Adcom's GFP-565 Preamplifier, Part 4

This final installment describes the new phono preamp. **By Gary Galo**

Adcom's GFP-565 preamplifier came with an excellent phono preamp designed by Walt Jung. The circuit (*Fig. 8*) is no secret, since Linear Technology published a nearly identical topology on the front page of their LT 1115 op-amp data sheet (I thank Victor Campos for granting permission to reproduce the circuit back when he was Vice President for Product Development at Adcom).

The gain block is a Linear Technology LT1028C op amp (Adcom 8A, and predecessor to the LT1115), buffered by the high-current LT1010CT video buffer (Adcom 1A). R119, the 49.9Ω bias resistor, sets the LT1010 output stage for pure Class-A operation. D101, a J555 JFET current source, forces the LT1028 output stage into Class-A operation. The LT1028 was the quietest op amp available when the 565 preamp was designed—voltage noise was specified at $1.1nV\sqrt{Hz}$ at 1kHz. To keep the preamp noise as low as possible, the 565 phono preamp has a low impedance RIAA feedback loop.

The LT1010 buffer provides plenty of output current for linear drive of the low-Z network. C107 (bypassed by film cap C109) keeps the DC gain at unity, making the DC offset manageable. The LT1028C has very low input bias current (for a bipolar-input device), and low DC offset, allowing DC coupling of the output (R115 provides a slight offset trim for the circuit).

The RIAA network capacitors—C111, C113, and C115—are 1% tolerance Roederstein KP-series polypropylene types. The 565 phono preamp has excellent RIAA accuracy, ±0.1dB, 20Hz–20kHz. This was a very fine phono preamp by late-1980s standards, and it would be very easy for a modifier to make it worse. A "safe" modification might consist of simply replacing the 1% Roederstein/Resista MK2 resistors with better types.

So why design a new phono preamp? The original Adcom topology has one sonic limitation that can't be fully solved with parts substitutions. The biggest sonic snags in this design are the electrolytic caps that keep the gain unity at DC. My goal in designing the new phono preamp was to eliminate these capacitors by using a gain block with lower offset and lower input bias current, and controlling the residual DC offset with a servo.

I settled on Analog Devices' AD745J, an FET-input op amp with ultra-low voltage noise ($2.9nV\sqrt{Hz}$ at 1kHz) and 12.5V/µS slew rate (compared to 11V/µS for the LT1028). Typical input offset voltage is 0.25mV, and input bias current is 150pA.

The input bias current is the critical spec. The LT1028C specifies this as 40nA. The significantly lower input bias current of the AD745 maintains stable

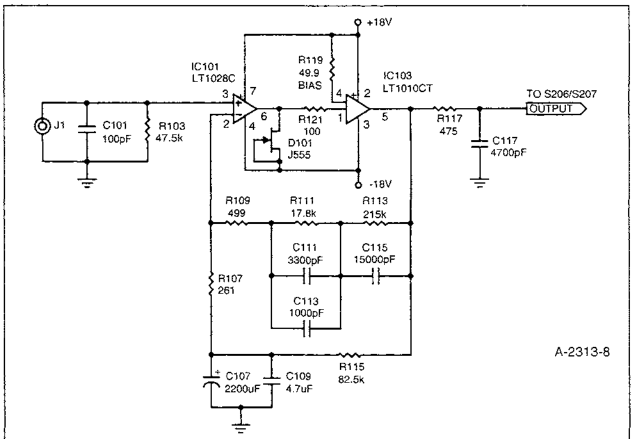

FIGURE 8: The original Adcom phono preamp. The preamp uses a Linear Technology LT1028 op amp buffered by an LT1010 video buffer. Linear Technology published a nearly identical circuit in the datasheet for the LT1115.

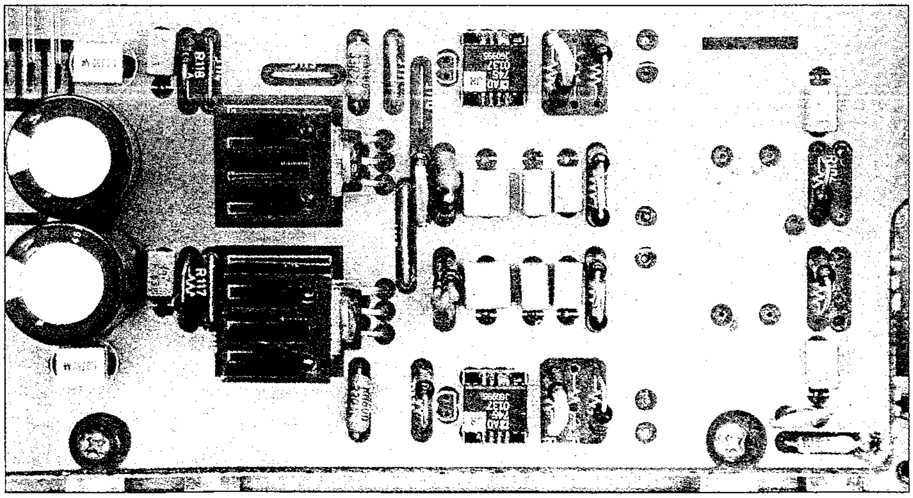

PHOTO 32: The modified phono preamp before the installation of the DC servo. C107 through C110 have been removed, and the LT1010 heatsinks have been replaced.

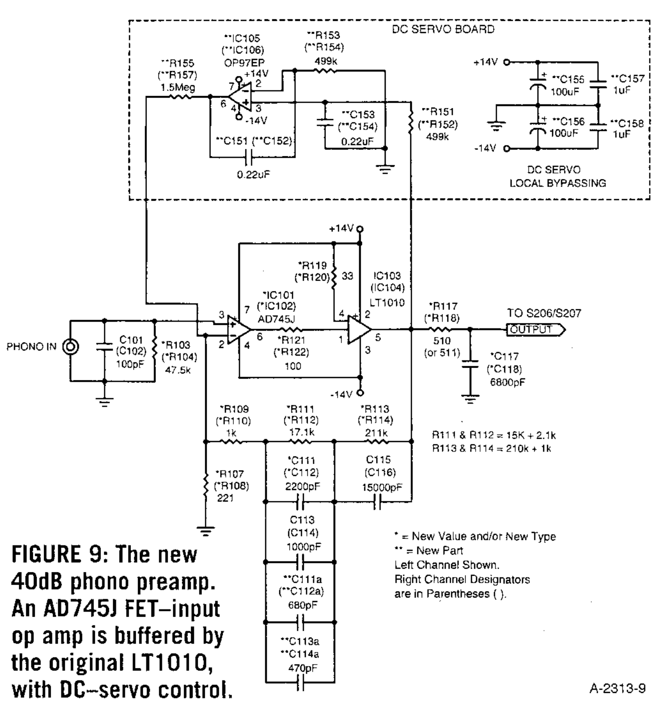

FIGURE 9: The new 40dB phono preamp. An AD745J FET-input op amp is buffered by the original LT1010, with DC-servo control.

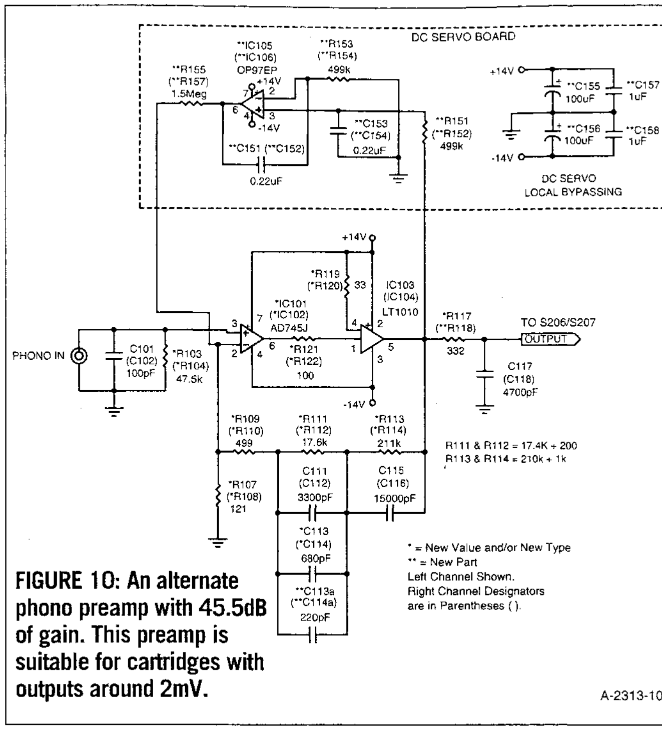

FIGURE 10: An alternate phono preamp with 45.5dB of gain. This preamp is suitable for cartridges with outputs around 2mV.

