1:75 turns ratio. R_{ep} was then added to the circuit to produce the graph shown in *Fig. 28*.

To tune R_{ep} , I added a potentiometer to the primary side of the transformer and increased the resistance until the overshoot and ringing were eliminated. I kept the resistance as low as possible to retain maximum "squareness" in the output. In this case, 1.4Ω proved optimal.

Neglecting the output impedance of the receiver and any resistance present in test leads, you have a resonance of 24kHz and a Q of 0.38. The Q implies that the system is overdamped and that the high-frequency output will be rolled

FIGURE 26: 2kHz square wave at unloaded receiver output—1V peak-to-peak.

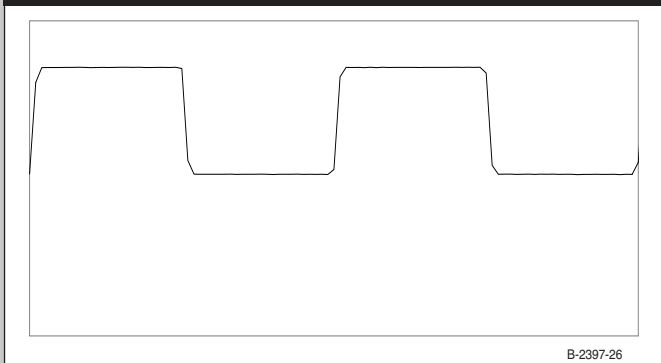


FIGURE 27: Input and output of PAT-4134-ES driving a 1200pF load.

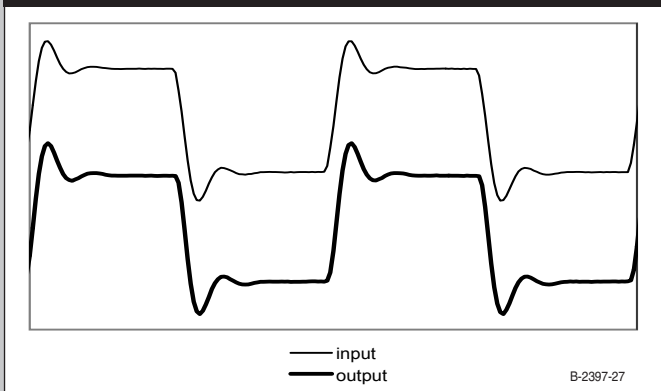


FIGURE 28: Input and output of PAT-4134-ES driving a 1200pF load with 1.4Ω R_{ep} .

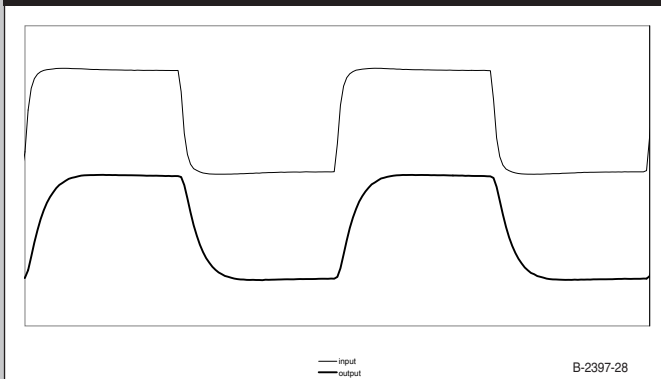
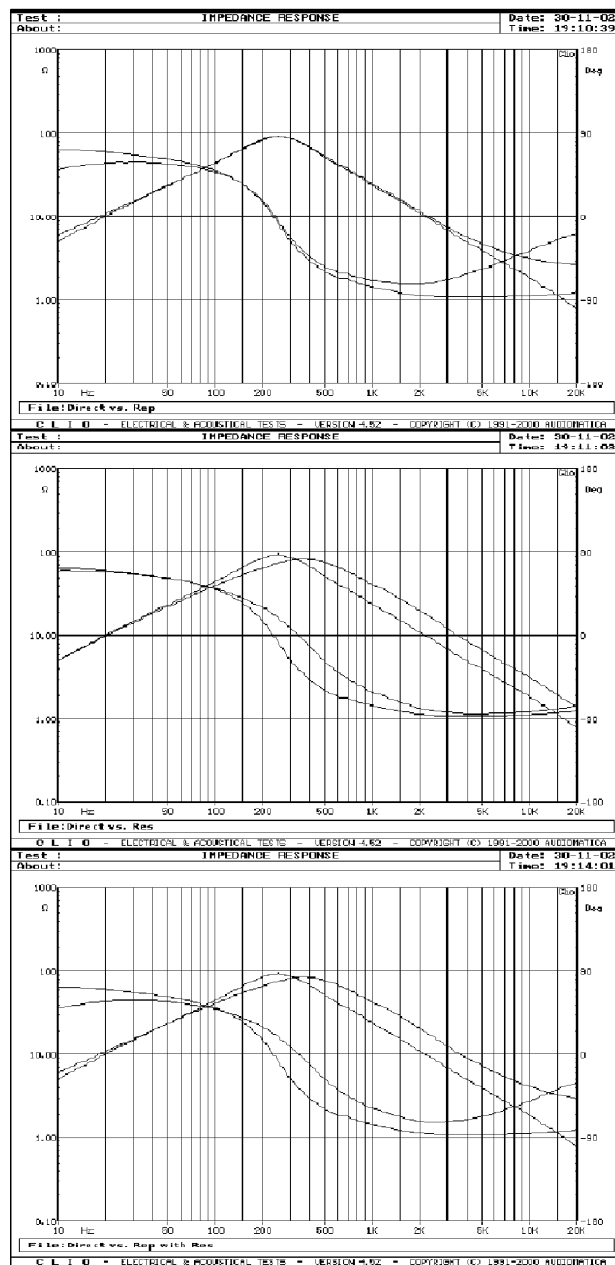


FIGURE 29: Effect of R_{ep} and R_{es} on impedance and phase.



off from its theoretical maximum bandwidth, but I will gladly trade that for the benefits the extra resistance provides for the receiver.

You can also see the benefits of Rep and Res as shown in Fig. 29. The top plot shows the original impedance and phase produced by a 1060pF load connected directly to the secondary of a PAT-4134-ES versus the same load driven with 2 Ω of Rep. The middle graph in the group shows the original load versus 500pF driven through 2.2M Ω of Res and 560pF driven directly. The Res provides a low-pass crossover at approximately 145Hz with a slope of 6dB/octave and helps to decrease the phase angle at mid frequencies.

The bottom plot is the original load versus both methods combined. The result of using both methods is still not the most benign load in the world, but the improvement is considerable.

CONCLUSION

I hope this article has answered more questions than it has generated. I'm still searching for the "ultimate" full-range ESL design that will convince me to dive in all the way and build a speaker that will

demand its full-time use in my system.

I hope others will share their experiences in this forum. It's not just groundbreaking discoveries that need to be written about; patents and designs that might initially seem out of date often contain many details that are still pertinent (and not widely known). If you've rediscovered the benefits of someone else's work and it hasn't been covered lately, please share with the group. **aX**

Thanks to John Triplett for the machine work—you can see some of his more ambitious endeavors at www.nothingbutcustoms.com

I also thank Galen Powers, who supplied the equipment and talent used to photograph this project.

Matthew Lattis has been experimenting with ESLs for approximately 10 years and has had projects published in **Speaker Builder** and **Audio Electronics**. His current employer specializes in plastic ophthalmic lenses and systems for their production. Eighteen US patents cover his contributions to that field.

SOURCES

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Tube Audio Construction Tips

By Graham Dicker

Part 6: A Coil Winder

Make your own coil-winding machine from spare parts.

In Part 5 I wrote about recycling microwave oven transformers, which you can also use as a great source of core material and bobbins for mains and output transformers. If you are going to experiment with winding your own transformers, you will need a coil-winding machine, which is available commercially for thousands of dollars, or you can make your own for a small cost.

A coil-winding machine can be as simple or complex as you like. Commercial ones have rotational motors and also feed motors to ensure layers are wound uniformly. Many have the capability to wind more than one bobbin at a time. I now make all my own transformers, and find that all you need is a winder (described here), the materials (you can recycle core material and bob-

bins), and a bit of practice and patience.

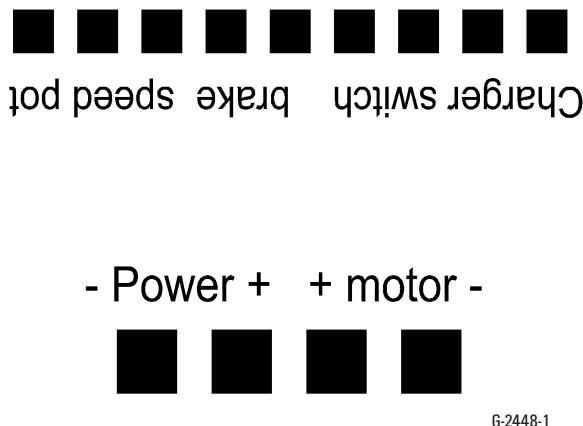
My coil winder is a simple one made from an electric scooter, commonly sold on eBay for around \$25 US (*Photo 1*). The final completed coil winder is shown in *Photo 2*. This is a small variant of the original, battery-powered winder. This one has a small mains DC supply, so that I do not need to charge batteries.

CONSTRUCTION

I constructed the coil winder on a 24" × 12" length of pine with four rubber feet on the bottom for non-slip purposes. This makes it a portable and convenient desktop item to use. The winder consists of the base, a motor, battery, controller from a scooter, a calculator, and some other simple parts.

The e-scooter, which is the main source of parts for the project (*Photo 3*), contains a nice DC motor, a DC speed controller (*Photo 4*), and two 12V rechargeable batteries and charger. I easily removed these from the e-scooter with simple hand tools.

FIGURE 1: Speed controller module connections.



MOTOR SHAFT ADAPTER

The first task is to cut the head of the 6" × 1/2" bolt to leave a threaded section for the bobbin clamp. Next make an adapter from a length of 3" × 1" aluminum rod to go between the motor shaft and the threaded section of the bolt (*Photo 5*). The best way to do this is to drill a small pilot hole through the 3" length of the aluminum rod with a 1/8" diameter drill. This is best done in a drill press or with a lathe. Make sure you secure the rod in a machine vise and center-punch the rod before drilling.

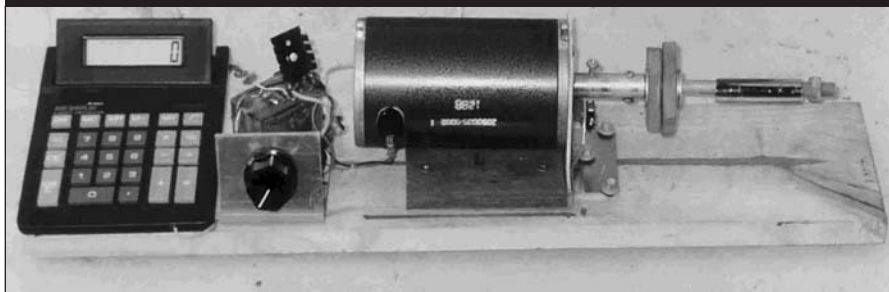
Next drill a clearance hole for the motor shaft all the way through the adapter, followed by a clearance hole for the 3/4" bolt shank, but this time only 1.5" deep (half the adapter length). Dry-fit the adapter to the motor shaft and bobbin clamp bolt. If all is well, apply Loctite adhesive to join the adapter to the motor shaft and the bolt. When the Loctite adhesive has cured, place the completed shaft in a machine vise and drill two 1/8" holes through the adapter to insert locking bolts at the motor and the clamp bolt end. A close-up view is shown in *Photo 6*.

