

The resurrection of tubes in audio amplifiers is a very interesting trend. Although I have been designing with semiconductors for the last 30 years, I started my career with tubes, and it has always been a fond memory. I must admit, though, that I never expected tubes would surface again as active elements in amplification, and when Ed Dell started *Glass Audio*, I thought it might survive a couple of years at most.

That must have been ten years ago, and tubes are now becoming more and more popular. Not that there is really a logic behind this: their advantages compared to semiconductors are few, and their disadvantages many. Selecting purely on a logical basis, nobody in his right mind would ever choose tubes now. But, then again, tubes are fun...

### The Line-Amp Topology

Much has been written about the "best" topology for audio use, and I will not argue with the proposals made. One circuit, the series-connected triodes, has been used in many audio circuits since its resurrection in Japan. With good linearity and a reasonably low output impedance, it has since found a popular following in *Glass Audio*, under the name of SRPP. I am using it myself in a number of designs, notably as the input stage in the 6C33C-B SE power amp.

A higher-gain version of this, called the mu-amplifier, is also found in a number of designs. Again, I am using one of these as the last stage of my phono preamp.

In selecting a line-amp topology, I look for linearity, overload capability, and the possibility of operating it in balanced mode. Naturally, it is an advantage to operate it open-loop, with the possibility of applying feedback when needed. One circuit that satisfies all these requirements is the differential amplifier. Well-known to most of us from phase splitters, it can produce the two high-level, out-of-phase signals needed to drive push-pull output stages.

Figure 1 shows the differential amp's basic configuration, which is very similar to one using transistors.<sup>1</sup> Seen from input 1, tube 1 operates in normal common-cathode mode, except that the cathode is connected to that of the second stage, operating it with cathode input. Seen from input 2, the same thing happens: tube 2 is in common-cathode mode, driving tube 1 in the cathode.

Assuming the two tubes are exactly equal, the sum of the two anode currents, which is equal to the current in

# DIFFERENTIAL LINE AMP WITH TUBES

BY ERNO BORBELY

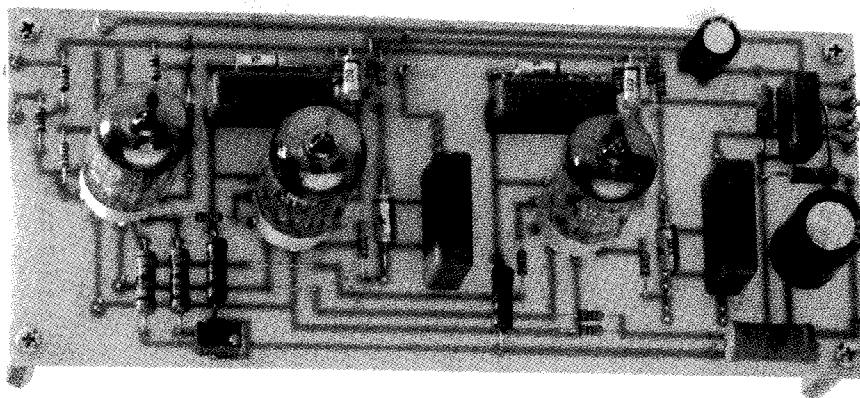


PHOTO 1: The differential line amplifier.

$R_k$ , is constant. If the two input voltages are either zero or equal and of the same polarity, the amplifier remains balanced; i.e., the anode currents and voltages both remain equal.

### Inverse Current Changes

When you drive the grid of tube V1A positive with respect to the grid of V1B (i.e., when you apply a differential voltage), the current through V1A will increase, with a corresponding decrease

of current in V1B. This occurs because of the constant current through  $R_k$ . With  $I_{a1}$  increasing and  $I_{a2}$  decreasing, the circuit develops a voltage differential between the anodes, with the V1B anode being more positive than that of V1A. In other words, the differential input voltage will produce a differential output voltage.