DC offset with source impedances ranging from very low-Z phono cartridges (below 100Ω) to the 47k cartridge terminating resistor. I believe that it's important to maintain safe DC operating levels even with the cartridge unplugged.

The excellent DC characteristics of the AD745 are possible because of the FET-input design. FET-input op amps are normally too noisy for high-gain circuits such as phono preamps. But the AD745 achieves its excellent noise performance with large-geometry FETs in the front end (the metallization photo shows that the FET differential input takes up well over one-third of the die space). The trade-off, as far as die space is concerned, is a less robust output stage than some other devices. But, buffering the op amp overcomes this limitation.

The AD745 does have higher voltage noise than the LT1028, but my measurements indicate that the new phono preamp is actually quieter than the Adcom original. This is probably due to the substantially lower current noise of the AD745, which results in lower measured phono noise with a low-Z source. You could use a current-feedback amplifier such as the AD811 or the discontinued BUF04 for the output buffer. However, I still like the sonic characteristics of the LT1010 in this application, so I retained it. I lowered the bias resistors to 33Ω, which improved the sonics of the LT1010 even further, but also requires additional heatsinking.

STABILITY ISSUES

Many op amps designed for high-gain applications are not unity-gain stable. The LT1028 is stable at voltage gains of two or higher (it can be used in unity-gain applications, with certain caveats described in the data sheet). Although RIAA preamplifiers normally have very high voltage gains at lower frequencies, at high frequencies the gain will eventually fall to unity and below as the reactances of the RIAA feedback capacitors approach zero.

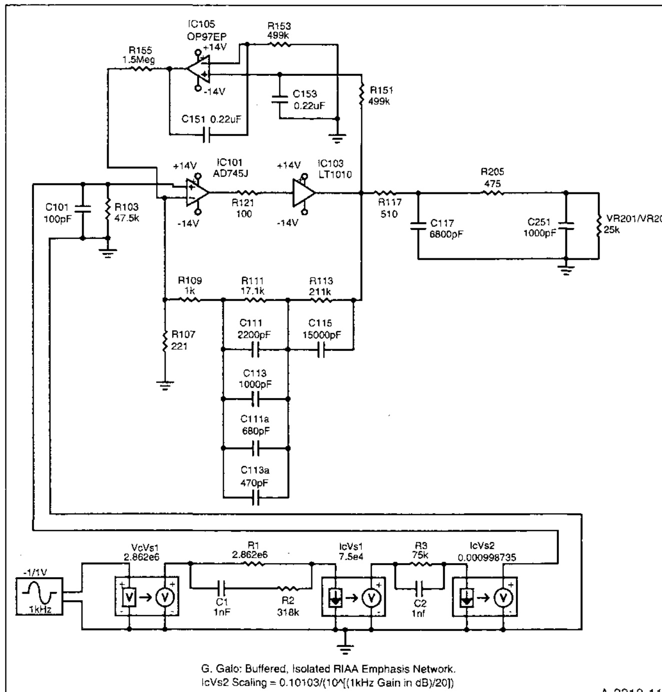

FIGURE 11: Simulation circuit for RIAA analysis of the phono preamps. The circuit on the bottom is a mathematically ideal RIAA emphasis model. Final values for R117 and C117 were determined in conjunction with the line stage loading.

A "gain-stop" resistor—R109 in the Adcom circuit—is added to prevent the voltage gain from falling below safe levels. You can determine the minimum high-frequency voltage gain in the Adcom circuit with the same formula used to calculate the voltage gain of any non-inverting amplifier:

$$\text{Gain} = R109/R107 + 1$$

The values used in the Adcom circuit prevent the voltage gain from falling below 2.9.

The AD745J is designed to operate at voltage gains of five or higher, so the values of R109 and R107 will not work. You could drop R107 to 121Ω, satisfying the AD745J's stability requirement, and raising the 1kHz gain of the circuit from the original 40dB to 45dB. This would be fine for lower-output cartridges (2 to 2.5mV), but moving magnet cartridges with outputs in the 5mV range would likely overload the preamp. Early on in my work with the AD745J in this circuit, I did drop R107 to 121Ω, which worked fine with my Grado Signature XTZII and Adcom XC-MRII cartridges. But, many builders would not find the 45dB preamp suitable.

I'm sure that many readers of *aX* are familiar with Stanley Lipshitz's 1979 AES paper "On RIAA Equalization Networks" (required reading for anyone designing RIAA phono preamps[1]). As the Lipshitz math shows, you can't add a gain-stop resistor—or change the value—without seriously affecting the RIAA accuracy. An RIAA network must be designed with this resistor taken into account, and any change in this resistor requires a redesign of at least part of the network.

The Lipshitz math is quite daunting, but you don't have to be a mathematician to make it work. A few years ago I designed a group of spreadsheets, using Microsoft Excel, to do the calculations for all four feedback RIAA topologies described in the Lipshitz article. With the spreadsheets to do the work, accurate RIAA design has become easy and painless. I use the spreadsheets along with SPICE-based circuit simulation in CircuitMaker 2000, which is my primary schematic capture and simulation program[2].

NEW PHONO PREAMPS

With the Lipshitz math in hand, I decided to redesign the Adcom RIAA circuits, and offer preamps with both 40dB and 45.5dB of gain. The RIAA feedback values are close to the original values, since I retained the large 15,000pF capacitor C115 (C116 in the right channel; for the rest of this article, parts designators in parentheses refer to the right channel).

Figure 9 shows the 40dB circuit and *Fig. 10* shows the 45.5dB circuit. In both preamps R109 ensures that the gain will never drop below five at high frequencies. It was not possible to get exact RIAA values from single, off-the-shelf parts. R111 and R113 are each made from two resistors in series. Four parallel capacitors are needed for the 40dB preamp; this number drops to three for the 45.5dB preamp. The Adcom PC layout accommodates only two capacitors in these locations, but you can easily solder the additional parallel caps to the bottom of the PC board.

The servo amplifier is an Analog Devices OP97EP, a device Walt Jung suggested for this application. The integrator R/C values produce a –3dB point of 0.22Hz for the preamps, and should keep the DC offset at low levels regardless of source impedance (I thank Walt for suggesting the integrator resistor values).

SIMULATIONS

Figure 11 shows my schematic for simulating the accuracy of the RIAA preamplifiers—the 40dB preamp is shown here. The circuit at the bottom is a SPICE model for a mathematically ideal RIAA emphasis network, with the bass and treble portions of the network isolated to prevent interaction. I based this network on an RIAA de-emphasis network Walt Jung designed(see sidebar).

At the time, he was doing RIAA simulation by comparing the outputs of a phono preamp design and a mathematically ideal de-emphasis network. But, CircuitMaker 2000 doesn't seem to support this (though CircuitMaker Version 6 did), so I essentially inverted his model to produce the emphasis model in *Fig. 11*. There seems to be a problem with Analog Devices' SPICE model for the OP97 op amp. I used the model for the OP297, which is the dual version of the OP97.

R1/R2/C1 set the mid- and low-frequency time constants at 3180µS and 318µS. R3/C2 sets the treble time constant at 75µS. With isolated networks, you don't need the Lipshitz math, since there are no interactions between the treble and bass networks—just plug in the real-time constants to determine the component values. VcVs1 and IcVs1 are scaled to match the series resistances that follow each device.