Make sure that you leave a full-length bolt on the motor end. This is

PHOTO 1: Low-cost electric scooter sold on eBay.



PHOTO 2: Completed coil winder.



used to pulse the turns counter microswitch. You may choose to cut off the locking bolt at the bobbin clamp bolt so that it does not protrude. Use adhesive on the locking bolts as well. *Photo 7* shows a completed winding on the drive shaft, clamped between the wooden end cheeks, washers, and locking nut.

MOUNTING THE HARDWARE

You can mount the winder motor assembly on an aluminum angle bracket fabricated to suit the motor used. *Photo 5* shows the bracket I used along with the motor supported on a scrap piece of timber to allow a larger diameter

bobbin to be wound. The distance from the baseboard to the center of my motor shaft is approximately 3". This allows a winding of about 5" in diameter. A winding this size is good for around a 1kW transformer.

Another aluminum bracket is required to hold the speed control pot. And another small angle bracket is used to hold the turns counter microswitch, which is positioned so that each time the motor shaft rotates, the locking bolt closes the microswitch's normally-open contacts.

Now you need to fabricate two timber bobbin cheek clamps (shown in the *Photo 5* close-up) from pieces of 1/2"

PHOTO 3: Parts removed from scooter



PHOTO 4: DC speed controller from scooter.



PHOTO 5: Complete motor assembly of winder.



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Use a selection of 5/8" diameter tubing

as a spacer to handle different width windings and bobbins. Normally the bobbin sits between the two pieces of timber as in *Photo 7*.

WIRING AND ELECTRONICS

The electronics package is simple. I reused the original scooter motor speed controller, as well as a \$5 calculator as the turns counter. The scooter speed

controller is a PWM type rated at about 10A. This is more than ample to control the coil winder.

I replaced the original throttle on the scooter with a conventional linear pot. I measured the throttle on my unit and found that it was a 10k pot. My original winder was powered by the two 12V batteries supplied with the scooter. These are also charged with the provided wall-type charger.

For safety's sake, this is a good method to power your winder. I was a little more adventurous at a later stage and fabricated a simple 24V mains operated power supply instead. The pinout connections for the speed controller are marked on each controller. *Figure 1* shows the markings on the unit I purchased.

THE TURNS COUNTER

As mentioned, I used a low-cost \$5 calculator as the turns counter (*Photo 8*). The microswitch contacts are simply wired in parallel with the equal (=) key on the calculator keypad.

In the calculator that I purchased, plastic buttons contacted a membrane-type switch under the



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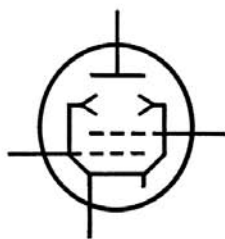
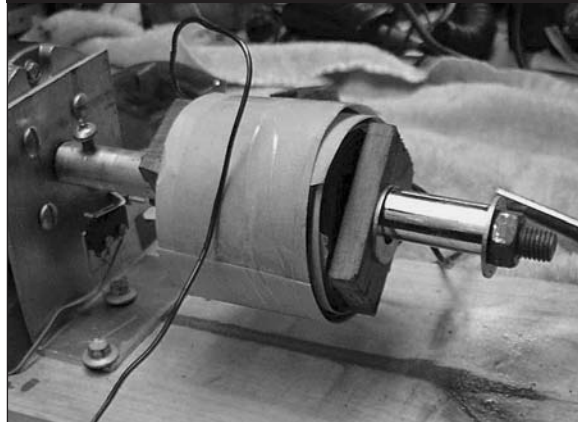
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PHOTO 6: Close-up of the motor shaft and adapter.



PHOTO 7: Completed winding on drive shaft



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keypad. The membrane switch is fabricated using a pattern printed on Mylar film. The conductive pattern in this case appears to be similar to Aquadag, a carbon-based material. Connection was simply made by stripping back about $\frac{1}{2}$ " of solid drawn copper wire and affixing it using some clear packing tape (Photo 9).

(I built this coil winder about two years ago and only recently took the close-up photo of the connection for publication. Even after two years there is little evidence of oxidation on the contact wires.)

To start the winding cycle, press 1+. Each time the microswitch contact closes,

it effectively presses the = key on the calculator, adding one to the count. The calculator is capable of keeping up with the fastest rotational speed of the motor. This counter also works if you are pulling down an old transformer and need to count the turns to work out the core turns per volt (TPV).

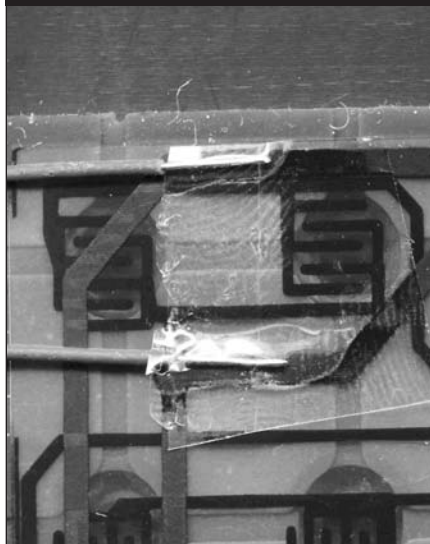
Another method of using the calculator counter is to work out the volts per turn, by simply dividing 1 by the core TPV. For example, a 5TPV core results in 0.2V per turn. If you are winding a power transformer, you can simply enter the volts per turn into the calculator, followed by the + key. Every turn that is added displays the winding voltage.

For example, 100 turns would add 0.2V to the total 100 times, displaying 20V. The calculator that I purchased was solar powered, which saves the drama of changing batteries. I mounted the calculator to the base board with double-sided tape. *ax*

PHOTO 8: Calculator used as a counter.



PHOTO 9: Close-up of connections to calculator.



PARTS LIST for Coil Winder

1 "e-scooter"

1 24" x 12" x $\frac{1}{2}$ " pine (for base)

1 calculator

1 microswitch

1 6" x $\frac{1}{2}$ " bolt

1 $\frac{1}{2}$ " nut

3 $\frac{1}{2}$ " washers

Scrap aluminum for mounting brackets

3 1" x $\frac{3}{16}$ " nuts and bolt

6" double-sided tape

4 rubber feet

1 3" length 1" diameter aluminum rod

Various cut lengths of $\frac{5}{8}$ " aluminum tubing as packers.

2 pieces plywood or solid timber $\frac{1}{8}$ " thick 3" x 2" with a $\frac{3}{4}$ " centered hole

1 10k linear pot

1 Knob to suit pot

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CORRECTION

I found an error in my article "The Double-Dipole Subwoofer," which was published in *audioXpress*, November 2004, p. 18.

In Fig. 12, the regulated power supply, the values of resistors R2 and R4 which adjust the output voltage of the voltage regulators, should both be 2k7.

*George Danavaras
Athens, Greece*

REVISED TEST

In response to inquiries about my recent article ("A Transconductance Tube Tester Test Standard," Feb. '05 aX, p. 18), I have made several changes to allow the Transconductance Test Standard to work on higher input (grid signal) voltages, such as on some selected ranges of the Hickok Model 539 series. Measurements on this standard were

within $\pm 1\%$ of 1500 μ S with input signal voltages of up to 7.5V RMS and plate voltages up to 250V DC. This necessitated some modifications to the circuit as shown in Fig. 1.

I devised a new circuit board. Due to the power dissipated within this device at higher plate voltages, I've also included additional holes to attach a heatsink with standard 1.0" spacing between pins. I turned the heatsink down on a metal lathe such that the bottom 1.5" fit within a standard 1.25" O.D., thin wall (0.050" wall thickness) tubing. I then fit the aluminum tube over the octal plug socket and potted using Loctite E-60NC Hysol epoxy potting compound. The outside of the case heated up approximately 30°C after 15 minutes of operation at 200V DC plate voltage.

*Joel Hatch
jhatch200@yahoo.com*

Revised Transconductance Test Standard Circuit Board---single-sided (Fig. 2)

C1 = 0.15 μ F P10969 (Panasonic ECQ, 250V metal polyester) [Digi-key]

R1 = 250k Ω (Vishay 1/4W) [Mouser]

R2 = 118 Ω (IRC Precision, 0.1%, 1/4W) [Mouser]

R3 = 511.2 Ω (Vishay 1/2W, selected from 511 Ω 1% resistors, 509.5 to 512 Ω are suitable) [Mouser]

D1 = UF4004 (Vishay 400V, 1A rectifier) [Mouser]

D2, D3 = 1N5245B (Diodes Inc., 15V zener) [Digi-key]

U1 = 10M45S (IXYS) [Digi-key]

HeatSink = HS239 (Aavid Thermalloy 5300002B02500) [Digi-key]

Octal Base socket = Octal Socket Accessory #15 (QQQ Octal Pin Plug) [Angela Instruments]

Reference: Outside Circle Dia. = 1.100", Bar adjacent to hole on diodes indicates cathode.

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FIGURE 1: Revised Transconductance Test circuit.

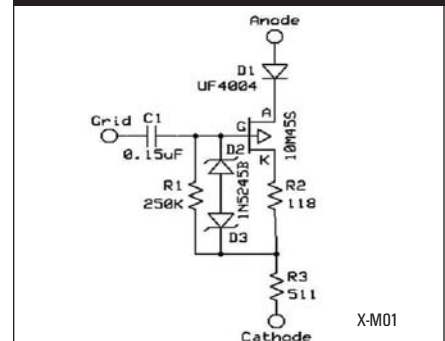
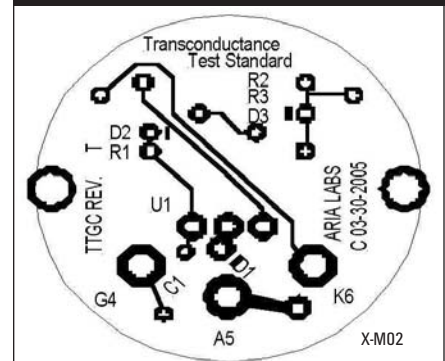


FIGURE 2: Revised board.



VACUUM STATE



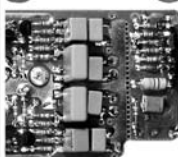
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TRANSFORMER SOUND

I read Norman Thagard's article about H.V. differential amplifiers in *audioXpress* ("Single-Ended to Differential Mode Made Easy," Dec. '04, p. 8) with great interest. Congratulations on your work. I never thought of connecting so many tube amplifiers in series/parallel to achieve such levels of power.

We (at Audio Consulting) are working on differential topologies for solid-state and tube amplifiers. Although in both cases, power never exceeds 30W, the sonic advantages of differential topologies are quite obvious (at least to us), especially in these times when the audiophile community calls for single-ended circuits. Here are two areas we would like to address:

Phase splitters. This is a very critical stage. We have tried many circuits—solid state and tube—and finally use transformers. We still believe that this is sonically the most satisfying way of producing 180° out-of-phase signals. The two out-of-phase signals are identical voltage wise and source impedances are identical, too. The latter is more important to sound performance than we

initially may think.

