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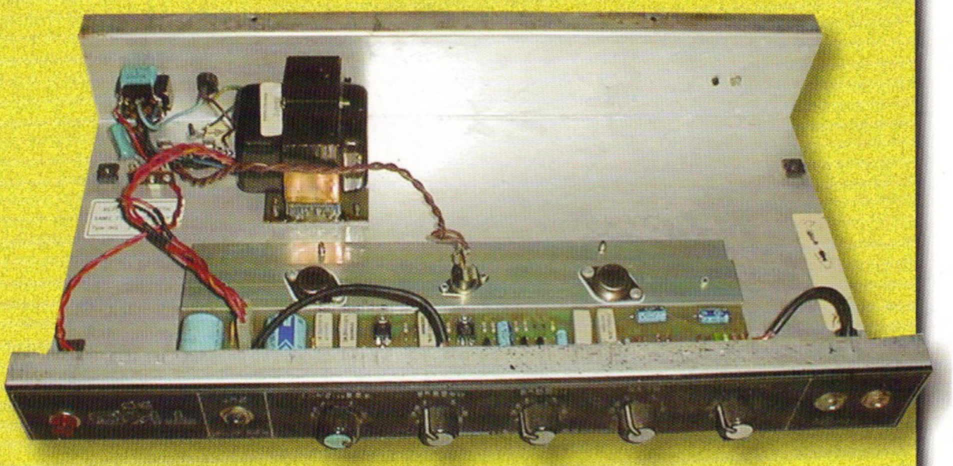

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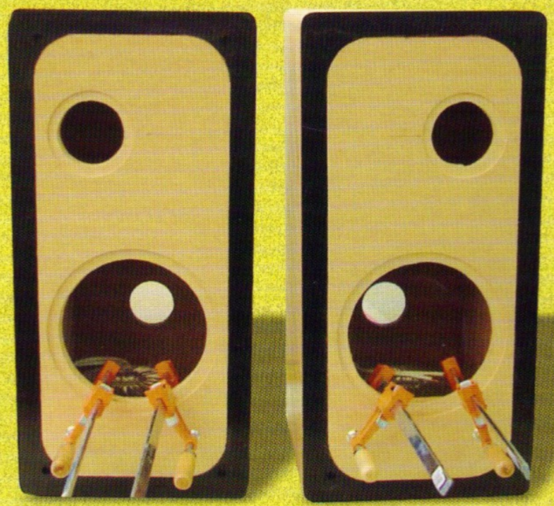

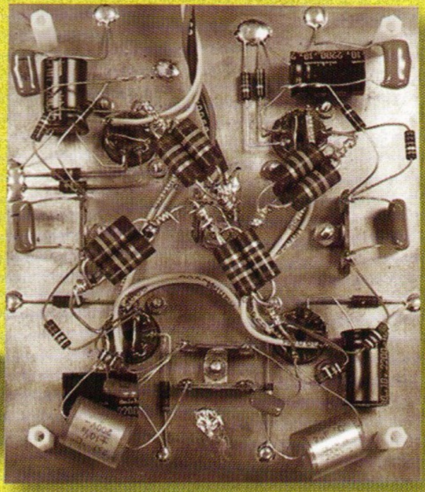

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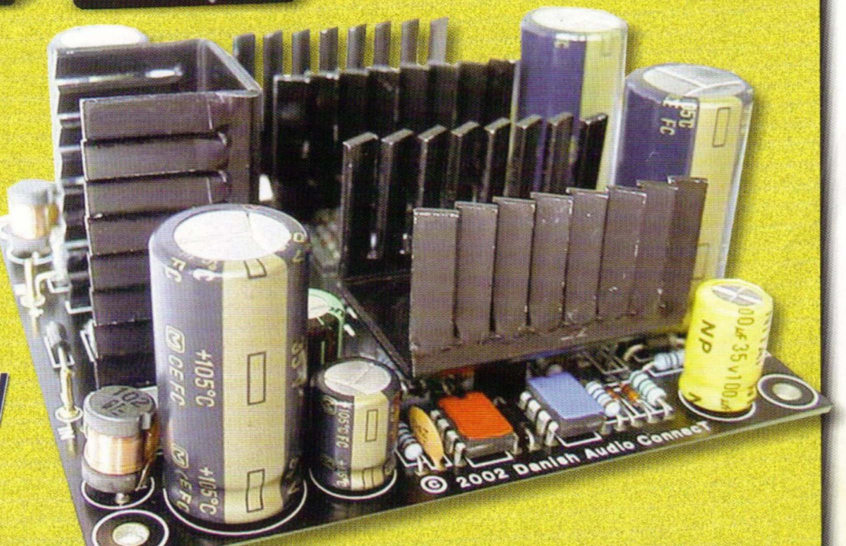