The IcVs2 scaling adjusts the output of the emphasis model to match the gain of the preamp. This applies 10mV to the input of the phono preamp, and makes the frequency response simulation curve lie around 0dB on the "Y" axis. Use this formula to determine the ICVs2 scaling:

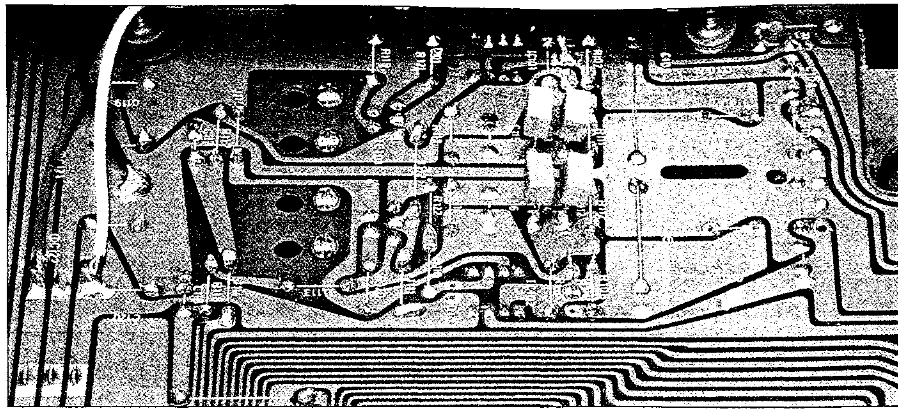

PHOTO 33: Bottom view of the phono preamp showing power supply connections to the DC servo, and parallel capacitors for the RIAA networks. C109 and C110 are replaced with jumpers.

$$\text{IcVs1 Scaling} = 0.10103/10^{[(\text{1kHz gain in dB})/20]}$$

The exact 1kHz gain of the 40dB preamp is 40.3, but this drops to 40.1dB with the line stage loading, so the required scaling is 0.000998735. For the 45.5dB preamps, the actual gain with line stage loading is 45.375dB, for a scaling of 0.000544127.

Figures 12 and *13* show the simulated RIAA accuracy for the 40dB and 45.5dB preamps. Cursors 1 and 2 are set to the lowest and highest points in the curve between 20Hz and 20kHz. The horizontal dashed lines mark the total spread of the error, which is around 0.012dB for both preamps. These circuits are accurate to within ±0.006dB (yes, that's six thousandths of a dB!), 20Hz to 20kHz.

Have I gotten carried away? I don't think so. The curves in *Figs. 12* and *13*

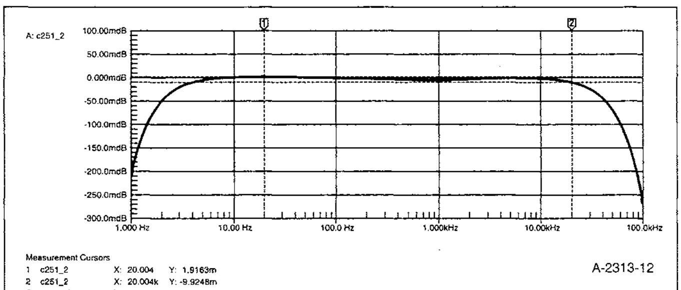

FIGURE 12: Simulated response of the 40dB phono preamp. The simulation shows the response to be accurate ±0.006dB, 20Hz to 20kHz. The tight simulated response ensures good results with real-world component tolerances.

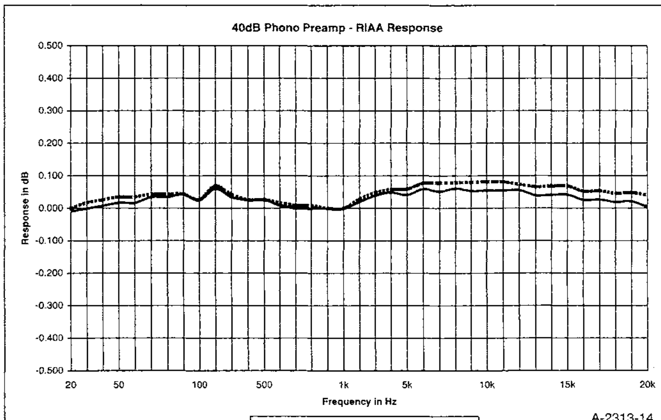

FIGURE 14: Measured response of the 40dB phono preamp. The graph was produced with a spreadsheet, taking errors in the generator, voltmeter, and inverse RIAA network into account. The response is accurate ±0.04dB, 20Hz to 20kHz.

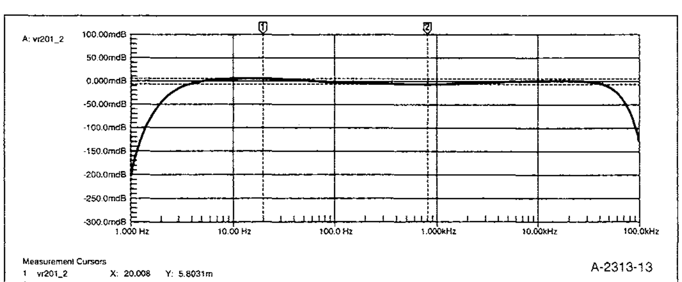

FIGURE 13: Simulated response of the 45.5dB phono preamp. The simulation shows the response to be accurate ±0.006dB, 20Hz to 20kHz.

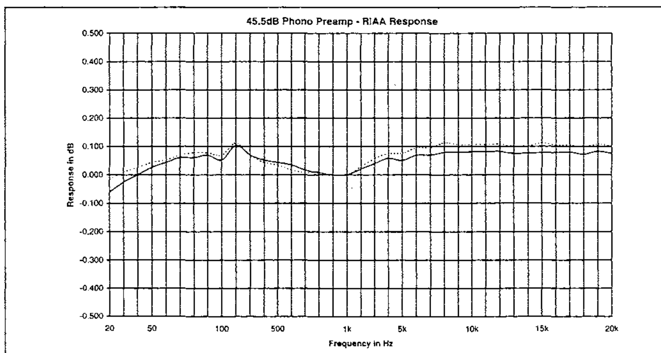

FIGURE 15: Measured response of the 45.5dB phono preamp. This preamp is accurate ±0.08dB, 20Hz to 20kHz.

can only be realized with zero percent tolerance components, which is impossible in the real world. The best that you can do with real-world components is 1% resistors and the 2.5% Wima FKP-2 capacitors sold by Welborne Labs.

My designs retain some of the 1% capacitors (C115) from the original Adcom circuit, which helps. But unless you're a manufacturer, 1% tolerances for the remaining caps will be prohibitively expensive, and generally unavailable in quantities less than 1000 per value. The Lipshitz math, with the help of my spreadsheet, makes it possible to design extremely accurate RIAA networks quickly and easily—it is really no more time-consuming to design a good one than a bad one. So why not do it right?

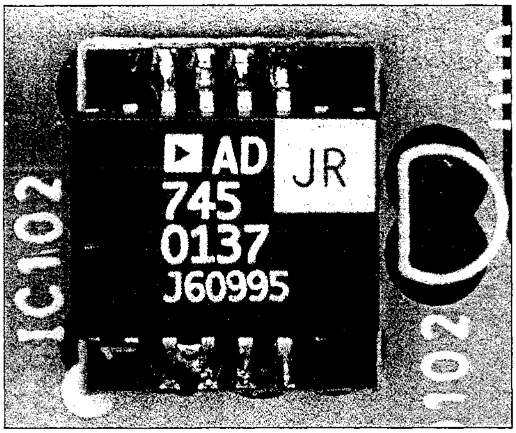

PHOTO 34: Close-up of the AD745JR in the SOIC package mounted on an Aries SOIC-to-DIP adapter. The four pins on each end of the op amp are cut off, and a solder bridge between pins 3 and 4 makes the connection to the inverting input.

The Wima FKP-2 polypropylene capacitors are of the same type and construction as the Roederstein KP-series Adcom used, so there's no problem using them with some of the original Adcom capacitors. I hand-selected the 2.5% capacitors I bought from Welborne on my BK Precision 875B LCR meter, which has 1% accuracy. I found that out of six or eight 3.5% Wima caps, at least two measured close to dead-on. The Wima caps are fairly inexpensive, which makes this a practical approach.

The extremely tight accuracy in the simulation will ensure that the end result will still be very good with real-world components. Ideally, I'd like to see a finished product with an accuracy of ±0.1%. Since the late 1970s, there seems to be general agreement in both the "golden ear" and "scientific" camps that this level of accuracy will ensure that the frequency response errors of the RIAA circuit will not be audible. If you start out with accuracy of ±0.1% in a simulation, the end result will probably be quite unacceptable.