Naturally, you can also use the circuit with a single input signal and take the output signal from one anode, instead of

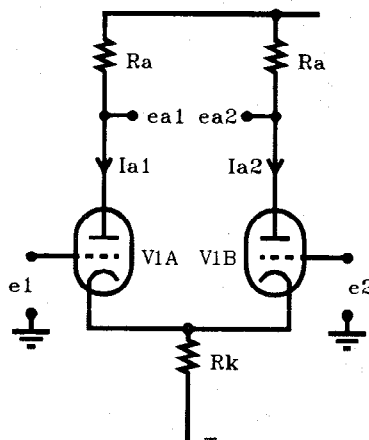


FIGURE 1: Differential amplifier.

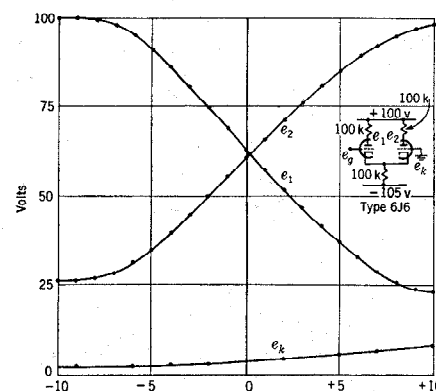


FIGURE 2: Example of differential amplifier and characteristic.

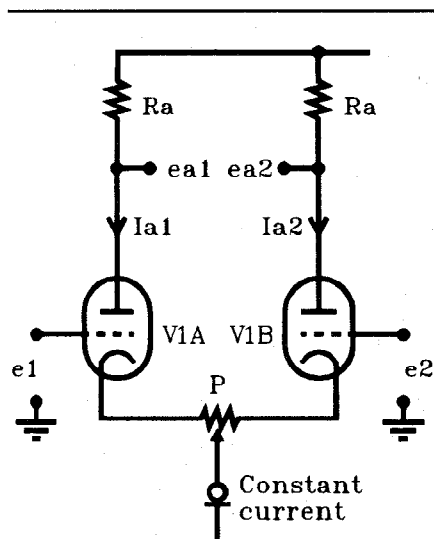


FIGURE 3: Differential amp with cathode adjustment.

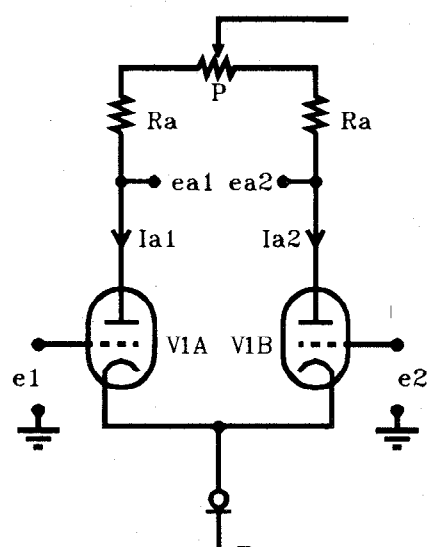


FIGURE 4: Differential amp with anode adjustment.

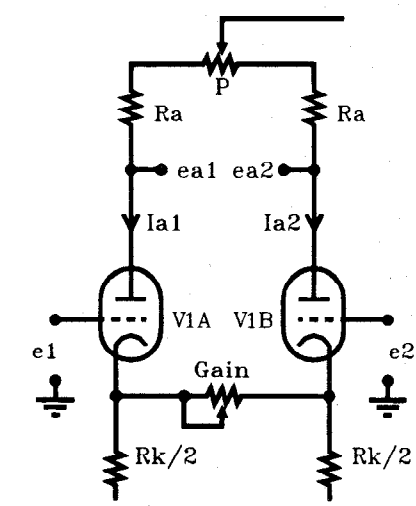


FIGURE 5: Differential amp with gain adjustment.

both. A typical transfer characteristic for a differential amplifier<sup>2</sup> is shown in Fig. 2. The two anode voltages are not quite symmetrical, but the level of matching between the tubes is not specified, so you don't know where the nonsymmetry is coming from.