Borbely's RIAA Preamp With Tubes

This approach to RIAA equalization results in a high-quality phono preamp featuring the high-transconductance 5842 tubes. **By Joe Tritschler**

In 1985, the illustrious Erno Borbely published an article in *The Audio Amateur*[1] describing the design and construction of a high-quality audio preamplifier. His design included a unique approach to the RIAA-equalized phonograph disc stage.

Traditionally, the phono preamp has been implemented using an equalization network in the feedback loop of a high-gain, cascade feedback pair (CFP) amplifier. Citing poor equalization accuracy, dynamic range problems, and overall bad sound, Richard Marsh[2] and others developed passive solutions to RIAA equalization—usually a network sandwiched between two linear amplifier stages. In an attempt to utilize the best features of each approach, Borbely devised a half-passive/half-active scheme for implementing the RIAA equalization curve in a very low-noise, high-headroom phono preamplifier.

Being of the persuasion that insists on tubes for highest quality sound, I believed that a vacuum tube implementation of the Borbely RIAA architecture might make a superb-sounding phono stage. Thus, when I needed a new preamp for critical evaluation of other components in early 2001, I began work on the design in this article.

ABOUT THE AUTHOR

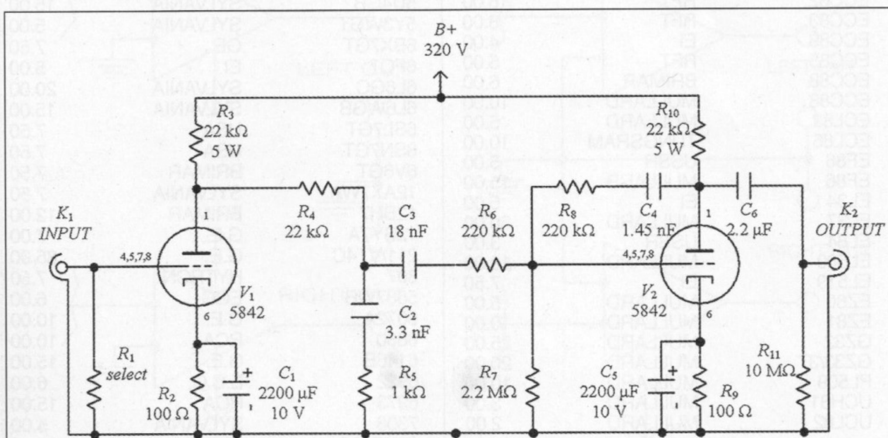
Joe Tritschler, 24, received his M.S.E. from Wright State University (Ohio) in June 2003 with a major in Electrical Engineering. He plans to begin work on his Ph.D. in the fall. When Joe's not busy conducting his latest hi-fi experiments, you'll find him working on his 1960 Cadillac Fleetwood, blasting his potato cannon near his parents' home in Enon, Ohio, and singing and playing guitar in his rockabilly trio, Crazy Joe and the Mad River Outlaws (www.madriveroutlaws.com).

BACKGROUND

For those unfamiliar with the playback requirements of phonograph records—specifically the long-playing microgroove record (LP)—perhaps a brief overview is in order. The process of cutting discs is not a trivial one. The modern feedback-coil cutting head operates as a "constant-velocity" device, in which the recorded signal produces a groove modulation with constant velocity with respect to frequency. This is in contrast to the "constant-amplitude" system, where the groove modulations exhibit constant amplitude with respect to frequency. In the constant-velocity system, groove amplitude is in inverse proportion to frequency when driven with a constant voltage.