My simulations required three deviations from the ideal RIAA network values, as determined by the Lipshitz math. First, the capacitors in the treble portion of the network (C111, C113, and so on) were trimmed to compensate for the loop-gain error of the AD745J. Second, R113 needed to be adjusted slightly to compensate for the impedance of the DC servo.

I made these adjustments with circuit simulation after determining the nominal values using the Lipshitz math. Finally, I decided to treat the line stage loading as part of the circuit, including the bandwidth-limiting network R205/C251, along with the 25k load of the balance and volume controls. The output R/C network R117 and C117 was trimmed with circuit simulation to produce the flattest high-frequency response with the line stage loading as part of the system, with the output taken at the junction of R205 and C251.

This approach will produce optimum high-frequency accuracy only with the phono preamp connected to the line stage with the listening selector switch. This may be of concern to those who tape LP records. If you put the recording selector on phono and the listening selector in some other position, there will be a high-frequency error in the RIAA response at the tape outputs. But, if recording LPs while monitoring your recorder is a necessary part of your audio life, you can change R117 to 590Ω in the 40dB preamp, and 432Ω in the 45.5dB preamp.

BUILDING THE RIAA PREAMPS

Before you order parts, you'll need to make the same choice for the resistors that you did for the line stage in part 3. My recommendations are the same as before. Some of the photos show a mix of Holco H4 and the Vishay-Dale CMF RN-60 types. After I had switched from capacitor-coupled outputs to DC servo control, I made the necessary changes in the circuits only to find that the Holco values I needed were no longer available.

Ideally, I recommend using the same type of resistor throughout, with a couple of exceptions. The 33Ω bias resistors need not be exotic—the Vishay-Dale resistors are fine here. There's also no need to use anything more expensive than the Vishay-Dale or Holco resistors in the servo.

For the remaining resistors, I built one preamp with Caddock MK132s and two others with Holcos and Vishay-Dales. The Caddock resistors are really stellar in these circuits, but the other resistors still perform extremely well. If you use Holco resistors, you'll need to stand them on end, as you did for part 3. Use sleeving on the exposed leads.

Analog Devices has discontinued the 8-pin DIP AD745JN—they now offer this chip only in a 16-pin SOIC package, which they call the AD745JR-16. You can use the AD745JR-16 with the same Aries SOIC to-DIP adapter used in the regulator in part 2 (the 16-pin SOIC package is too wide to fit the Accutek Microcircuit adapter). But, you may still be able to buy the AD745JN.

Rochester Electronics specializes in discontinued semiconductors from most of the major manufacturers. As of this writing, they still had 13,800 AD745JN op amps in stock. With a $50 minimum order, you may consider many other devices of interest, including BUF04s and BUF03s.

COMMON STEPS

Begin construction with steps that are common to both the 40dB and 45.5dB preamps (*Photos 32* and *33*). For a few of the resistor replacements in these preamps, you'll use the same value, but substitute a new type.

- Remove D101 (D102; these parts won't be replaced).
- Remove R115 (R116; these parts won't be replaced).
- Replace R103 (R104) with 47.5k.
- Replace R121 (R122) with 100Ω.
- Replace R119 (R120) with 33Ω Vishay-Dale CMF type RN60.
- Remove C107 (C108; these parts won't be replaced).
- Remove C109 (C110; these parts won't be replaced).
- Install jumpers in the C109 and C110 footprints on the bottom of the PC board (*Photo 33*).

Feel free to change C101 (C102) to suit the loading requirements of your phono cartridge, taking the capacitance of your tonearm cable into account. Use Wima FKP-2 capacitors from Welborne Labs.

Perform the following step if you are using the 8-pin DIP AD745JN:

- Replace IC101 (IC102) with the AD745JN.

Perform the following steps if you are using the 16-pin SOIC AD745JR-16 (*Photo 34*):

- Cut off the four pins on each end of the AD745JR-16 op amps. These are pins 1, 2, 7, 8, 9, 10, 15, and 16. The

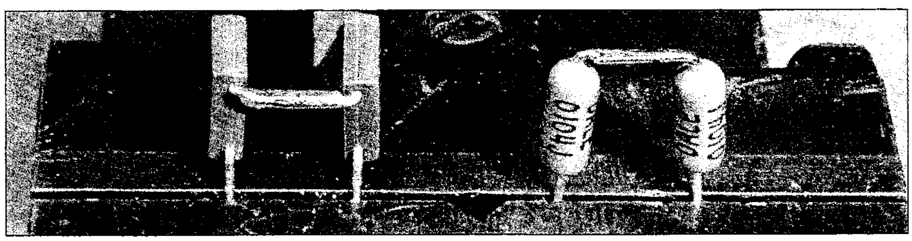

PHOTO 35: Method for soldering resistors in series. Caddock MK132 are shown on the left, and Vishay–Dale on the right. Series resistors are necessary to get the exact values needed for the RIAA feedback network.

TABLE 1
MEASUREMENTS ON 40dB SAMPLE BUILT FOR C. VICTOR CAMPOS

S.N.AC14755

LEFT PHONO TO TAPE OUT LEFT
THD (W/JUNG-LIPSHITZ INVERSE RIAA NETWORK; 2V OUT)

	WIDEBAND	W/80KHZ LP FILTER
20Hz	0.0022%	0.0016%
1kHz	0.0023%	0.0017%
10kHz	0.0033%	0.0029%
20kHz	0.0047%	0.0046%

RIGHT PHONO TO TAPE OUT RIGHT
THD (W/JUNG-LIPSHITZ INVERSE RIAA NETWORK; 2V OUT)

	WIDEBAND	W/80KHZ LP FILTER
20Hz	0.0022%	0.0016%
1kHz	0.0023%	0.0017%
10kHz	0.0032%	0.0029%
20kHz	0.0047%	0.0046%

PHONO TO TAPE OUT (2V IN > 2V OUT)	SMPTE (4:1)	1:1
Left	0.00175%	0.0016%
Right	0.0015%	0.0012%

Phono signal-to-noise ratio (relative to 2V out @ 1kHz)
−94.5dB *Unweighted* (left and right channels identical)
All measurements made with Sound Technology 1700B
By Gary Galo, 11/2/2002

eight remaining pins are 3, 4, 5, 6, 11, 12, 13, and 14 (these are the middle four pins on each side of the op amp).

- Solder the AD745JR-16 op amps to a pair of Aries 8-pin SOIC to DIP adapters.

For some strange reason, Analog Devices made pin 3 the inverting input on the AD745JR-16. Logically, they should have made this input pin 4, so the eight pins in the middle of the package would exactly match the functions of their counterparts in the 8-pin DIP package. Pin 4 is unused, so this quirk is easy to fix (*Photo 34*).

- Make a solder bridge between pins 3 and 4 of the AD745JR-16 op amp on the Aries header. You'd be surprised how difficult it is to make a solder bridge when that's what you're trying to do! Now, pin 2 on the PC board footprint will connect to the inverting input of the op amp.
- Install the AD745JR-16 modules in the IC101 and IC102 footprints. Carefully observe orientation.

HEATSINK REPLACEMENT

- Remove the LT1010 buffers, IC103 and IC104. Unsolder all five leads and remove the screws that hold the heatsinks in place.
- Replace the 1″ heatsinks with the 1½″ Wakefield or Aavid types recommended in the parts list. These are the same type used for the pre-regulators in part 2. Use thermal compound or the Adcom sili-pads, and mount the LT1010s to the heatsinks with 6-32 hardware, without insulators. As with the pre-regulators, there's no need for insulating hardware, since the heatsinks do not make electrical contact with anything.
- Replace the 22AWG jumpers J111, J112, and J115 with 18AWG jumpers. This keeps the impedance of the power supply lines as low as possible. You may need to enlarge the PC holes with a #50 drill.

Now follow the instructions for the preamp you are building, 40dB or 45.5dB. In two of the steps for each preamp, you will connect two resistors in series to make the correct value. I recommend standing the two resistors on end in a vise, bending the top leads at right angles, and soldering the top leads together. Adjust the length of the top leads and the spacing between the resistors so the series assembly will drop into the Adcom PC footprint.