Many topologies that are used to produce out-of-phase signals use different devices or a number of devices for each phase, which lowers the performance.

Of course, the quality of the transformer is absolutely crucial. It happens that transformers are our specialty and we have produced many different types that may be used to achieve 180° out-of-phase signals: from low impedance to high impedance, with or without voltage gain, copper wire or silver wire, various magnetics, from regular 0.35mm grain-oriented steel to extremely exotic materials in wooden cabinets.

Power from power lines to high power amplifiers. Your very original way of using standard tube power amplifiers and its advantages can also be applied to the utility mains. You mentioned that you were having mains voltage down to 107V AC when operating all your power amplifiers, showing the limitations of running 115V AC power lines where power is provided with high value AC currents.

In our constant battle for better-sounding mains, we have developed very spe-

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cial power supply and mains isolation transformers that allow for much higher energy transfer from the mains to the amplifiers. Today's mains quality is extremely bad for audio components, and this has nothing to do with sags, HF, or RF. But this is another story.

One transformer that we use for Europe and Asia has a 400V AC primary winding that allows it to be connected between two of the three phases we get in our homes. Mains here comes with three 230V AC lines that are out-of-phase by 120° and one "0" connection. Normal connections between the "0" and one of the three 230V AC lines lead to the standard 0-230V AC mains situation we have over in Europe and parts of Asia.

Using power between two out of the three 230V AC lines leads to 400V AC ($\sqrt{3} \times 230V$ AC). Using power that way has the big advantage of avoiding the "0" connection, which carries the bigger part of the unwanted "pollution."

Thus a 400-230V AC isolation transformer allows for a totally new and isolated 230V AC line feeding your audio system. There is a similar situation in the US.

In the US, 230-115V AC transformers work perfectly for homes having access to both 115V AC phases (out-of-phase by 180° here). The situation in the US really is a differential topology, by analogy to your way of using power amplifiers. Sound wise, this also leads to big improvements, for reasons that would take another few pages to mention.

I really became excited about your work and we would be most happy to provide you with free samples of phase-splitter transformers in case you are interested in further experiments. We just need to know the output stage topology and impedance of your preamplifier in order to produce an optimum phase-splitter transformer. If the impedance is low enough, we may even consider voltage gain within the transformer.

*Serge Schmidlin
Audio Consulting*

*14 B Chemin Des Vignes
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Switzerland*

Norman Thagard responds:

Thank you very much for your kind letter. It was the incremental improvement in reproduced sound noted with each increase in

the number of amps that spurred me to find a way to maximize the power.

My reason for settling on the single-transistor phase-splitter was its excellent objective performance combined with simplicity. I wanted to avoid additional active stages if I could.

In theory, transformers offer a superior method of converting a single-ended signal to a differential one, but as you note, transformer quality is crucial. Since I have some facility at electronic circuit design and none at transformer construction, I opted for the electronic approach to phase-splitting.

Some years ago I purchased a book on transformer design and construction, so I do have a pretty good idea how to go about it while preserving frequency response. I am still unmotivated to attempt it myself, as it looks like a fairly daunting task. Nonetheless, there are folks who can "roll their own," modify existing transformers, and/or re-wind defective tube amplifier output transformers, a capability that I especially admire.

I would love to compare the sound of a transformer phase-splitter with the one currently in my system, which is the MOS-FET-based version of the Concertina phase-splitter as described in my article. For vinyl playback the phase-splitter is directly driven by the output of a two-stage MC cartridge phono preamp, which has a BiMOS folded-cascode, single-ended (as opposed to complementary with push-pull action) output stage whose output impedance ranges from about 25Ω at 20Hz to 10Ω at 20kHz thanks to negative feedback. For CD, SACD, digital cable, tuner, and so on, playback, a Marantz preamp drives the phase-splitter.

I have no idea what its output impedance is, but would guess it's probably pretty low. Since most of my listening is through the phono preamp, I would have a greater interest in a transformer optimized for the MC phono preamp. The differential input resistance of either channel's tube amp complement is 0.5MΩ. Of course, my single-transistor phase-splitter outputs each drive four paralleled input channels of the tube amps and therefore "see" a single-ended resistance of 250kΩ.

Again, I appreciate your kind letter and your offer.

NOISE AMP

Thanks to Charles Hansen for his article on the Noise Meter Amp (*audioXpress*, Jan. 2005). As an "advanced dabbler" who reads *audioXpress* and who knows

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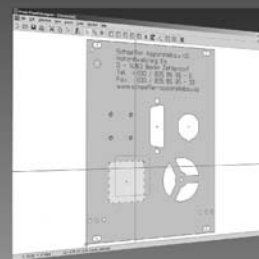


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just enough about electronics to get himself into trouble, I have a few questions about this project.

My main interest is in audio recording, and it seems that this noise amp could be used to determine the quietest tubes to use in microphone preamps. Is this amp overkill in such a situation?

Also, I'm building some solid-state power supplies for some old German tube mike preamps. Is this amp a good choice for obtaining lowest noise in the supply circuits, or is there a better choice?

Mr. Hansen says that he routed the circuit board with a Dremel tool. I'd never heard of this technique, but after some surfing on the Web, I found out that this is common practice. Perhaps Mr. Hansen would be willing to tell us about his routing setup—what sort of jig he uses, computer controlled, and so on?

Is it necessary to rout the board for the Noise Meter Amp, or is etching a possibility considering the need for low noise? Etching would certainly simplify matters for me after seeing

the complexity of computer-controlled routers.

Last, as someone who is seriously considering building this project, are there other testing tools that might be more appropriate for me? I realize spectrum analyzers don't come cheap, but wonder whether they might serve a dual purpose: determining offending frequencies in power supplies as well as determining lowest noise.

*Mark Drury
Pleasanton, Calif.*

Charles Hansen responds:

My Noise Meter Amplifier has a low input impedance (600Ω or 8k5) that would be incompatible with the high impedances at the plate of a common-cathode tube amplifier stage. The high values of grid and plate resistances will generate correspondingly high levels of Johnson noise, which may be difficult to separate from tube noise on an absolute basis.

A 1MΩ grid resistor will generate about 18μV of noise at room temperature over a 20kHz bandwidth. This grid resistor noise looks like an input signal and will be amplified by the gain of the amplifier stage.



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AC-powered heaters can also introduce 60Hz hum. I don't know whether valid noise measurements could be made at the cathode of these stages, where low value resistors are typically used.

The most significant noise source in the tube itself is shot noise, caused by fluctuations in the plate current due to the random collection of electrons at the plate. The shot noise in a temperature-limited cathode is higher than the noise with a space-charge limited tube. Other sources of tube noise are the random ionization of the few remaining gas molecules in the "vacuum," the noise induced by electron flow near the control grid wires, noise caused by current fluctuations between the screen and plate in a pentode, and microphonics.

You might want to do some research on the Internet to find a suitable test method for measuring noise in vacuum tubes.

Two good books that cover noise in electronic applications are:

Low Noise Electronic System Design by C. D. Motchenbacher and J. A. Connelly (Wiley-Interscience) ISBN 0-471-57742-1, and *Op Amp Applications Handbook* edited by Walt Jung (Newnes-Analog Devices) ISBN

0-7506-7844-5.

I designed the Noise Meter Amplifier after running into limitations while making power supply noise measurements, so this is an ideal application.

I used the Dremel router in six other projects for *Audio Amateur*.

"RIAA Preamplifier With HeadRoom™ Module," 6/97 *Audio Electronics*, pp. 8-21 (this included a photo on page 12 of the routing technique).

"Precision Sine Wave Oscillator," 5/98 *Audio Electronics*, pp. 8-23.

"Budget Wave Analyzer (Part 1)," 3/99 *Audio Electronics*, pp. 8-17.

"Mating Subs and Satellites via Passive Crossovers" (with GR Koonce), 8/99 *Speaker Builder*, pp. 38-51.

"An Audio Balun," 6/00 *Audio Electronics*, pp. 16-23.

"HV Differential Amplifier," *audioXpress*, pp. 20-25, Dec '04.

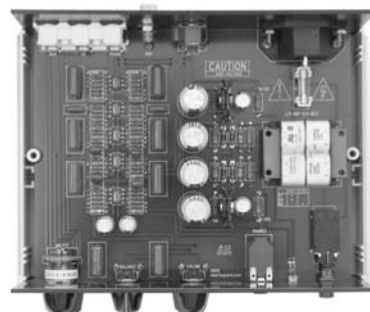
It is not necessary to rout the board as I did. You can use an etched board (preferably double-sided with a maximum ground plane area). Note that I did not use a computer-controlled router. My routing was done manually using a fixture to hold down the board and a clamped straight edge to guide

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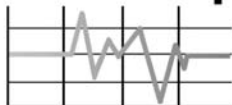
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A reasonably-priced spectrum analyzer by itself may not be sensitive enough to detect microvolts of noise. 1 μ V of noise referred to 2V RMS is -126dBV. However, it is ideal for separating switching power supply noise, power line harmonics (hum), and intermodulation products due to non-linear amplification. These tend to have levels above -100dBV (0.001%) when problematic. I have found the Pico Technology ADC-216 to be valuable for audio use. Their website is picotech.com

VOLTAGE FIX

I recently built the SE amp that appeared in the 4/04 *audioXpress*, ("A Mini SE Amp," p. 6) written by Rick Spencer. I had some issues with the DC power supply voltage. Using the parts specified, I had 15.5V DC after the filaments warmed up. This is probably excessive. I put three paralleled 10 Ω 25W resistors past the cap C6, which brought the voltage down to 12.1V.

*Bruce Brown
TuninFork@aol.com*

Rick Spencer responds:

Congratulations on the completion of your version of the mini SE amp. I hope you were as surprised as I was by the richness of the sound that this amp can deliver through good high-efficiency speakers. With the Radio Shack transistor and the incoming utility voltage that I have here, the actual final reading on the heaters was 12.75V when my line voltage is around 120V and 12.45V when the power is down around 118V.

I have found that not all transformers will produce the same exact output voltage even though they come from the same production run. I even needed to reduce the capacitance rating of the filter cap in order to lower the DC voltage going to the heaters on some of my other projects. (Too bad they don't match transformers the same way that they can match vacuum tubes.) Depending on what your home power utility voltage is, you may find some variances in your readings. It sounds as though you handled the problem quite well with the dropping resistors.

I recently completed a push-pull triode amp using 6B4s, and I needed to use dropping resistors to keep the filament voltage down to 6.3V instead of the 7.8V

that I started out with. One of the greatest advantages of this hobby is being able to modify and improvise in order to obtain the results that we are searching for! Happy listening, Mr. Brown, and thank you again for your interest in the mini SE amp.

REAL-WORLD TESTING

I own Definitive Technology BP2000 speakers that I use in a home theater setup. My problem is that I have a set of five speakers but I really get 90% use out of the two-channel system. My question is, how do I test the various parts of the speaker to verify things are working as required? I purchased two test CDs from Old Colony Sound Laboratory ("My Disc—The Sheffield/A2TB Test Disc" and *Stereophile* Test CD 3) in an attempt to check them out.

I have been concerned that the speakers may have been pushed and just do not sound as detailed as they have in the past and would like to learn how to test them. I have access to basic electronic test equipment such as oscilloscopes and DVM meters, as I work in an electronics lab. What do you recommend?