Also, for proper operation, the current through  $R_k$  must really be constant. Using a resistor with a very high negative voltage (i.e., several 100V) approaches this, because a small variation of the supply voltage will have little effect on the current. A better approach is to use a constant-current generator, which has a very high output impedance and sources a current independent of the voltage across it. You can make up constant-current sources using tubes or transistors, or you can use one of the sources of current available on the market. I have chosen the last, because it gives me a simple solution.

### Rejecting Common-Mode Signals

One feature of the differential amplifier is its ability to reject common-mode signals. If you increase the input voltages simultaneously—that is, apply a common-mode signal—the cathode currents remain equal. Because their sum must equal the constant current,  $I_o$ , no change in either cathode current occurs. Consequently, there is no change in the anode voltages, thus giving the differential amp its ability to reject common-mode signals. In practical circuits, you can get approximately 40dB when you measure the common-mode signal single-endedly.

Now, what happens if the two tubes are not identical in  $\mu$  and  $r_p$ , and the current feeding the cathodes is not constant? The result is that the output voltage will not be zero at zero input voltage. You can correct this by installing a trimpot in the cathode circuit (Fig. 3). This will decrease the

gain somewhat, which is acceptable in most cases.

It is also possible to make the anode resistors variable, as indicated in Fig. 4. In either case, the adjustment will influence the rejection of common-mode signals and hence the balanced output. I recommend using matched triodes for this operation if possible. If gain adjustment is required, you can accomplish it with the circuit in Fig. 5.

The typical gain of one stage of a differential amplifier is 20–25dB. If you need more gain, you can connect two differential amplifiers in cascade. By operating the first stage from a lower supply voltage and the second stage from a higher one, you can DC-couple the two stages. The second can easily drive normal push-pull output stages, with feedback connected to input 2 of the first stage. Several such circuits have previously appeared in *Glass Audio*.

### The EB-894/211 Amplifier

The EB-894/211 is a high-quality balanced line amplifier and power-amp driver (Fig. 6), using one ECC83 tube as a differential amplifier and two ECC81s as low-impedance output stages. It operates without feedback. Table 1 is the parts list, and Fig. 7 shows the component layout.

Tube V1, the ECC83, is operated as a normal differential amplifier. Each half is operated at 1mA, which is defined by the constant-current diode D1, or D1/D2 in parallel. You can use a 2mA constant-current diode for D1, or two 1mA diodes for D1/D2. For proper biasing, D1 must be connected to a negative voltage, which can be derived from an independent 12.6V winding. A simple bridge with a capacitor and a 79L12 TO-92 regulator will work fine. If you have problems providing a –12V regulated supply, you can use a 9V battery; the current consumption is only 2mA, which allows several months of

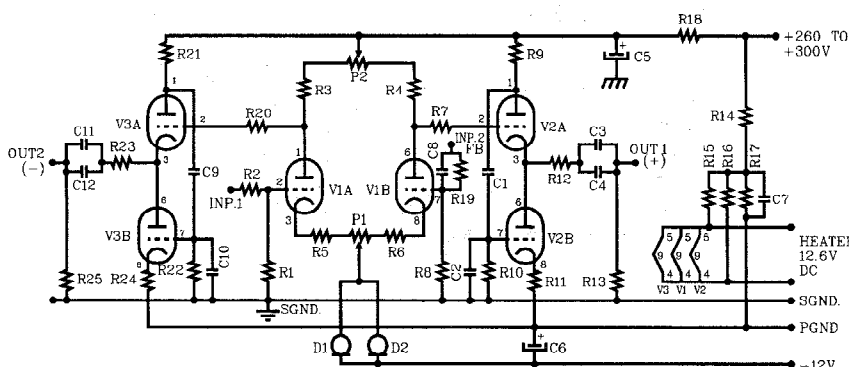


FIGURE 6: Balanced line amplifier.

operation (I have just changed the batteries in mine, after operating it more than one year).