The net result of this is a 6dB-per-octave rise in groove amplitude towards low frequencies. To ensure that record cutover (where groove amplitude is so large that the cutting stylus blasts through the groove wall) does not occur, the RIAA specifies that all discs cut in the US be equalized with a first-order attenuation of low frequencies below 500Hz, flattening at 50Hz. To improve signal-to-noise ratio, a high-frequency pre-emphasis is added with an initial time constant of 75µs (approximately 2.12kHz). The RIAA playback equalization curve is, therefore, the inverse of this characteristic, with a low-frequency boost starting at 500Hz and leveling off at 50Hz, and a high-frequency cut starting at 75µs.

Allen Wright has pointed out that there is obviously a limit as to how high in frequency the recording boost can prevail,[3] and this is generally accepted to be in the neighborhood of 50kHz. Therefore, in most modern phonograph preamplifiers, the high-frequency de-emphasis levels off above this point. It would seem that a first-order differentiator spanning the range of 20Hz to 20kHz during cutting would be much easier to implement and decode, and might sound better. Perhaps some more studied readers could enlighten



Notes:
1) All capacitors 400V unless otherwise stated.
2) All resistors ½ W unless otherwise stated.
3) 6.3 V to 5842 heaters (pins 3,9); regulated DC recommended.
4) Select R_1 for proper cartridge termination (see text).

Model TPA-103, © 2001
Tritschler Precision Audio

FIGURE 1: Preamp circuit.

G-2245-1

me about why the RIAA decided on two first-order transfer functions separated by only a couple of octaves.

Implementing the RIAA equalization characteristic in a low-noise disc playback amplifier has always been a formidable task, and the two principal approaches have been hotly debated. Borbely's solution is to use a wideband voltage amplifier direct-coupled to a passive low-pass filter for the 75µs rolloff, and then an amplifier with active shelving EQ for the 500Hz boost. Erno Borbely deserves kudos for his extremely original and effective solution. Please refer to his original article[1] for a detailed account of his design considerations.

THE DESIGN

My phono preamp (*Fig. 1*) begins with a common-cathode triode amplifier used as a linear voltage gain stage. I chose the 5842 for its outrageously high transconductance (g_m) of 25mA/V at the published nominal operating current (25mA). High transconductance is absolutely necessary for low noise, and is important when the signal source is good for only 3-4mV_{RMS} at 1kHz (typical output for a moving-magnet phonograph cartridge).

Quiescent plate voltage is set to approximately 100V with a plate current of 10mA. This lower current results in slightly lower g_m (20mA/V), but it is still much better than the typical low-g_m, high-µ twin-triodes such as the (miserable) 12AX7. Amplification factor (µ) at this operating point is 42, and dynamic plate resistance (r_p) is 2kΩ. Plate load resistor (R_L) is 22kΩ, selected to be more than ten times the plate resistance for excellent linearity and high gain. B+ is 320V, regulated.

I used a 100Ω cathode resistor to bias the tube to the required grid-to-cathode potential of −1V, and inserted a 2200µF

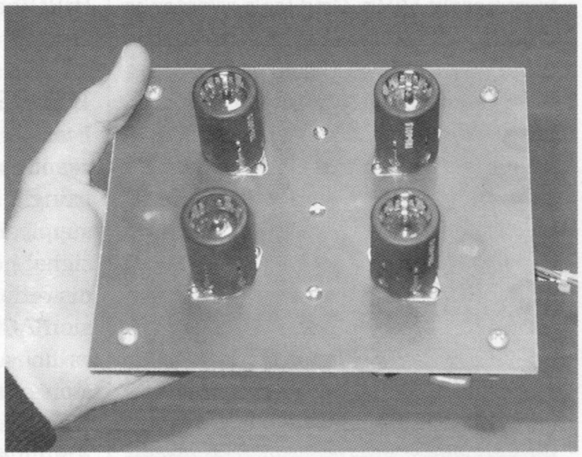


PHOTO 1: Prototype preamp.