Ron Pisarski
Ronpisarski@aol.com

Joe D'Appolito responds:

Mr. Pisarski's letter has no simple answer. Unless there is a gross problem with his loudspeakers, the equipment available to him is not sufficient to detect more subtle problems.

The first thing to do is a frequency response test. Relatively simple procedures for doing this are detailed in my book, *Testing Loudspeakers* (available from Old Colony Sound Lab, PO Box 876, Peterborough, NH 03458, 888-924-9465,

custserv@audioXpress.com). As a minimum you will need a good free-field microphone and a 1/3 octave real time analyzer (RTA). If there are gross frequency response anomalies, they will show up here.

If the problem is more subtle, you will need much more equipment. This includes an FFT frequency response analyzer, THD and IMD distortion analyzers, and impedance measurements. It would help if you had reference data for this such as these same measurements when the speakers were working properly.

At the risk of being accused of the

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shameless plug, if Mr. Pisarski is serious about analyzing his speakers I can only suggest that he read my book. The subject is much too complex for a simple answer.

CONNECTIONS

In the early sixties I graduated from college, found myself lacking a decent stereo, and ended up building Fisher kits for an integrated amplifier and FM tuner, both tube-equipped. Many years later I now listen to bipolar transistors, but one habit from the old days still survives.

There was always the periodic chore of unplugging the tubes and reinstalling them, the process being relied on to rub off the minute layer of oxide between the pins and sockets. This was always accompanied by a certain improvement in the quality of high frequency sound.

Now we have gold-plated connectors so that cleaning them the first time they are assembled takes care of the contaminant problem. But not all is bliss. Although I use a high-quality gold-plated F-connector on the coaxial TV antenna lead, the threaded jack on the TV set is plated with an unexceptional alloy. It always surprises me how much sharper the picture is after I clean the threads and center conductor of this joint. The DVD player video and audio cables, terminated with RCA plugs, get the same treatment.

*Darcy Staggs
Orange, Calif.*

PERFECT FIT

Great preamp project by Gary Galo in the March '05 edition (p. 24). I'm having trouble, though, finding an adapter for the circular pattern pins of the BUF-03 to be fitted on the DIP-style hole pattern of the circuit board. Digi-Key did have one, but it was in reverse configuration. Any info would be appreciated.

*Paul Check
Lodi, N.J.*

Gary Galo responds:

Thanks for your comments on the Music Library Preamp. You really don't need an adapter for the BUF-03. Simply bend the leads to fit the 8-pin DIP footprint on the PC board, and solder the BUF-03 in place. Remember that the tab on the TO-99 case is pin 8, and make sure that none of the leads accidentally touch one another.

LOG UNIT

Your March 2005 issue arrived today and while perusing it, one graph caught my attention: Fig. 3 of Gary Galo's "A Musical Library Preamp" (p. 27). Here we have a frequency response graph of the RIAA equalization error. What's notable about such a graph is that the Y-axis is scaled in units of mdB, which I presume to mean milli-dB.

Milli-dB. Let's see if I understand what a milli-dB is.

That, if I am not mistaken, is a milli-deci-bel.

That's equivalent, it should be noted, to a centi-centi-bel, or ten deka-micro-bel. Or whatever absurd combination of prefixes you care to get to the same place.

Please, the basic unit is the bel, equivalent to log base 10 of the ratio of two powers. The basic unit is not a deci-bel.

Using units such as milli-deci-bels is about as handy as calling a kilometer a deka-hecto-meter. That you could call it that is no excuse for numerical obfuscation.

And this in a magazine whose editor seemed not so long ago to be going on at

length about that "damned spot."

A flesh wound from wielding a bidirectional cutlass, perhaps?

Dick Pierce

Professional Audio Development

dpierce@cartchunk.org

Gary Galo responds:

Figure 3 is a simulation graph generated by CircuitMaker 2000. CircuitMaker switches from dB to mdB when the largest unit on the Y-axis drops below 1.000dB. It's the program's choice, not mine. Having a double prefix ahead of the basic unit is hardly without precedent, however. Remember the micromicroFarad (mmF or $\mu\mu\text{F}$), before pF became standard?

I suggest that Dick Pierce direct his dissatisfaction with the mdB to CircuitMaker technical support: circuitmaker.support.na@altium.com.

Figure 7 is the RIAA response I measured. I used Microsoft Excel to generate this graph from the data I entered. The Y-axis was formatted by me, in this case. No obfuscation on my part.

Dick has confused Ed Dell with Shakespeare. In aX Aug. 2001, Ed wrote "Out, Out, Damned Dot." aX

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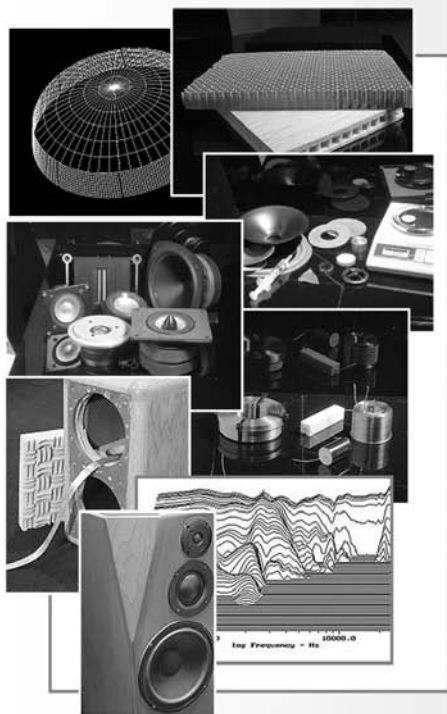
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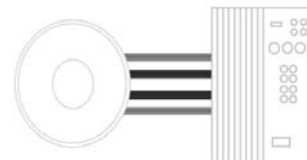
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solid state

USB Audio: PC Sound Amp

By Jeno Keceli

Back

No extra sound card is required for this PC sound amplifier, which gets its signal via the USB port.

Nowadays there is a sound card in every PC, which, in most cases, has only analog connectors. In this interface the signal is applied to the sound amplifier. These two units (the sound card and the sound amplifier)—together with the S/PDIF connectors—are mounted on a board inside the computer chassis. This way there is neither external cabling nor an external amplifier; the amp is powered by the computer itself.

Figure 1 shows the block diagram of the USB audio equipment. You can see that a USB audio codec IC provides the A/D conversion. Universal implementation is enabled by S/PDIF (fiberoptic) and analog connectors; which substitute for the sound card.

IC1 performs the communication functions with the computer and also is responsible for the D/A conversion. This is followed by IC2, the low-pass filtering stage, which is used for filtering components that result from the conversion. IC3 is responsible for regulation—volume and tone control. Finally, the power amplifier, IC4, amplifies the signal.

I added some more components that enable universal use of the device. The audio codec IC1 is connected to IC8 and IC9, which are fiberoptic (S/PDIF) interfaces; the analog signal is available from the line output. The output level is set by the P6 potentiometer, which you can adjust by using a screwdriver. IC7 functions as a signal buffer. By setting the S2 switch, you can select the analog microphone or the line input for recording. The recording level is regulated by P5; its amplification is achieved through IC6. With the S3 switch you can choose between the

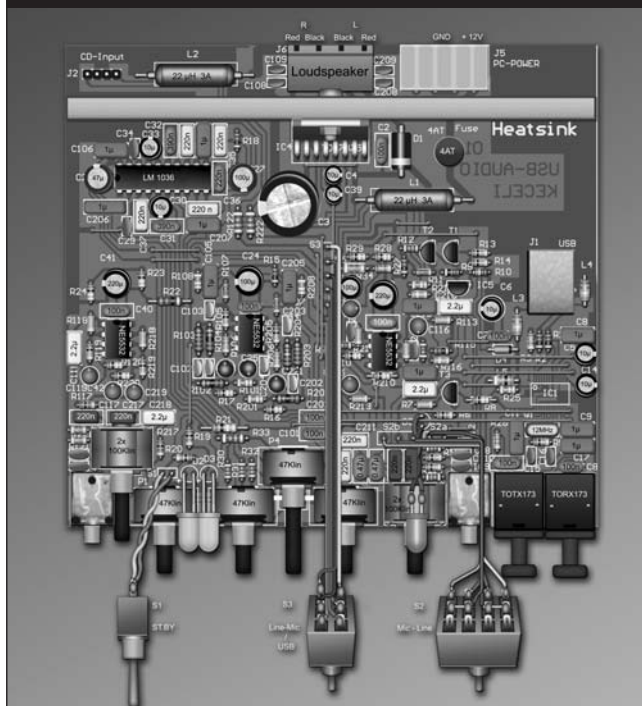
USB input and the analog input (monitor).

THE APPLIED PCM2902

The PCM2902 is a single-chip USB stereo audio codec with a USB 1.1 compliant full-speed protocol controller with single-ended analog input/output and S/PDIF. The USB protocol controller works with no software code.

Figure 2 shows the functional block diagram of PCM2902. The decoded output signal appears on both the S/PDIF and the analog outputs. The input sound signal (Record) is selected automatically as either S/PDIF or analog input. When S/PDIF is detected, it will be active because it has the higher priority. If the digital signal is not present, the

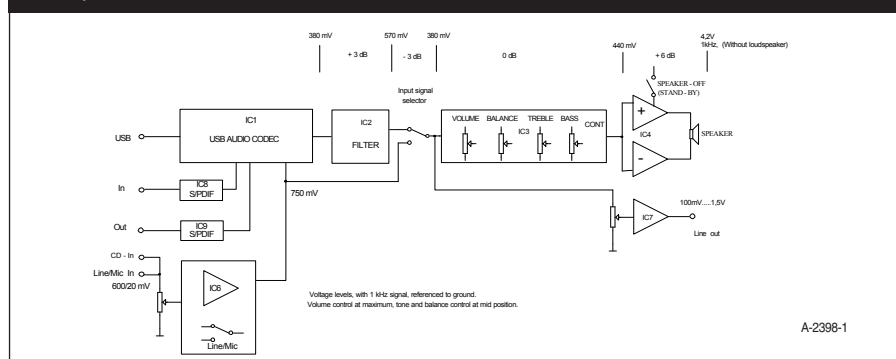
PHOTO 1: Completed audio amp. There is a hole on the heatsink for the USB plug.



analog input will be activated. Because the applied IC has copyright-detection circuitry, the copyright-protected signal cannot be transmitted through S/PDIF. The IC detects this and switches to the analog input.

The analog input has fixed sensitivity—it cannot be regulated—but

FIGURE 1: Block diagram (voltage levels, with 1kHz signal, referenced to ground. Volume control at maximum, tone and balance control at mid-position).