I have provided both cathode and anode adjustment for the circuit. P1 and P2 balance the DC conditions and the gain in the differential amplifier. Resistors R5 and R6 (plus the trimpot P1) introduce local feedback, which reduces the gain. However, the feed-

back also improves linearity and large-signal handling. Used as a single-ended line amp, the amp has a gain of approximately 22dB. Balanced operation increases the gain by 6dB.

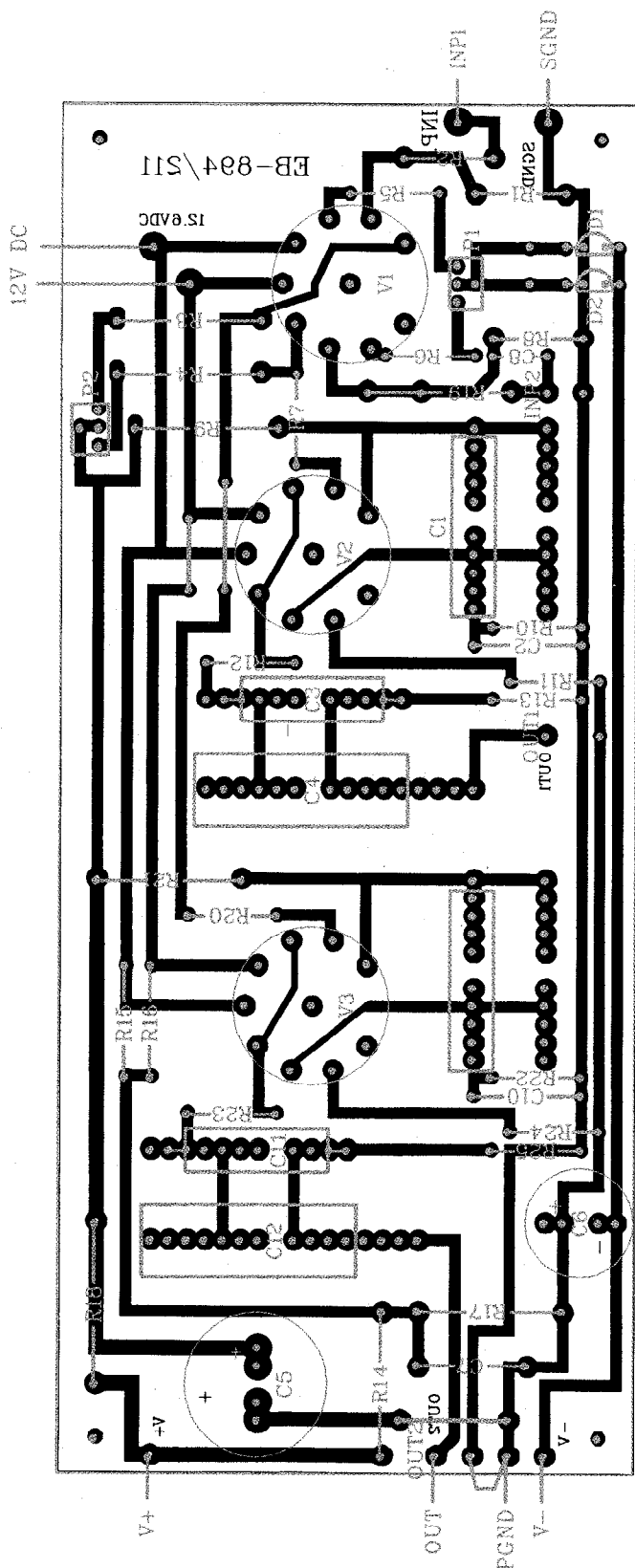


FIGURE 7: Component layout for balanced line amp, 2:1.