Photo 35 shows how this is done for both Caddock and Vishay-Dale resistors. Refer to *Fig. 9* for the 40dB, *Fig. 10* for the 45.5dB preamp, and *Photos 32* and *33* for both.

40dB PREAMP ASSEMBLY

- Replace R107 (R108) with 221Ω.
- Replace R109 (R110) with 1k.
- Replace R111 (R112) with 15k + 2.1k in series (R_T = 17.1k).
- Replace R113 (R114) with 210k + 1k in series (R_T = 211k). If you are using Caddock resistors, the series assemblies will straddle C115 and C116 (*Photo 41*).
- Replace R117 (R118) with 510Ω (Caddock) or 511Ω (Holco or Vishay).
- Replace C111 (C112) with 2200pF.
- Solder C111a (C112a)—680pF—to the bottom of the PC board, in parallel with C111 (C112).
- Solder C113a (C114a)—470pF—to the bottom of the PC board, in parallel with C113 (C114).
- Replace C117 (C118) with 6800pF.

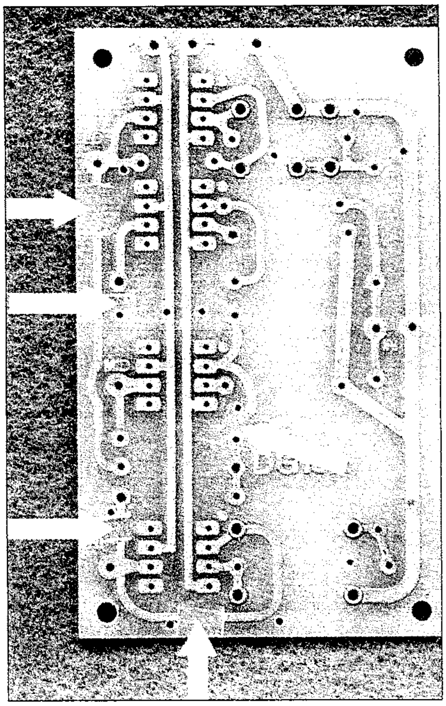

PHOTO 36: The Old Colony DG13R circuit board modified for use as the DC servo board. Five traces are cut, and several new holes are drilled to accommodate the servo circuit.

Note that C113 (C114) and C115 (C116) are unchanged—the original Roederstein KP capacitors are retained. *Photo 32* shows the preamp at this stage in the construction.

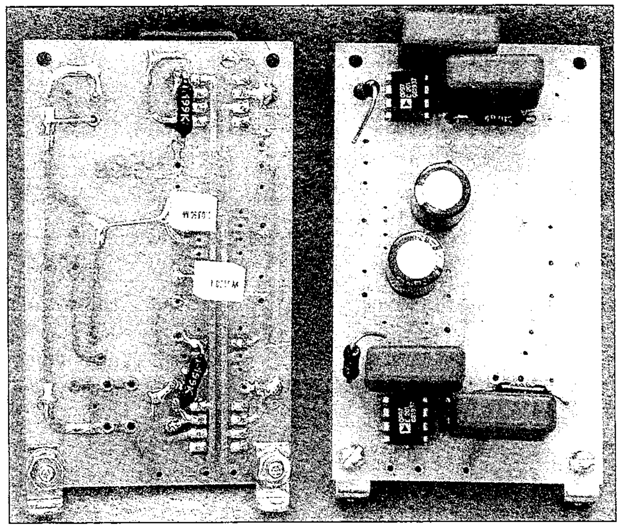

PHOTO 37: Bottom and top views of the DC servo board. R151, R152, C157, and C158 are soldered to the bottom of the board. Only one board is needed for both channels.

At this point, the phono preamp will operate, but with a significant DC offset. You should check the preamp on the bench to verify proper operation up to this point. Apply a 1kHz sine wave to each input at a level of 10mV, and monitor one of the tape output buffers. The level should be 1.05V, since the actual gain of this preamp is 40.1dB.

Check the DC offset at the phono preamp outputs. Maximum output offset for the 40dB preamp will be 1.5V, and most AD745J samples should be less. *Don't listen to the preamp at this point. The DC offset could cause damage to other components, especially your power amp and speakers!*

LISTENING TO GALO'S MODIFIED ADCOM GFP-565

It happens that I have had Adcom's GFP-565 preamplifier as part of my sound system for a number of years. When Gary Galo proposed, some time ago, that he write a modification article for upgrading this equipment, I was pleased and yet somewhat dubious that the product could be improved to any significant extent. I knew that the preamp was one of the Adcom products whose design and manufacture was the responsibility of C. Victor Campos. Mr. Campos does work that is difficult to improve.

I did know that this equipment—like any designed for the consumer market—was necessarily a compromise since only handcrafted, one-of-a-kind devices could be produced as super perfectionist products. Economics and competition are always issues in components designed for consumer markets.

Gary's work, now published in four installments in this magazine, was done over several years since Gary has a demanding day job as well as being involved in other professional audio activities. When he was near completion of his modifications, he asked if I would audition the finished project. Gary asked this knowing full well that I would say exactly what I thought about the result, keeping in mind that this was an audition and that my ears are not all they might have been in years past.

So I unpacked the two cartons containing one of his three modified units, the second box containing his new external power supply. I installed the new unit in the same rack with the rest of my system and listened carefully to three recorded samples, first through the unmodified preamp, then with Gary's modified unit in place and then again through the unmodified unit.

The first sample is from a Telarc SACD, Lorin Maazel and the Cleveland Orchestra performing Igor Stravinsky's "The Rite of Spring." Second, I listened to the New Budapest Quartet playing Bela Bartok's "String Quartet No. 1" (Sz40 Op. 7.) on a Hyperion Dyad CD. My third sample was a Westminster Laboratory Series LP (W LAB 7056) with Sir Adrian Bolt conducting the Philharmonic Promenade Orchestra playing Benjamin Britten's "Young Person's Guide to the Orchestra." The SACD and CD were played on a Sony SACD/DVD player (DVP-NS755V) while the LP was played on a Linn Sondek LP12, updated with a new motor from Origin Live (www.originlive.com) and a Linn Ittok LV II arm with a LINN ASAK cartridge. The preamp drives two Pass Zen stereo amps each driving one of my Thor speakers.

I am pleased to report that there are at least three notable differences in the sound from the two units. First, the individual instruments are more clearly defined and differentiated from each other. This is most noticeable on the Stravinsky, but almost as much on the CD. On the LP the differences were not quite as dramatic.

Second, the soundstage was quite obviously wider on all three of the samples. The response seemed to move outside the two Thors and to fill the space in the room to a greater degree than with the unmodified preamp. The LP is, although very high quality, a monophonic recording. The breadth and detail even on this sample was surprisingly good.

Three, the depth of the orchestral image was much greater. On the Stravinsky all the sound seemed to come from *behind* the speakers and to even go behind the rear wall itself. My room is not ideal for listening, being nearly square—with two large door openings, but the speakers are carefully placed equidistant from the side walls and the back wall. The illusion of the orchestral spread was very firm and stable, and coupled with the increased definition of the individual instruments, the effect was deeply satisfying. The quartet presence was of the four players sitting in, and slightly behind the speakers, and quite vividly reproduced. This preamp has the ability, in my system, to help you forget that the music is being reproduced.

I had only one small objection to the modified result. The separate power supply is housed in a stock aluminum box which has a very slight vibration at what sounds like 120Hz. A slight pressure on the top of the box quiets the noise very effectively. A remedy should be easy.

I believe the modifications Gary has made to his units are a very worthwhile undertaking, even considering the amount of work involved. His modified Adcom GFP 565 is probably the best sounding preamp I have ever had the pleasure of auditioning.—E.T.D.

45.5DB PREAMP ASSEMBLY

- Replace R107 (R108) with 121Ω.
- Replace R109 (R110) with 499Ω.
- Replace R111 (R112) with 17.4k + 200Ω in series (R_T = 17.6k).
- Replace R113 (R114) with 210k + 1k in series (R_T = 211k). If you are using Caddock resistors, the series assemblies will straddle C115 and C116 (*Photo 41*).
- Replace R117 (R118) with 332Ω.
- Replace C113 (C114) with 680pF.
- Solder C113a (C114a)—220pF—to the bottom of the PC board in parallel with C113 (C114).