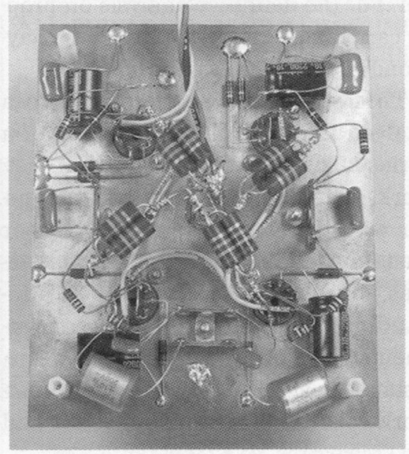


PHOTO 2: Underside of board.

bypass capacitor to maintain low effective plate resistance and encourage maximum gain. Input grid-leak resistor can be 47kΩ or whatever the cartridge manufacturer specifies for proper loading; the same applies to any capacitance added to the input. Just remember that amplifier input capacitance due to the Miller effect is already around 75pF, and be sure to include cable/tonearm capacitance, which is effectively in parallel with the input, when computing the necessary remainder. For the definitive analysis on proper cartridge termination, refer to Raymond A. Futrell's excellent article.[4]

This stage is direct-coupled to a shelved low-pass filter consisting of a series 22kΩ resistor and shunt RC network. Admittedly, a larger series resistor would have presented a lighter load for the first stage at high frequencies, but only at the expense of midband gain, and an effective high-frequency load of five times the plate resistance is still quite good. The RC network consists of a 3.3nF capacitor and 1kΩ resistor.

Assuming second-stage input loading of 220kΩ and bearing in mind that the effective series resistance includes the output resistance of the stage ($r_p \parallel R_L$), the turnover point is within 1% of 75µs with a shelf within about 3% of 50kHz. Midband gain is approximately 34.7, or 31dB, again assuming the aforementioned loading conditions, and including midband loss due to the 75µs filter.

Fans of the legendary Charles Boegli will immediately recognize the second amplifier stage, which is configured as an anode follower[5], or inverting voltage amplifier with shunt-derived/shunt-applied feedback. I chose shunt/shunt feedback for its profoundly better subjective sound quality over conventional series-applied feedback. Input series resistor is 220kΩ in accordance with previous assumptions, and this is in series with a decoupling capacitor to block the standing plate voltage from the first stage. The feedback resistor is also 220kΩ for approximately unity midband gain, and the boost below 500Hz is courtesy of a series 1.45nF capacitor, which can be selected from 1.5nF capacitors.

For the 50Hz shelving frequency, I encountered problems with insufficient open-loop gain; neither a shelving resistor across the feedback RC network nor tuning the input network to 50Hz gave adequate results because of this. After much agony and frustration (and a stern refusal to add more gain stages), I discovered empirically that a bit of "English" applied to the decoupling capacitor gives remarkably accurate conformation to the RIAA curve. The final value of 18nF gives a predicted shelf below 36Hz, but the actual turnover is very nearly 50Hz. Grid-leak resistor is 2.2MΩ, selected to be ten times the input and feedback resistances to minimize the possibility of interaction. Output capacitor is 2.2µF, and the entire phono stage will drive loads down to about 50kΩ without affecting gain or RIAA accuracy.

CONSTRUCTION

I built the prototype on a piece of copper-clad epoxy PC board material (*Photos 1* and *2*). The copper makes a very good ground plane, which is important for a low-hum preamplifier. The circuit is point-to-point wired using terminal strips, which I believe has far superior sound to PC wiring. Resistors are Allen-Bradley carbon composition with 5% tolerance, which I prefer over film types for their sound despite less-than-stellar noise performance (although if de-rated to approximately one-third their nominal power rating, noise and stability are dramatically improved).

Each plate load resistor is composed of three 68kΩ, 2W resistors in parallel to make a composite resistor within 3% of the specified value. The remaining resistors are all ½W types. Decoupling and equalization capacitors are metallized polypropylene Sprague "Orange Drops," which I use here because they are cheap, available in surplus, and pretty good in sound quality. The 2200µF cathode-bypass capacitors are Nichicon electrolytics. IERC heatsinks are used, which also serve to shield the tubes.