TABLE 1

PARTS LIST

RESISTORS	
R1, R10, R13, R22, R25	1M
R2, R7, R8, R20	100R
R3, R4	120k, 1.4W, metal oxide
R5, R6	2k21
R9, R21	10k, 1.4W, metal oxide
R11, R24	562R
R12, R23	47R5
R14	150k, 1.4W, metal oxide
R15, R16	470R, 1.1W, metal film
R17	100k, 1.4W, metal oxide
R18	1k, 2.3W, metal oxide
R19	100R, or optional feedback resistor
Resistors are ROE MK-2 0.5W, 1% metal film, unless otherwise noted. They can be replaced with 0.5W, 1% tantalum resistors, and the 1.4W metal-oxide resistors can be replaced with 1W, 1% tantalum resistors.	
TRIMPOTS	
P1	1k, 0.5W, Cermet, ROE CT-9W
P2	10k, 0.5W, Cermet, ROE CT-9W
CAPACITORS	
C1, C9	0.22µF, 400V, WIMA MKP-10
C3, C11	0.01µF, 630V, Siemens PP
C4, C12	1µF, 250V, WIMA MKP-10
C5	10µF, 450V, Rubycon
C6	220µF, 25V, ROE/FROLYT EKR
C7	0.1µF, 400V, WIMA MKP-10
C8	Feedback cap., optional
C2, C10	220pF, 630V, Siemens PP
TUBES	
V1	ECC83, Tungstram
V2, V3	ECC81, Siemens
MISCELLANEOUS	
D1, D2	J505 or E-102, 1mA current diode, or CR200, 2mA current diode
16 1mm solder pins	
PCB	EB-894/211
6 9-pin noval PCB socket (ceramic, gold-plated)	

TABLE 2

TYPICAL SPECIFICATIONS

(Measurements were done with a regulated power supply of 260V.)	
Frequency response	10Hz-120kHz
Gain	22dB
THD at 1kHz	3V: 0.04%
	10V: 0.14%
	20V: 0.45%
	30V: 1.25%
	40V: saturation
Rise time	0-50V peak: <2µs
Output impedance	approx. 100Ω
Recommended min. load	20k (if load is <100k, increase C1, C9 to a minimum of 1µF/250V)
PCB	80 × 190mm

Tube V1 can also operate at a lower current. If you use a 1mA-current diode for D1, each half operates at 0.5mA. Then you need to change resistors R3 and R4 to establish the same DC conditions as before. Total gain goes up to approximately 25dB, but linearity improves as well, especially at higher signal levels.

If you use the driver with a single input, you should connect the input signal to INP1 and ground INP2. If the overall gain of the power amp is too high, you might want to use some of

the excess for negative feedback. The feedback must be connected to INP2. If you have a balanced input signal, connect it to both inputs.

### Varying Tube Quality

I have tried a number of ECC83s from different manufacturers, and they do not all perform equally well. I developed the circuit around the Tungstam ECC83, but you could use others instead. The Telefunken and the Ultratron were particularly good. I recommend matching the two triodes, but the circuit

works all right with unmatched ones.

The output impedance of the differential amp is very high (close to the value of the anode resistors), and you can't load it very much without loss of gain and increased distortion. I therefore configured V2 and V3 as White cathode followers (WCF),<sup>3</sup> which offer unity gain, wide bandwidth, and low output impedance. They also have good linearity and add little of their own to the amp's total distortion.

I have DC-coupled the WCFs to the differential amp and am operating them at approximately 2.9mA. V2 and V3 should be ECC81s or the equivalent. Due to the low output impedance and the drive capability of the WCFs, you can drive just about any power amp with the EB-894/211, including semiconductor power amps.

Note that whenever I use a coupling capacitor, I do so with two capacitors in parallel. Although all my coupling capacitors are polypropylene, I use a smaller one in parallel with the larger. This appears to improve the midrange and high-frequency sound. The layout accommodates the use of two capacitors. Feel free to experiment with different ones to get the best sound from your amplifier.

The filaments of the tubes are heated by DC and biased off ground with the voltage divider R14-R17 to protect the tubes from breakdown and to reduce hum. If this is already done at the filament regulators, then leave out the components associated with it.