Note that C111 (C112), C115 (C116), and C117 (C118) are unchanged—the original Roederstein KP capacitors are retained. *Photo 32* shows the preamp at this stage in the construction. At this point, the phono preamp will operate, but with a significant DC offset. You should check the preamp on the bench to verify proper operation up to this point. Apply a 1kHz sine wave to each input at a level of 5mV, and monitor one of the tape output buffers.

The level at the output of the phono preamp should be just under 0.96V. Check the DC offset at the phono preamp outputs. Maximum output offset for the 45.5dB preamp will be 3V, and most AD745J samples should be less. *Don't listen to the preamp at this point. The DC offset could cause damage to other components, especially your power amp and speakers!*

DC SERVO CONSTRUCTION

The DC servo is the same for both preamps. I built the servo on one of Ed

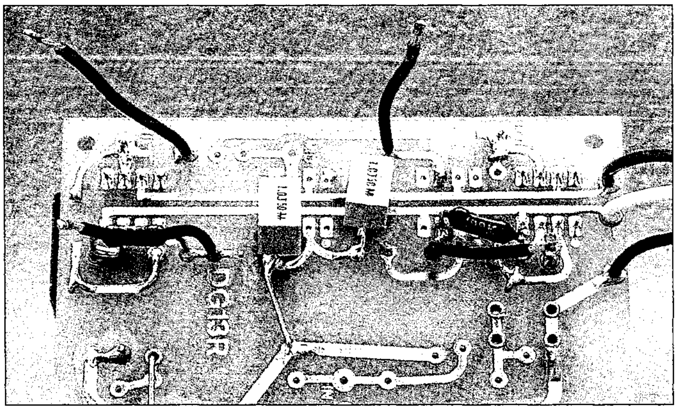

PHOTO 38: Bottom view of the DC servo board with input, output, and power supply leads attached.

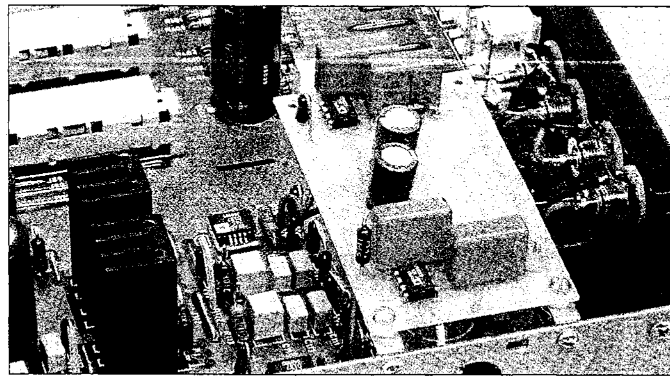

PHOTO 39: Side view of the completed phono preamp with the servo board installed. The servo board is mounted to the preamp's metal side rail with angle brackets.

MEASURING RIAA ACCURACY

If you can afford an Audio Precision System 1 or System 2, its built-in algorithms make RIAA measurement relatively easy. For the rest of us, measuring RIAA accuracy is a tricky and tedious process, requiring the right equipment and a lot of patience. I have developed a procedure using conventional equipment that works very well.

For many years I have used the Jung-Lipshitz inverse RIAA network, which is a passive device I built from the Old Colony kit, with 1%-tolerance parts (no longer available)[3]. But, matching your generator source impedance to this network can be frustrating, and a source of error. Jung and Lipshitz offered two versions of the network, with component values trimmed to accommodate source impedances of 0Ω or 300Ω.

The problem is that most generators have output impedances in the 500 to 600W range. I decided to actively buffer my Jung/Lipshitz network. I ran some computer simulations to check the accuracy of the buffered device against Walt's mathematically ideal RIAA de-emphasis network, and found that the best accuracy was with the 0Ω source impedance network driven directly from IC1's output *(Fig. 16)*. My simulations showed an excellent response across most of the spectrum, with an error of only −0.024dB at 20kHz *(Fig. 17)*.

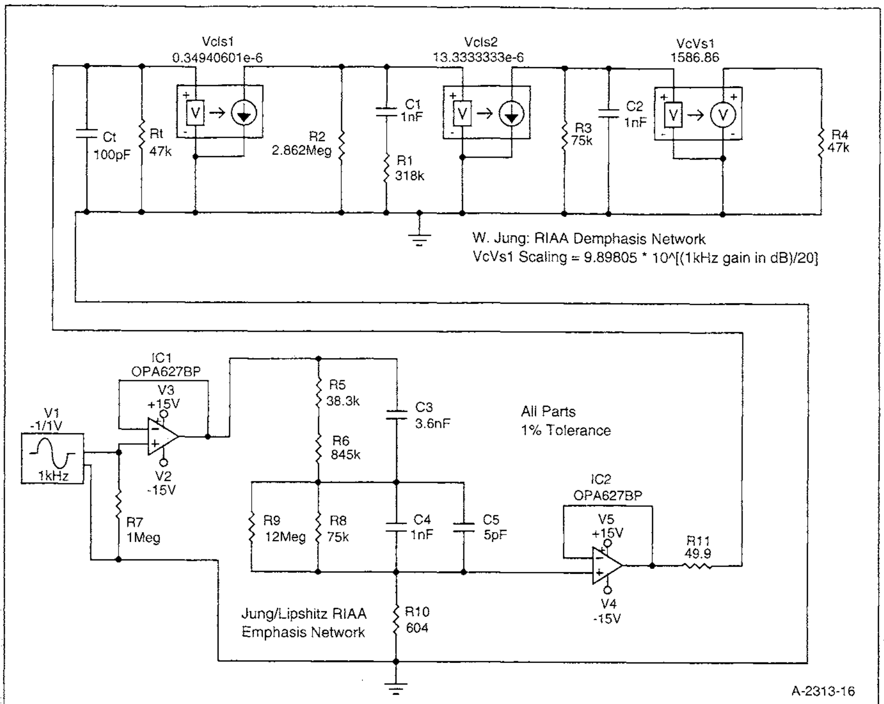

FIGURE 16: Simulation circuit for testing the buffered Jung/Lipshitz inverse RIAA network. The network is checked against a mathematically ideal RIAA de-emphasis model.

The op amps for IC1 and IC2 need to be high-current devices capable of driving a 600Ω load, which is the terminating impedance of the network. The op amp should also be a low-offset, FET-input device, to allow DC coupling. A noisy op amp can cause meter readings to wander, particularly at lower frequencies. I had this problem with Analog Devices AD845, so I changed the op amps to TI/Burr-Brown OPA627BP devices, which can deliver 45mA of output current, with an input voltage noise of 4.5nV√Hz at 10kHz.

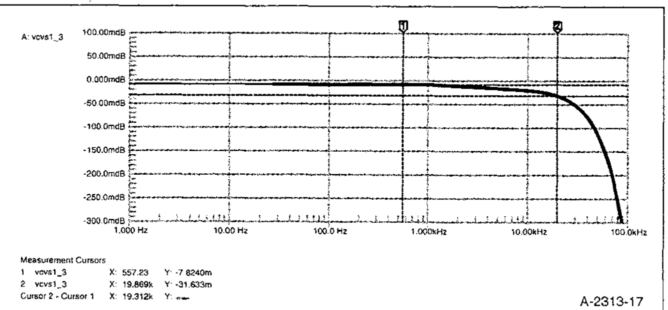

FIGURE 17: Error of the buffered inverse RIAA network, compared to the mathematically ideal de-emphasis model. The network is ruler-flat to 1kHz, and down only 0.024dB at 20kHz.

The difficulty in measuring RIAA response is the need to resolve differences in the hundredths of a decibel. Most signal generators do not maintain exactly the same output at all frequencies, and most meters have variations, as well. Accurate, high-resolution dB meters are rare, and the popular Loftech TS-1 and TS-2 have only 0.1dB resolution, making them useless for RIAA measurements. The best choice is an AC DMM with 20kHz bandwidth and 1mV resolution. I used the generator in my Sound Technology 1700B and a Tenma (MCM Electronics) 72-410A bench-type, true-RMS DMM.

I first tested the accuracy of the generator and DMM as a system, after warming up the test equipment for two hours. I set the generator to 1V output at 1kHz, and fine-tuned the output so the DMM read *exactly* 1.000V. I then ran a decade frequency response test from 20Hz to 20kHz, noting the exact voltage reading at every frequency. Over the course of two days, I re-checked the errors several times to see whether the measurements were repeatable. They were.