A-2398-1

due to the AD converter it depends on the VCCCI voltage. In this case it is approximately 750mVeff, (VCCI = 3.5V). The analog output can be regulated through the IC or the software program

Main Features of PCM2902

(for more details see the product manual)

- Fully compliant with USB 1.1
- Bus powered
- 16-bit delta sigma ADC and DAC
- Sampling rate: DAC: 32, 44.1, 48kHz,
- ADC: 8, 11.025, 16, 22.05, 32, 44.1, 48kHz
- On-chip clock generator: 12MHz
- Single power supply: 5V (VBUS)
- Stereo ADC analog performance:
THD+N = 0.01%, SNR = 89dB, dynamic range = 89dB
- Stereo DAC analog performance:
THD+N = 0.005%, SNR = 96dB, dynamic range = 93dB
- Volume and mute control
- Suspend flag

USB Audio Amplifier Test Results

Supply voltage amplifier: +12V from PC
 Supply voltage USB codec: +5V from USB bus
 Current drain (amplifier): approximately 120mA (idle), approximately 3.5A (full power)
 Current drain (USB codec): approximately 90mA
 Output power: 2 × 20W @ 4Ω, musical, 2 × 15W (THD 0.5%)
 Frequency response: 20 Hz ... 20kHz, + 0.5 ... -2dB
 Line input, 600mV
 Electret mike input 20mV microphone supply
 Line output, max 1.5V (cca -15. ... +10dB) from preamplifier (adjustable with a screwdriver)
 S/PDIF input and output
 Power output shorting and overheat protection control
 Standby switch, volume (built-in contour), tone and balance control on the front panel
 Size: front panel 148 × 42mm (similar to a CD-ROM), depth 135mm

as well. Internal analog power supply for codec VCCCI = 3.3V.

In order to increase the quality of the AD conversion, the manufacturer recommends slightly increasing the VCCCI (e.g., VCCCI = 3.5 ... 3.65V) with a separate voltage regulator. The analog in- and output signals have approximately +1.7V DC superimposed, which enables direct connection to rail-to-rail operational amplifiers. (However, in this case, this feature is not utilized.)

PRINCIPLES OF OPERATION

Figure 3 shows the amplifier's detailed schematics. There is duplex communication on the USB connector; this is connected to IC1, where—after the identification—the connection is made and the conversion of D-A/A-D starts to function. Because IC1 has a suspended output as well, this can be used for external switching control. In this case an LED is applied through T3. When the connection is

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FIGURE 2: PCM 2902 functional block diagram.

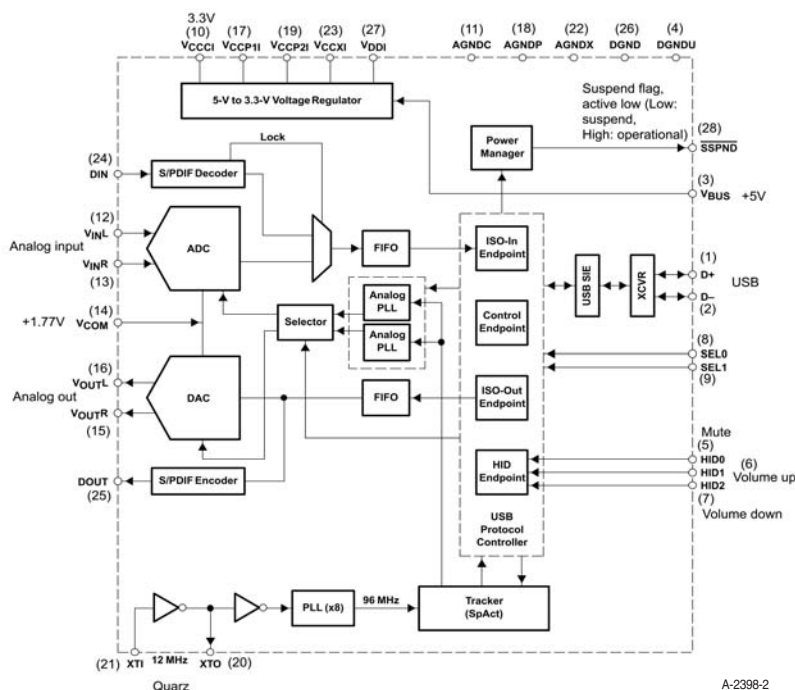
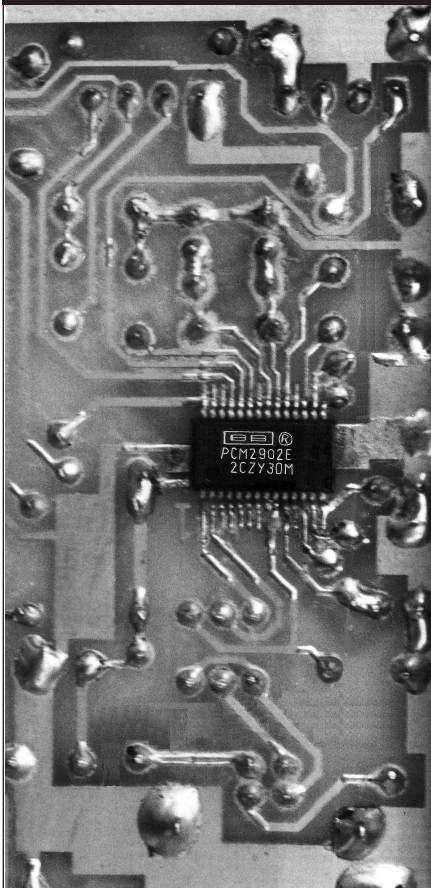


PHOTO 2: The soldered IC1.



achieved the LED switches off. Active LED means that the connection with the computer has not been established.

The frequency of the quartz oscillator is relevant for the establishment of the connection. Because the parallel resonance capacity of various quartz types may differ, the connection might become difficult to establish or unsta-

ble. If this happens, you need to modify the capacitors C15 and C16. According to the manufacturer the appropriate value should be between 10–30pF. With a standard 12MHz HC18 used, I found 15pF to be the optimum value. When working with an SMD quartz you will probably need a higher value of C15/16. After establishing the software con-

PHOTO 3: The USB audio amplifier.

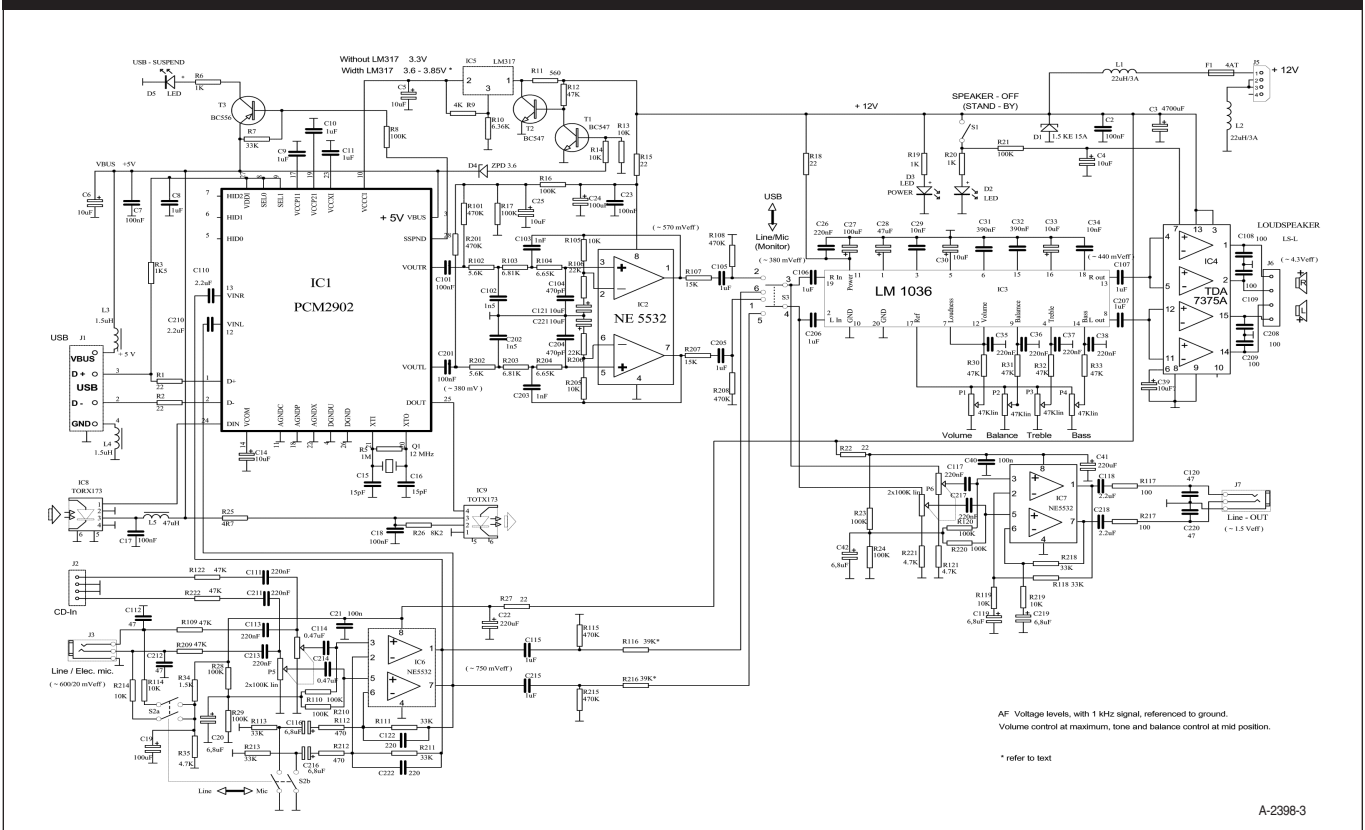


nection, the sound-frequency signal appears on outputs 15 and 16, but it also appears on output 25 as digital signal (DOUT), which is applied to IC9 as S/PDIF connector.

IC8 is another S/PDIF connector serving as a digital input for recording, but there is an analog input (pin 2 and 3) as well. The input is automatically selected in IC1. If the digital signal (DIN) is absent, the analog input will be activated (VINR, VINL). The appearance of the digital signal causes a switchover.

IC1 is copyright-protected against illegal reproduction (Serial Copy Management Sys-

FIGURE 3: The amplifier's detailed schematic. (AF voltage levels, with 1kHz signal, referenced to ground. Volume control at maximum, tone and balance control at mid-position.) * = refer to text.



AF: Voltage levels, with 1 kHz signal, referenced to ground.
Volume control at maximum, tone and balance control at mid position.

* refer to text

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tem SCMS). If a copied signal is discovered on the digital input, IC1 will switch to the analog input, preventing the production of perfect digital copies.

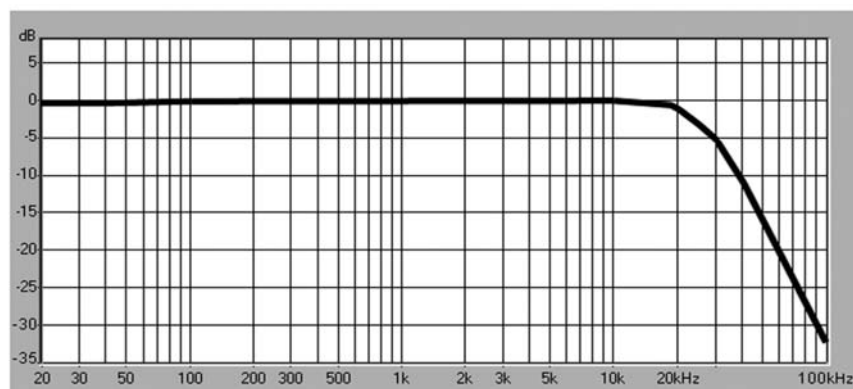
The sensitivity of the analog input is permanent (approximately 750mV), and software regulation is not possible. Since the ADC has an on-chip anti-aliasing filter, the input circuit is quite simple. However, to ensure good audio quality, MKT (Siemens) or equivalent capacitors are specified for positions

C101, C201, and C110, C210. Do not use electrolytic capacitors here.