### Specifications

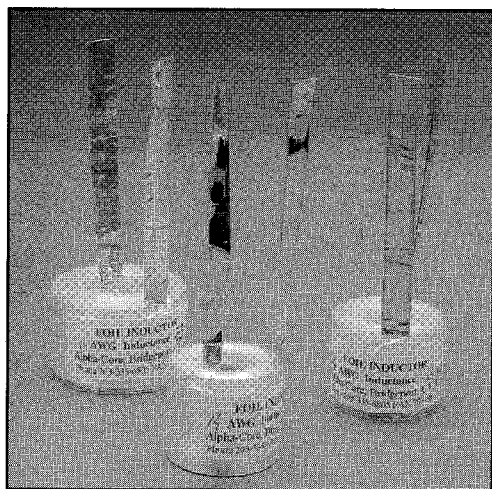
I know it is not very popular to quote tube-gear specs, for the reason that "only the sound counts." Although I don't disagree with the "sound" part, I

Borbely Audio also offers a simplified version of this amp, the EB-1193/201, with single-ended output. Both kits include drilled FR-4 circuit boards, all resistors, capacitors and mechanical components that go on the board. A tantalum resistor upgrade kit is also available. Regulated filament and anode supplies are also part of the offering. Mains transformers for 115/230V/ 50-60Hz are available on request.

Borbely Audio reserves the right to improve or otherwise alter any specification supplied in this documentation or in any other supplied hereafter.

The EB-894/211 and the EB-1193/ 201 designs are the property of Erno Borbely/Borbely Audio. Commercial use is not authorized without a license agreement with Erno Borbely/Borbely Audio.

## Don't believe us . . . listen to your speakers! WHAT AN UPGRADE!



**Alpha-Core  
Inductors  
deliver  
the latest  
and very best  
in crossover  
technology**

*Alpha-Core's foil-wound inductors will do what others can't:*

Deliver leading edge technology  
for audio transducer and speaker crossover networks.  
Available in 12 and 14 gauge.

**No magnetic cores — eliminates saturation distortion  
BUT THERE'S MORE!**

Made with high purity copper and solid fine silver,  
inductors are constant-tension wound onto a Lexan polycarbonate tube  
with a polypropylene dielectric; mounting face is vacuum fused.

Core inductors provide consistent values, maximum stability.

**PLAY AFTER PLAY — YEAR AFTER YEAR**

With no minimums, you may choose from standard inductor values  
or have them custom-made to your specifications.

*It's that easy to upgrade!*



**Alpha-Core, Inc.**

915 Pembroke Street, Bridgeport, CT 06608

Tel: (800) 836-5920 — Fax: (203) 384-8120

Visit us on the Web: <http://www.alphacore.com> E-mail: [alpha@snet.net](mailto:alpha@snet.net)

see no reason not to follow perfectly normal engineering practices. In any case, I use measurement methods when developing the amplifiers, and I have the data available in my notebooks, so I include it (Table 2).

You can use higher supply voltage when you need higher output voltage, for example, when driving output stages. I have tried the circuit from 360V, which further improves linearity and large-signal handling. Be careful with the power dissipation, though, for the WCFs run quite hot.

### Setup Procedure

If possible, test each amplifier module separately before installing it in the box. This simplifies measurements, adjustments, and, if necessary, component changes. If you have access to a scope, connect it to the output of the module and check to see whether radio frequency (RF) oscillations are present. If you have complete audio instrumentation in your workshop, perform the usual gain, frequency-response, noise, total-harmonic-distortion (THD), and intermodulation-distortion (IM) measurements. Inputs should be shorted to ground under DC measurements and adjustments.

Short the input to ground, and short the signal ground to power ground at the output. Connect a +260V regulated anode supply and a 12.6V DC-filament supply to the board. Check the anode voltages on tube V1; pin 1 and pin 6 should be approximately +125V. Anode 1 of tubes V2A and V3A is about +225V; the cathode of V2B and V3B, pin 8, is at +1.65V. The DC voltage at the output (pins 3 and 6 of V2/V3) is around +138V.

The DC adjustment of the circuit is simple. Connect a high-impedance DC voltmeter alternately to the two anodes and adjust P1 until the anode voltages of V1 are equal. Remove the short from the input of the module and connect an audio oscillator to the input.