I plugged these error figures into a spreadsheet (Microsoft Excel), which allowed me to automatically correct for the generator/meter error. If the generator and meter read 1.007V at 20kHz, as an example, my correction column has −0.007V as the correction needed.

To measure the preamps, I inserted my active Jung/Lipshitz inverse RIAA network between the generator and the phono input on the preamp, set the generator output to 1V, and connected the preamp's main output to the DMM (remember that I treated the phono preamp plus line-stage loading as a system). The inverse network's 40dB insertion loss cuts the level down to 10mV at the preamp's phono input.

The preamp's volume control is carefully adjusted to make the DMM read 1.000V at 1kHz. Then I ran a complete decade frequency response check from 20Hz to 20kHz (in 1kHz steps between 10kHz and 20kHz), writing the results down in the "measured" column in the spreadsheet. I put a formula into the spreadsheet to take preamp measurement and necessary generator/meter correction to give a "corrected" response in the next column.

The spreadsheet converted the voltage measurements to dB, using the formula:

$$dB = 20 \log (E1/E2)$$

where E2 is the 1.000V reference at 1kHz and E1 is the measurement at the other frequencies. This gave the correct ±dB indication in the "response in dB" column. I also entered the errors of the buffered inverse RIAA network above 1kHz, using data from my computer simulation. I did this for both channels, and then used Excel to make a graph with both the left and right curves *(Figs. 14 and 15)*. This procedure is extremely painstaking, but it seems to be accurate and repeatable—GG.

Dell's venerable DG13R electronic crossover boards, sold by Old Colony. I still find this op-amp PC board to be extremely versatile, and I have adapted it for a variety of projects over the years.

You need only one board for both channels. You can also use a small perfboard, if you wish. You can easily adapt the DG13R board for this circuit by cutting a few traces, adding a couple of jumpers, and drilling a few new holes (*Photos 36*, *37*, and *38*).

- Cut the five traces on the DG13R board shown in *Photo 36*.
- *Photo 36* also shows the locations of extra holes that you must drill in the PC board. Use a #55 drill.
- Assemble the servo components on the board, using *Photos 37* and *38* as a guide.
- R151 and R152 are soldered to the bottom side of the PC board. All other servo parts are mounted on the top of the board.
- C155 and C156—the 100µF electrolytic supply bypass capacitors— should be mounted on the top of the board.
- C157 and C158—the 1µF film bypass caps–are soldered to the bottom of the board, in parallel with C155 and C156.
- Solder 2″ lengths of 18AWG hookup wire for the input and output connections for each channel. I used black wire for the inputs and red for the outputs (*Photo 38*).
- Solder three 18AWG hookup wires for the positive and negative supply connections, and ground. Make these wires long enough to reach the bottom of the PC board, where you will solder them to the main preamp supply bus. I used red wire for positive, white for negative, and black for ground (*Photo 38*).

Check the assembly of the servo boards very carefully to make sure that each channel matches the schematics in *Fig. 9* or *10*. Clean the PC board with CaiCleen TRP DG7S-6 Cleaner. Cleaning is extremely important, because residual solder flux can cause leakages in these high impedance circuits.

SERVO BOARD MOUNTING

The DC servo input connections are taken from holes left vacant by the removal of R115 and R116. You must drill two new holes for the output connections:

- Drill a small hole with a #50 drill through the PC board between the vacant R115 holes. Make sure that this hole lands in the middle of the PC trace that goes between the R115 holes on the bottom of the board. Scrape enough lacquer off the PC trace to ensure a good connection.
- Drill a small hole with a #50 drill through the PC board between the vacant R116 holes. Make sure that this hole lands in the middle of the PC trace that goes between the R116 holes on the bottom of the board. Scrape enough lacquer off the PC trace to ensure a good connection.
- Enlarge the R115 and R116 holes closest to C112 and C113 with a #50 drill.

You can mount the DC servo board on the preamp's metal side rail with two small angle brackets, 1/8-nylon spacers and 4-40 hardware (*Photos 39*, *40*, and *41*). The board will sit directly above the old C107 to C110 footprints on the main PC board.

- Mount two angle brackets to the end

PARTS LIST

NOTE: ALL RESISTORS ARE BUILDER'S CHOICE:

Vishay-Dale CMF Type RN60 (Welborne Labs, Mouser 71-RN60D-Value)

Holco H4 (older non-ferrous type, if available, Welborne Labs, Michael Percy Audio, Parts Connexion)

Caddock MK132 (Welborne Labs, Michael Percy Audio, Parts Connexion)

Vishay S-102 (Michael Percy Audio)

DC servo (same for both preamps):

(1)	DG13R circuit board, Old Colony PCBC-4
(2)	Analog Devices OP97EP op amp, Newark 66F5763 or Analog.com
(4)	0.22µF (220nF) 160V Wima MKP-10 capacitors, Welborne Labs WM214 (C151, C152, C153, C154)
(4)	499k ½W resistors (R151, R152, R153, R154; use Vishay-Dale CMF type RN60 or Holco H4)
(2)	1.5M ½W resistors (R156, R157; use Vishay-Dale CMF type RN60 or Holco H4)
(2)	100µF, 25V DC Nichicon KZ, Michael Percy Audio (C155, C156)
(2)	1.0µF, 50V DC Mallory 168-series, Newark 89F1692 (C157, C158)

MISC.

Angle brackets, Mouser 534-616

⅛" nylon spacers, Digi-Key 875K-ND

4-40 hardware

18 AWG hookup wire: Welborne Labs TWR, TWB and TWW (Welborne Labs);

40dB phono preamp:

(2)	Wakefield 634-15ABP 1½" heatsink, Newark 91F3674—or— Aavid 581102B00000, Digi-Key HS303-ND (for LT1010 buffers)
(2)	Analog Devices AD745JN op amp, 8-pin DIP, Rochester Electronics—or—Analog Devices AD745JR-16 op amp, 16-pin SOIC, Analog.com (IC101, IC102)
(2)	Aries 8-pin SOIC/DIP adapters, Digi-Key A724-ND (adapters needed only for the AD745JR-16)
(2)	47.5k resistor (R103, R104)
(2)	33Ω ½W resistor (R119, R120; use Vishay-Dale CMF type RN60 or Holco H4)
(2)	100Ω ½W resistor (R121, R122)
(2)	221Ω ½W resistor (R107, R108)
(4)	1k ½W resistor (R109, R110, R113, R114)
(2)	15k ½W resistor (R111, R112)
(2)	2.1k ½W resistor (R111, R112)
(2)	210k ½W resistor (R113, R114)
(2)	510Ω ½W resistor (R117, R118; 510Ω is the Caddock value carried by Welborne; use 511Ω for Holco or Vishay-Dale)
(2)	2200pF 100V 2.5% Wima FKP-2, Welborne Labs WM9 (C111, C112)
(2)	680pF 100V 2.5% Wima FKP-2, Welborne Labs WM6 (C111a, C112a)
(2)	470pF 100V 2.5% Wima FKP-2, Welborne Labs WM5 (C113a, C114a)
(2)	6800pF 63V 2.5% Wima FKP-2, Welborne Labs WM12 (C117, C118)

45.5dB phono preamp:

(2)	Wakefield 634-15ABP 1½" heatsink, Newark 91F3674—or— Aavid 581102B00000, Digi-Key HS303-ND (for LT1010 buffers)
(2)	Analog Devices AD745JN op amp, 8-pin DIP, Rochester Electronics—or—Analog Devices AD745JR-16 op amp, 16-pin SOIC, Analog.com (IC101, IC102)
(2)	Aries 8-pin SOIC/DIP adapters, Digi-Key A724-ND (adapters needed only for the AD745JR-16)
(2)	47.5k resistor (R103, R104)
(2)	33Ω ½W resistor (R119, R120; use Vishay-Dale CMF type RN60 or Holco H4)
(2)	100Ω ½W resistor (R121, R122)
(2)	121Ω ½W resistor (R107, R108)
(2)	499Ω ½W resistor (R109, R110)
(2)	17.4k ½W resistor (R111, R112)
(2)	200Ω ½W resistor (R111, R112)
(2)	210k ½W resistor (R113, R114)
(2)	1k ½W resistor (R113, R114)
(2)	332Ω ½W resistor (R117, R118)
(2)	680pF 100V 2.5% Wima FKP-2, Welborne Labs WM6 (C113, C114)
(2)	220pF 100V 2.5% Wima FKP-2, Welborne Labs WM3 (C113a, C114a)

of the servo board with the power supply connections. Use nylon spacers, 4-40 machine screws, lock washers, and nuts. The Mouser brackets recommended in the parts list have one hole tapped for a 4-40 machine screw. I used the tapped hole to mount the board/bracket assembly to the preamp's metal side rail.