The volume regulation provided by IC1 has not been utilized, as it is identical to the software regulation in the computer. IC1 is powered with +5V VBUS from the USB bus. For filtering disturbances two inductors, L3 and L4, have been installed here. Further filtering is assured by capacitors C6 and C7.

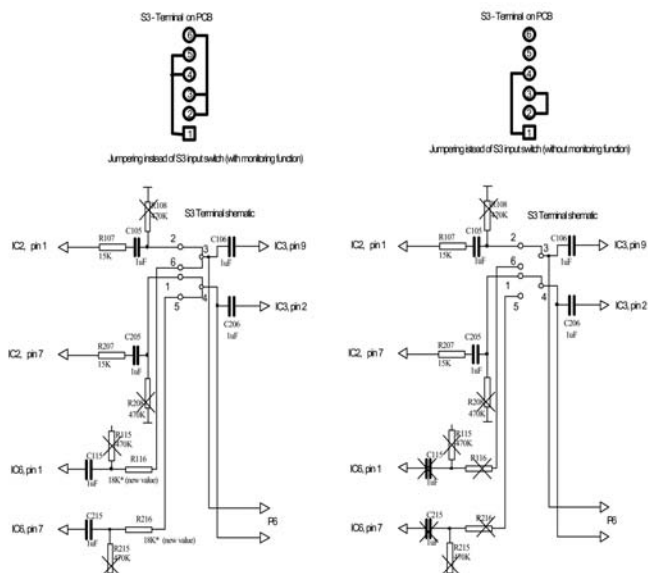
The PCM 2902 has an on-chip voltage regulator. On pin 10 the voltage is

FIGURE 4: Low-pass filter electrical response — IC2.



A-2398-4

FIGURE 5: Switch S3 can be eliminated. Variations: S3 terminal and PCB, jumpering instead of the S3 switch (keeping the monitoring function). Here, resistors R108, R208, R115, and R215 become superfluous. R116 and R216 are changed for 18k. S3 terminal and PCB, jumpering instead of the S3 switch (eliminating the monitoring function). The following components become unnecessary: C115, C215, R115, R215, R116, R216, R108, and R208. S3 terminal schematics, new value.



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PHOTO 4: USB audio amplifier, front side.

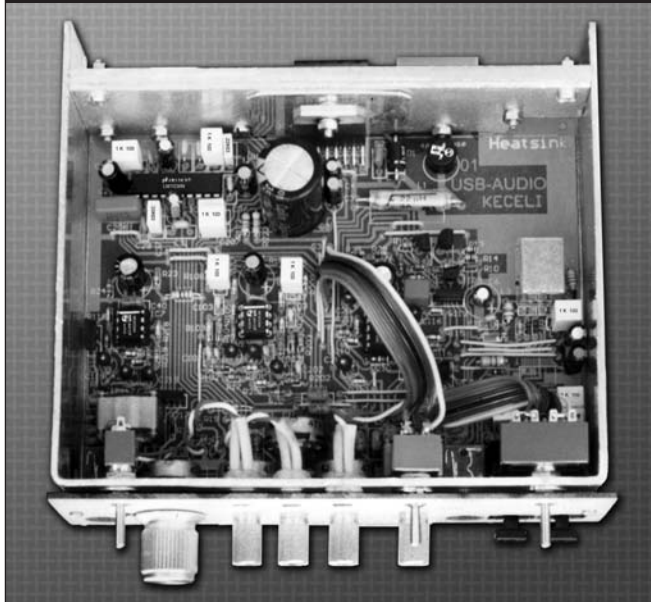
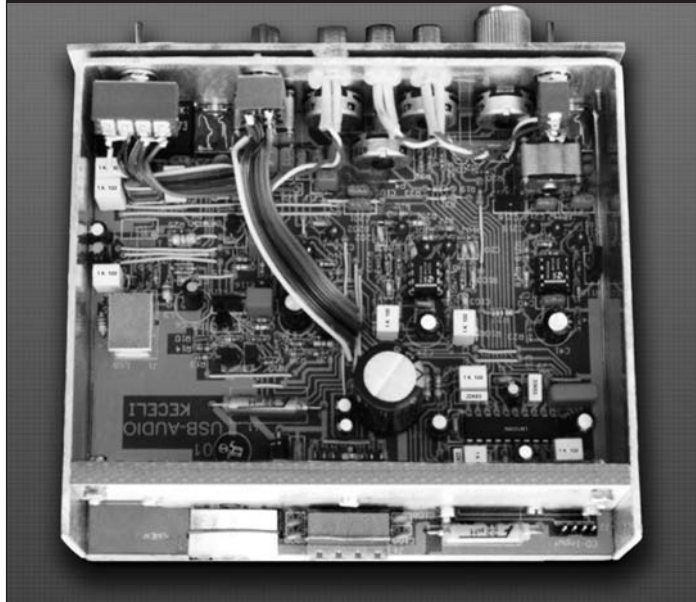


PHOTO 5: USB audio amplifier, back side.



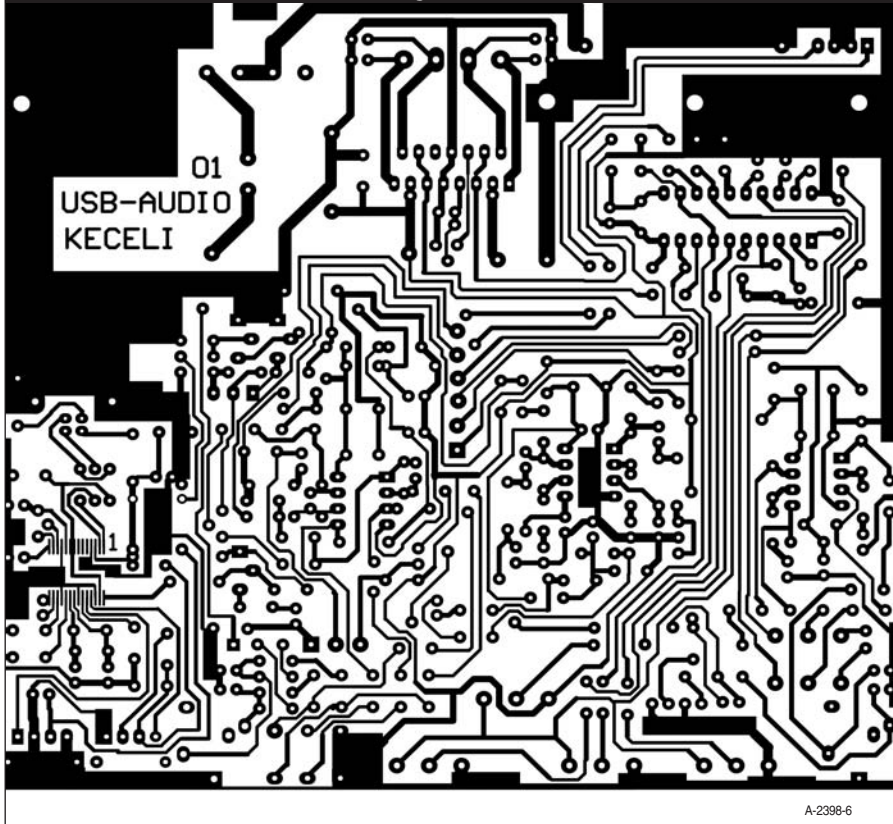
VCCCI = 3.3V (internal analog power supply for codec). The circuit functions well with this voltage, but according to the manufacturer's recommendations, the distortion can be somewhat reduced if you slightly increase the voltage with the IC5 voltage stabilizer. Here, a voltage regulator type LM317 is used. Its

presence reduces harmonic levels by more than 10dB as compared to the internal voltage regulator. Note that IC1 itself provides excellent quality—you cannot hear the impact of the voltage increased by an external stabilizer.

Accordingly, you can omit IC5, but you must apply the filter capacitor C5

belonging to it. Because LM317 is supplied from 12V—in case of the absence of the 5V VBUS (USB out)—IC5 must be switched off, otherwise the identification cannot be completed when reconnecting to the USB. This is achieved by transistors T1 and T2. If the 5V is present on diode D4, the 12V has a free path as well. If the 5V is absent, the 12V is switched off the IC5.

FIGURE 6: The solder side of the single-sided PCB. IC1 is soldered on this side.



SIGNAL FUNCTION

In IC1 the ADC has an on-chip antialiasing due to noise shaping. To eliminate the various distortion products, you must apply a third-order Butterworth low-pass filter with $f_c = 28\text{kHz}$. The amplifier IC2 is realized by an op amp type NE5532. The signal at the DAC output may be slightly amplified (1.5 times). The virtual ground (+6V)—filtered by C25 capacitor—is generated by resistors R16, R17, R101, and R201. This is necessary for setting the op amp bias. Figure 4 shows the low-pass electrical response.

The signal from the filter IC2 goes to the input signal selector S3, through capacitors C105, C205 and resistors R107, R207, which reduce the unnecessary gain. If you change R107 and R207, the (input sensitivity) gain may change. DC null potential is produced by R108, R208, R115, and R215. This is necessary for preventing the switchover click.

A switch does input selection; this way the signal reaches the tone control

stage. IC3 carries out the tone control task. Its gain is 0dB and cannot be altered. Besides the bass and treble tone control, the volume and balance control are also here. This is a complex stage; DC levels carry out the control. From the point of view of construction, this makes the stage less complicated because the RC items of the usual tone control stage are not required, and mono potentiometers are sufficient for the control.

IC3 also contains a loudness tone correction stage. This is important when the volume is low because it sets the sound transmission to the sensitivity of the human ear. In our case, this stage is always switched on. You can switch it off for experimenting if you switch off pin 7 from pin 12, and switch it over to pin 17.

After setting the frequency response, the signal goes to the power stage through C107, C207 capacitors. IC4 performs the power gain. For this, I have

chosen an item that requires only a few external components that still can produce good quality.

The gain of the TDA 7375 is set at 26dB. According to the manufacturer's specifications, the inverted and non-inverted inputs of the IC are joined together. The inverted inputs provide phase-shifted signal, which is required for the functioning of the bridge circuit. In this way no separate phase inverter is required.