TESTING

I tested the preamplifier for frequency response and equalization accuracy using a Fluke 407DR laboratory power supply, Hewlett-Packard 33120A 15MHz signal generator, and Tektronix AA501 distortion analyzer used as a high-precision AC voltmeter (*Table 1*). Standard values are taken from a modified version of a computer program found in Morgan Jones' excellent volume, *Valve Amplifiers*.[6]

As you can see, the equalization is accurate within 0.4dB from 10Hz to 100kHz. Most of the variation occurs between 50 and 500Hz, probably because I made no concentrated effort to select parts. The 1.45nF capacitor previously mentioned is most likely the culprit, being directly responsible for the 500Hz turnover frequency. Gain at

TABLE 1
PREAMP RESPONSE

FREQUENCY (Hz)	STANDARD GAIN (dB) (REF. 1kHz = 0dB)	MEASURED GAIN (dB) (REF. 1kHz = 0dB)	ERROR (dB)
D.C. (0Hz)	+19.9	−∞	−∞
10	+19.7	+19.5	−0.2
20	+19.3	+19.7	+0.4
50.05	+16.9	+17.0	+0.1
70	+15.3	+15.1	−0.2
100	+13.1	+12.8	−0.3
200	+8.2	+7.9	−0.3
500.5	+2.6	+2.5	−0.1
700	+1.2	+1.2	0.0
1k	0	0	0.0
2k	−2.6	−2.6	0.0
2.122k	−2.9	−2.9	0.0
5k	−8.2	−8.3	−0.1
7k	−10.7	−10.8	−0.1
10k	−13.6	−13.7	−0.1
20k	−19.0	−18.9	−0.1
50k	−24.5	−24.4	+0.1
70k	−25.7	−25.7	0.0
100k	−26.6	−26.7	−0.1
200k	−27.3	−28.8	+1.5

1kHz is 30.8dB, resulting in only 140mV output from a 4mV cartridge, so a line stage will be required to drive most power amplifiers. This situation is similar to that encountered with tube-type FM tuners.

I then tested the preamplifier for sonic quality using a Lambda Model C-481M-505 regulated power supply, Thorens TD-125 turntable, Premier MMT tonearm, and Shure M97xE moving-magnet cartridge through home-brew tube power amps and speakers and a variety of (mostly jazz) LPs. While this is a simple setup by audiophile standards, the sonics can hardly be described as modest. The sound of this preamplifier is clean, natural, and balanced, without a trace of harshness or exaggerated "tube warmth." Detail is excellent without being obnoxiously analytical.

The Sheffield Labs direct-to-disc recording of Harry James, the King James Version, yields so much realism that the Chair of the EE department at Wright State University commented, "I've never heard recorded music sound like this before." Hum and noise are truly negligible. In fact, this preamp has been a fixture in my main hi-fi system for over two years, shattering the normal lifespan of a component by at least 18 months.

If and when time permits, I plan to construct a second stereo preamplifier using non-inductive wirewound precision resistors and oil-type Sprague Vitamin-Q capacitors. I strongly encourage any reader looking for a high-quality phonograph preamplifier to try this one.

TABLE 2
PARTS LIST

COMPONENT	DESCRIPTION
C1	CL
C2, C6	2200µF, 10V
C3	3N3
C4	18N
C5	1N45
C7	2µ2
K1, K2	RCA
R1	RL
R2, R9	82
R3, R10	22k, 5W
R4	22k
R5	1k
R6, R7	220k
R8	2M2
R11	10M
V1, V2	5842

For those not willing to use NOS 5842's, a kit version of this preamp using a paralleled 6922 in place of each is available from Tritschler Precision Audio (www.tritschlerprecisionaudio.com). If there is significant interest in the project, a PC board will be made available through Old Colony Sound Lab.

ACKNOWLEDGMENTS

Special thanks to the EE department at WSU for their encouragement and use of their test equipment. ❖

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