You'll need to drill two holes in the preamp's side rail to mount the board/bracket assembly.

- Position the board as shown in *Photo 39*, and mark the locations of the two mounting holes.
- Drill the two holes with a ⅛" drill. I suggest removing the metal side rail before drilling, and re-mounting it after. The side rail is held in place with six screws, and is easy to remove.
- Put the metal side rail back in place, but don't mount the servo board assembly just yet.

Trim the servo input and output leads when you connect them to the main PC board, to keep them as short as possible (*Photos 40* and *41*).

- Solder the left servo input lead to the hole previously occupied by the R115 resistor lead, closest to C111.
- Solder the left servo output lead to the newly drilled hole next to the input lead.
- Solder the right servo input lead to the hole previously occupied by the R116 resistor lead, closest to C112.
- Solder the right servo output lead to the newly drilled hole next to the input lead.
- Route the three power-supply wires to the bottom of the main PC board, between the main PC board and the side rail.
- Fasten the servo board assembly to the side rail with two 4-40 machine screws, using the tapped holes in the angle brackets. There should be plenty of clearance between the main PC board and the components on the bottom of the servo board.
- Solder the positive and negative supply wires, and the ground wire, to the main supply buses on the bottom of the PC board (*Photo 33*).

The phono preamp and DC servo modifications are now complete. Carefully re-check all of the assembly to make sure that your preamp—including the DC servo and its connections to the main PC board—matches the schematic diagrams. Clean the main PC board with CaiCleen TRP DG7S-6 Cleaner.

TESTING

Now it's time for some tests. Move the listening selector to Video/Aux (just to get it out of the way, for now). Put shorting plugs in both of the phono inputs and check the DC offsets with a digital multimeter (DMM) at the outputs of each channel. The easiest place to read the left channel is at jumper J114; measure the right channel at the junction of R118 and C118. The DC offsets in the three preamps I built are very close to 0V. The noise from the phono preamps will make a DMM wander a few tenths of a mV either side of zero on the 200mV scale (or whatever your meter's most sensitive DC scale happens to be).

The 45dB preamp makes my DMM wander a little more than a mV either side of zero, since the noise level is higher in the preamp. But, you can also look at the offset on a scope set to 5mV or 1mV per division. With your probe grounded, carefully set the trace in the center of the screen, and then look at the offset with your probe.

On my preamps, I see random noise above and below the zero line, but no real shift in the DC level. The offset readings should be close to the same regardless of the source impedance. In other words, there should be little difference in the readings with shorting plugs or with the phono inputs wide open (when you change the source Z, the servo does take a few seconds to settle).

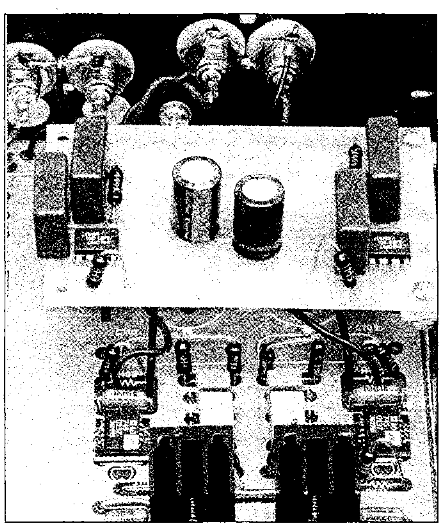

PHOTO 40: Close-up of the phono preamp showing the input and output connections to the servo board. This preamp was built with a combination of Holco and Vishay-Dale resistors.

After you've put the covers back on the preamp, you can still check the phono DC offset at the tape outputs. Put the recording selector in the CD position. Check the DC offsets at either of the left and right tape outputs, and note the readings. If you used OPA2604 op amps for the tape output buffers, the output offsets will be no more than 5mV.

Now move the recording selector to the phono position to read the combined tape buffer and phono preamp offset. The offset at the tape outputs will wander above and below the readings you obtained with the recording selector in the CD position, but about the same amount they did when you checked the offset directly from the phono preamp outputs. If your tests match these, the DC servo is operating properly. I highly recommend running the preamp on the bench for 24 hours and re-checking the DC offset.

If you have a distortion analyzer, you can compare the THD and IMD of your preamp to the measurements in *Table 1*, which shows the measurements I made on the preamp I modified for Victor Campos, which has 40dB of gain. I used a Jung/Lipshitz passive inverse RIAA network, and adjusted the generator output at 1kHz for 2V at the tape outputs. My noise measurements were made relative to 2V at the tape outputs. To measure the residual noise, I removed the signal generator from the phono input and inserted 100Ω resistor plugs in the phono inputs, simulating a low-impedance cartridge.

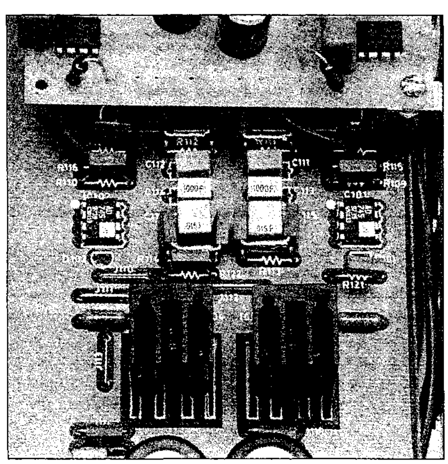

PHOTO 41: Close-up of a phono preamp built with Caddock MK132 resistors. The series resistors that make up R113 and R114 straddle C115 and C116.

My measurements show noise from the 40dB preamp to be 94.5dB below 2V out, *unweighted*. Adcom specifies the noise for the original preamp at 95dB below 2V, but A-weighted. The modified preamp has lower noise than the original.

I discuss my measurement procedure for RIAA accuracy in the sidebar that accompanies this article. The results are shown in *Figs. 14* and *15*. *Figure 14* is the response of the 40dB preamp. The 20Hz to 20kHz RIAA accuracy is ±0.036dB for the left channel and ±0.04dB for the right. *Figure 15* is the response of the 45.5dB preamp. The 20Hz to 20kHz RIAA accuracy is ±0.0825dB for the left channel and ±0.0655dB for the right.

Both preamps are well within the target of ±0.1dB, and every bit as good as the Adcom originals as measured by the manufacturer with an Audio Precision System 1 (the 40dB measurements are actually an order of magnitude better than the Adcom originals). With the conclusion of this preamp modification project, there's nothing left for you to do but listen and enjoy the music. ❖

VENDORS:

Old Colony Sound Laboratory
PO Box 876
Peterborough, NH 03458-0876
1-888-924-9465
1-603-924-9464
1-603-924-9467 (FAX)
www.audioXpress.com
custserv@audioXpress.com

Rochester Electronics, Inc.
10 Malcolm Hoyt Drive
Newburyport, MA 01950
978-462-9332
978-462-9512 (FAX)
www.rocelec.com
sales@rocelec.com

(Remaining vendors are listed in Part 1)

REFERENCES

1. Lipshitz, Stanley P. "On RIAA Equalization Networks," *Journal* of the Audio Engineering Society, V. 27, No. 6, June 1979, pp. 458-481.

2. Although I have found CircuitMaker 2000 to be a good program, their technical support leaves a lot to be desired. There are a number of known issues with the program that the manufacturer—Altium, Ltd.—seems to have no interest in fixing (www.circuitmaker.com and www.altium.com), but I have learned how to work around them. The program does offer a great deal for the money, including schematic capture, mixed-signal simulation, and PC layout.

3. Lipshitz, Stanley P., and Walt Jung. "A High Accuracy Inverse RIAA Network," *Audio Amateur*, 1/1980.