If you have a dual-channel oscilloscope, connect the two inputs to the two outputs, OUT1 and OUT2. Connect the scope to "ADD" and observe the added signals, which indicate the difference between the two outputs. Adjust P2 until the added signal is a flat line, or as close to it as you can get. This indicates that the two outputs have the same amplitude, i.e., the gain is the same. (Incidentally, this will also indicate distortion at higher levels by showing "bumps" on the flat line.)

If you have no dual-channel scope,

you can do this adjustment with an audio millivoltmeter. Connect the meter alternately to OUT1 and OUT2, and adjust P2 until the two outputs have the same amplitude. You should repeat this adjustment when you install the board in the power amplifier so as to compensate for the slight difference in the two halves of the output stage.

Connect a distortion analyzer to the outputs one at a time, and check the distortion at different output levels. If you have good balance between the two triodes of the ECC83, the distortion

will be low. You might want to experiment with different tubes to get the best distortion figures and best sound from the circuit. ♦

### REFERENCES

1. Erno Borbely, "New Devices for Audio from National Semiconductor," *TAA* 5/83, p. 7.
2. Valley & Wallman, *Vacuum Tube Amplifiers*, McGraw-Hill, 1948.
3. J.B. Earnshaw, "Stacked Valve Circuits," *Electronic & Radio Engineer*, November 1957.

## Over 2,000 Tube Types for All Applications

RECEIVING • SPECIAL PURPOSE • POWER • INDUSTRIAL • ANTIQUE

★ Highest Quality from the World's Most Popular Manufacturers ★

TYPE	EACH	TYPE	EACH	TYPE	EACH	TYPE	EACH
3A3C	4.50	6EJ7	2.90	12AZ7A	3.75	811A	12.00
5AR4	7.25	6GH8A	2.00	12BA6	3.00	812A	23.00
5R4GY	8.40	6GJ7	3.54	12BE6	3.40	813	33.00
5U4G	5.75	6HA5	3.25	12BH7A	10.80	2050/2050A	21.00
5Y3GT	4.25	6J5	5.10	15CW5	3.25	5749/6BA6W	2.60
6AJ8	4.75	6J7	6.75	17J28	6.00	5814A	3.50
6AL5	2.00	6JZ8	11.70	30AE3	5.50	5881	6.00
6AQ5	6.00	6K7	3.25	33GY7A	8.95	5965	4.00
6AU6	3.75	6SA7	2.20	35W4	3.25	6146A/B	14.25
6AX5GT	4.50	6SG7	3.95	38HE7	7.00	6350	3.00
6BA6	3.00	6SJ7	6.00	50C5	2.95	6463	2.95
6BE6	2.90	6SK7	6.50	6267	6.75		
6BH6	5.00	6SN7GTB	4.50	6973	28.00		
6BL8	3.00	6SQ7	5.00	7025A	4.50		
6CA4	4.00	6U8A	3.25	7189A	7.70		
6CA7	7.00	6X4	4.48	7581A	23.00		
6CG3	6.00	6X5GT	3.20	KT88	14.00		
6CX8	4.00	6X8	3.50	2D21/EN91	4.50		
6CW5	3.50	12AT7	4.00	85A2/0G3	2.50		
6DL5	4.25	12AU6	2.80	108C1/0B2	3.00		
6DQ6B	5.75	12AU7	4.00	150C4/0A2	3.00		
6DR7	4.00	12AV6	3.00	572B	45.00		
6DX8	3.75	12AV7	3.50	805	30.75		
6EA8	3.00	12AX7A	4.00	807	9.00		
6EH7	2.90	12AY7	6.50	810	80.00		

### VOLUME DISCOUNTS

Solid State  
Replacements  
as low as \$4.00

Write or call for  
complete tube  
range, price list  
and accessories  
catalog.

Price and availability subject to change without notice.



**International** ©



**International Components Corporation**

107 Maxess Rd., Melville, NY 11747 • N.Y. State 516-293-1500 • FAX 516-293-4983

Call TOLL FREE **800-645-9154**

**www.icc107.com**



Reader Service #31