As I have already mentioned, TDA 7375 IC has a standby pin that is connected to the switch on the front panel. Shutting down the whole amplifier is not possible, but you can switch off the loudspeakers with the standby switch. Because the other stages of the amplifier operate independently of this, you can listen to the music through the line output. J6 terminal block is the loudspeaker connector on the PCB, but only for internal connection, because the loudspeaker connector is on the back

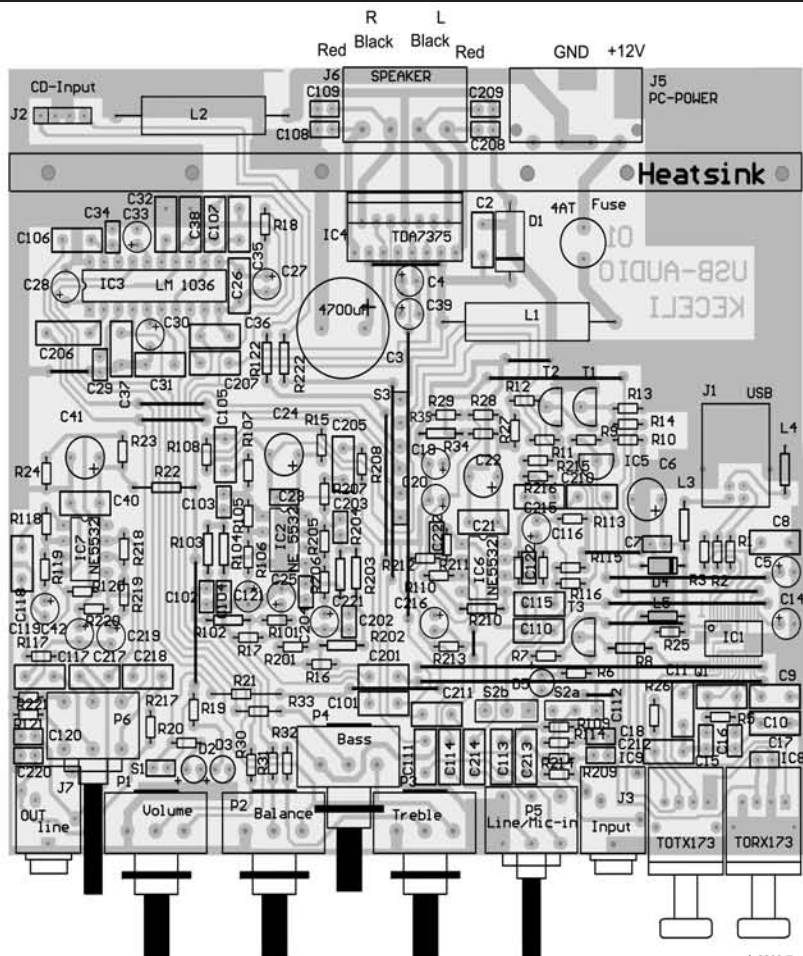
panel of the computer. Propagation of interfering signals is minimized by capacitors C108, C109, C208, and C209.

ADDITIONAL MODIFICATIONS

The amplifier is able to function now, but for the sake of general implementation, I applied two more ICs. IC7 provides a line output signal from the pre-amplifier. This output can serve as a PA-driver or line output. The circuitry of the stage is conventional. IC7 has minimal gain, the output level is adjustable (using a screwdriver) with the P6 that is on the front panel. The virtual ground (+6V) is produced by R23, R24, R120, and R220, and is filtered by capacitor C42. As protection against the impact of capacitive load, resistors R117, R217 are installed. The output is filtered by C118, C218. The connector J7 is found on the front panel of the PCB.

IC6 is a preamplifier. Because there is no software solution for setting the input (Rec) level, a potentiometer P5 has been installed. The terminal block J2 is a CD audio input—placed on the inner side of the PCB—functioning as inner connection primarily for lis-

FIGURE 7: Parts placement, components side. IC1 is on the soldering side of the PCB.



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tening. Connector J3—on the front panel—functions as a line or an electret microphone input. Besides the monitoring function, you can also use this input for recording, making phone calls, and so on. You can switch between line and microphone input with the switch S2b controlling the gain of the stage that is the input sensitivity. The electret microphone is supplied from resistors R34, R35, and is filtered by capacitor C19. R114 and R214 are the ballast resistors. Resistors R28, R29, R110, and R210

produce the virtual ground (+6V), which is filtered by electrolyte capacitor C20. Because of the higher gain, this stage should be neutralized by capacitors C122, C222, avoiding buildup. The task of capacitors C112 and C212 is high-frequency filtering.

The amplifying stages are supplied by +12V from the computer through connector J5. Filtering is done by inductor L1 and capacitors C2 and C3. Diode D1 provides protection against over-voltage.

As there is ground connection from the USB connector side as well, this can be a noise source. This is why two more inductors, L4 and L2, have been installed, suppressing all kinds of noises. The power supply of each stage is filtered, too. This is done by R27, C22, C21 (preamplifier), R22, C41, C40 (line output), R18, C26, C27 (control unit), and R15, C23, C24 (filter).

You can omit switch S1 by simply jumping the switch—if no standby function is needed. As a result, you can also

TABLE1: Parts List of the USB Audio Amplifier.

SCHEMATIC REFERENCE DESIGNATOR	PART TYPE VALUE	CASE/ LEAD PITCH	DESCRIPTION	SCHEMATIC REFERENCE DESIGNATOR	PART TYPE VALUE	CASE/ LEAD PITCH	DESCRIPTION
IC1	PCM2902	JEDEC MO-150	SMD	L3, L4	1.5μH	7.62	Axial
IC2, IC6, IC7	NE 5532	DIP-8		L5	47μH	7.62	Axial
IC3	LM 1036	DIP-20		R1, R2, R15, R18, R22, R27	22Ω	5.08	1/8W
IC4	TDA7375			R3, R34	1.5k	5.08	1/8W
IC5	LM317	T0-92		R5	1M	5.08	1/8W
IC8,	TORX173			R6, R19, R20	1k	5.08	1/8W
IC9	TOTX173			R7, R111, R113, R118, R211, R213, R218	33k	5.08	1/8W
D1	1.5 KE 15A	15.24	Protection-suppression diode standard	R8, R16, R17, R21, R23, R24, R28, R29, R110, R120, R220	100k	5.08	1/8W
D2, D3	LED	2.54		R9	4k	5.08	1/8W
D4	ZPD 3.6	7.62		R10	6.36k	5.08	1/8W
D5	LED	2.54	low current, red	R11	560Ω	5.08	1/8W
T1, T2	BC547	T0-92		R12, R30, R31, R32, R33, R109, R122, R209, R222	47k	5.08	1/8W
T3	BC556	T0-92		R13, R14, R105, R114, R119, R205, R214, R219	10k	5.08	1/8W
C2	100nF	5.08	MKS, MKP, ceramic	R25	4.7Ω	5.08	1/8W
C3	4700μF	7.62	Electrolytic-radial	R26	8.2K	5.08	1/8W
C4, C5, C6, C14, C25, C30, C33, C39, C121, C221	10μF	2.54	Electrolytic-radial	R35, R121, R221	4.7k	5.08	1/8W
C7, C17, C18, C23	100nF	2.54	MKS, MKP, ceramic	R101, R108, R115, R201, R208, R215	470k	5.08	1/8W
C8, C9, C10, C11, C105, C106, C107, C115, C205, C206, C207, C215	1μF	5.08	MKS, MKP	R102	5.6k	7.62	1/4W
C15, C16	15pF	2.54	Ceramic	R103	6.81k	7.62	1/4W
C19, C27	100μF	2.54	Electrolytic-radial	R104	6.65k	7.62	1/4W
C20, C42, C116, C119, C216, C219	6.8μF	2.54	Tantalum	R106, R206	22k	5.08	1/8W
C21, C201	100nF	5.08	MKS, MKP, ceramic	R107, R207	15k	5.08	1/8W
C22, C41	220μF	5.08	Electrolytic-radial	R112, R212	470Ω	5.08	1/8W
C24	100μF	5.08	Electrolytic-radial	R116, R216	39k	5.08	refer to text
C26, C35, C36, C37, C38, C111, C113, C117, C211, C213, C217	220nF	5.08	MKS, MKP	R117, R217	100Ω	5.08	1/8W
C28	47μF	2.54	Electrolytic-radial	R202	5.6k	5.08	1/8W
C29, C34	10nF	2.54	Ceramic	R203	6.81k	7.62	1/8W
C31, C32	390nF	5.08	MKS, MKP	R204	6.65k	5.08	1/8W
C40, C101	100nF	5.08	MKS, MKP, ceramic	R210	100k	7.62	1/2W
C102, C202	1.5nF	2.54	Ceramic	P1, P2, P3, P4	47klin	Potentiometer	PCB mounted
C103, C203	1nF	2.54	Ceramic	P5, P6	2×100k-lin	Potentiometer on-off	PCB mounted
C104, C204	470pF	2.54	Ceramic	S1	Subminiature	toggle switch	panel mounting
C108, C109, C208, C209	100pF	2.54	Ceramic	S2	Subminiature	4 pole on-on toggle switch	panel mounting
C110, C118, C210, C218	2.2μF	5.08	MKS, MKP	S3	Subminiature	2 pole on-on toggle switch	panel mounting
C112, C120, C212, C220	47pF	2.54	Ceramic	F1	mini T4.0A	FUSE	
C114, C214	0.47μF	5.08	MKS, MKP	J1	USB connector	B type	panel mounted
C122, C222	220pF	2.54	Ceramic	J2, J6	Terminal block	4pin	PCB mounted
Q1	12MHz	5.08	Quartz	J3, J7	Phone-jack	Socket PCB	PCB mounted
L1, L2	22μH/3A	Axial	Inductor	J5	3.5mm stereo		
				PCB	PC power connector	4 pin, male	PCB mounted
					104 × 86mm	Single-sided	

omit R20 and D2 LED. If the electronics is modified according to *Fig. 5*, switch S3 can be eliminated, as well.

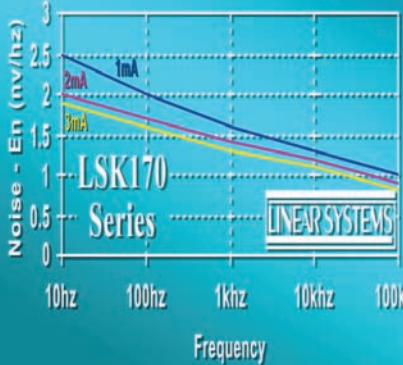
By the first solution—jumping the switch—you add up the signals. The monitoring function is there, but for preventing interferences only one input is used at a time. Here, resistors R108, R208, R115, and R215 become unwanted. R116 and R216 are changed to 18k.

By the second solution, there is no monitoring function, as—omitting the switch—the signal is applied from the USB input. The following components become unnecessary: C115, C215, R115, R215, R116, R216, R108, and R208.

CIRCUIT ASSEMBLY

The PCB is a single-sided board; *Fig. 6* shows the soldering side. With the exception of IC1, all the components are installed on one side. The installation of the components is illustrated in *Fig. 7*. For the sake of simplicity I have chosen conventional components that can be soldered in without complication. The only exception is IC1 PCM 2902, which is available only in SMD 28-Pin Flatpack (SSOP 28) and is very tiny. For

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soldering this component you need a precision soldering iron, a magnifying glass, experienced, calm hands, and good eyesight. The thickness of the pin and the distance between the pins is approximately 0.3mm, or 12 Imp. These cannot be soldered in by casual methods.

First, you must install this component. To do so you should cover the PCB around the IC with a thin layer of solder. Check to see whether there is a bond—there should not be. Antistatic precautions should be observed in handling the IC. Excessive static electricity is harmful for it, hence neutralization of the static build-up is a must. Your working surface should be conductive and

you should use an antistatic wristband tied to the working surface. Also, connect the neutral of the soldering iron to the conductive surface. The wristbands are regularly available from hobby or electronics component shops.

Check all the pins—under no circumstances should they be bent, and it is important that they should be on the same plane. Then place the component on the PCB and adjust its exact position. To fix it, solder in—diagonally—two opposite pins or—even better—stick it down with SMD glue. The difficult part of the assembly is yet to come.

The pins must be soldered in one by one with a needlepoint soldering iron—not putting any extra tin on it (what

FIGURE 8: Heatsink.

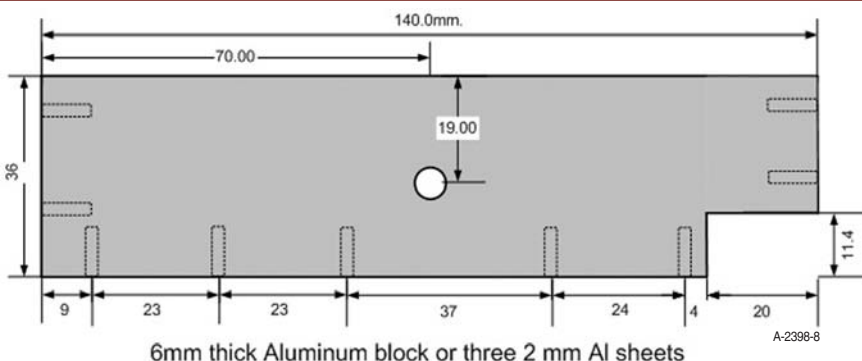


FIGURE 9: Frame.

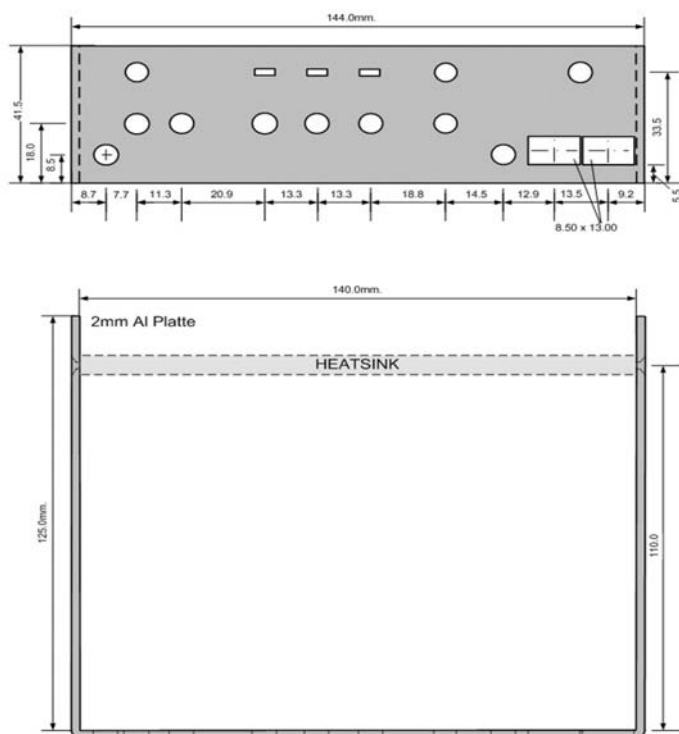
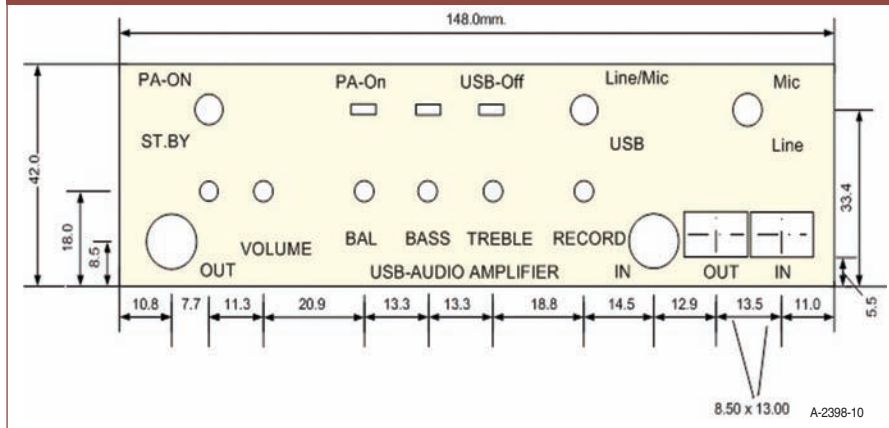


FIGURE 10: Front panel.



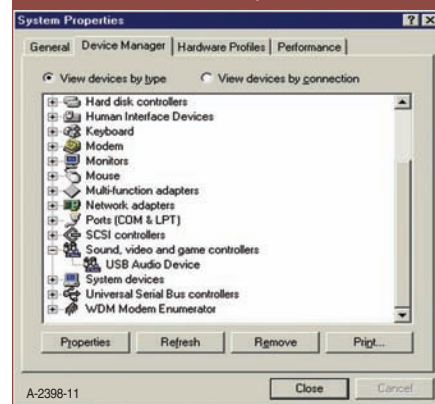
you used for covering the IC on the PCB is enough). Pull the soldering tip from the outside toward the IC—through the copper foil—melting the tin up to the IC pin. This melted tin solders the pins.

After soldering in the 28th pin, check your work in detail under a magnifying glass. The work is only then perfect if you check all the pins—one by one—for breakage and/or bridges between pins and no fault is found. (You can use sewing needles as test probes.) Photo 1 shows the soldered IC1. Solder in the other compo-

nents that belong to IC1 and the USB part, then test the circuitry. If the identification is unstable, modify the C15, C16 capacitors. When the computer recognizes the USB codec, the LED D5 switches off. The rest of the assembly is nothing unusual.

The heatsink is prepared according to Fig. 8. It can be made of a 6mm thick aluminum (Al) block or three 2mm Al sheets which are bound tight together with screws to form a single block. Cut a hole for the USB jack. If the work has been well done, no further adjustment is

FIGURE 11: The PC recognizes the new USB-audio amplifier.



needed; the equipment is ready for operation. To fasten it, place the PCB in a frame made of a 2mm Al sheet that has been prepared according to Fig. 9. A front panel, illustrated in Fig. 10, hides the screws and components, but this has only an esthetic function.

AMPLIFIER ASSEMBLY

Assembling the amplifier is easy, no adjustment is required. If you work carefully and avoid mistakes, the amplifier will work at once. After having tested what

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FIGURE 12: 1kHz squarewave, with full power at 4Ω load.

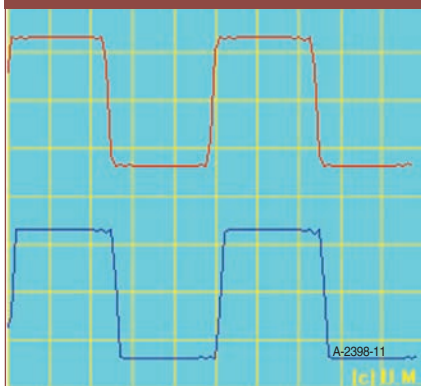
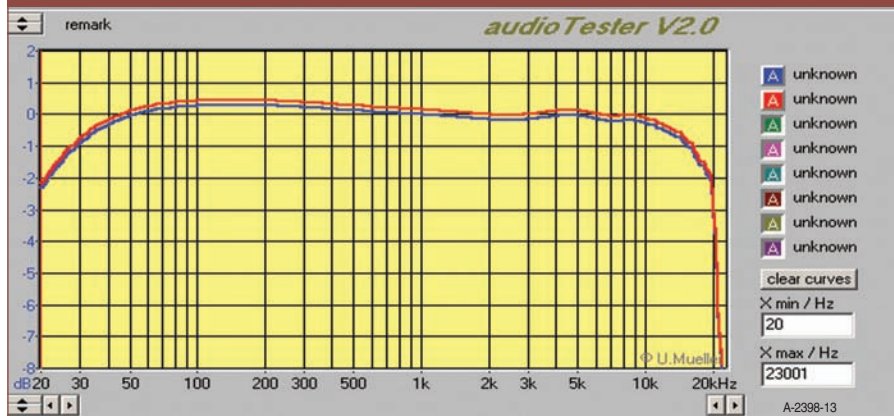


FIGURE 13: Frequency response, with full power at 4Ω load.



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you have built so far, you can install the amplifier. Warning: while installing and connecting equipment inside the PC, be sure the PC is switched off.

Connection of the amplifier to an operating PC might cause a system crash due to the charging current and the high capacity of C3. The USB audio module receives the signal through a USB cable from the PC. A ferrite bead functions as a filter on this cable. You can install a similar ferrite bead on the loudspeaker cable as well. In order to avoid short circuits, it is advisable to place an insulating sheet below the amplifier.

SOFTWARE INSTALLATION

Problems are unlikely to occur with the installation of the board under Windows. First there comes a notification that a “USB Audio Codec” has been found, which requires drivers to be installed. Then the following three devices are found: a “USB Composite Device,” a “USB human Interface Device,” and a “USB Audio Device.” These items are located under the System Properties/Device Manager tab (Fig. 11). Next, with Playback properties you will see three slide controls: Desktop, Wave, and SW Synth.

The fourth slider CD Player (for Windows’ own simple software player for audio CDs) will be missing and will be available only after the computer is restarted. In Control Panel, under the Multimedia/CD Music tab, remember to check “Enable digital CD audio for this CD-ROM device.” If the USB link is briefly interrupted, the control may disappear. This is normal (for Windows, at least) and results due to a bug

in the operating system. The problem has not been solved under Windows ME or XP, which apply different names for some of the windows and controls.

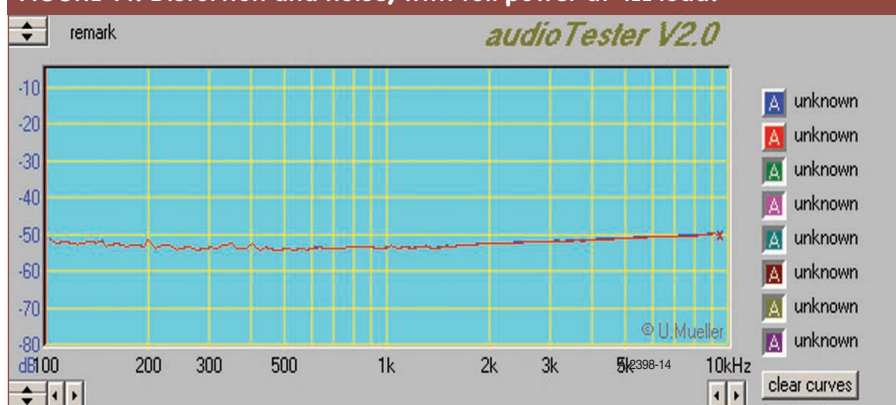
TEST

The voice frequency circuitry is tested by casual measurements, but the USB codec expects the presence of an operating computer as well. Because there are usually no adequate instruments available for amateurs, it is a good idea to use the Internet for help.

You can find various audio tester programs on the Internet to test the full USB audio transmission line. I applied the software program found at the website www.summuller.de/audiotester. You can download this program for 30 days' evaluation. As for the complete testing of the full duplex operational mode, apply a conventional soundcard as input and the newly built equipment as output. Their selection is done in the Windows audio program. The test results are shown in Figs. 12, 13, and 14. *ax*

Jeno Keceli is a long-time electronics enthusiast with 40 years of experience. His main fields of interest are designing and building tube and transistor power amplifiers. He has much experience with sound and disco equipment. His articles have been published in electrotechnical journals. He now runs his own firm, where he builds, repairs, and gives advice. Email: kecelijeno@freemail.hu.

FIGURE 14: Distortion and noise, with full power at 4Ω load.



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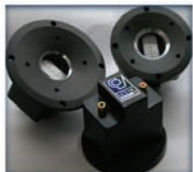
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