Stereo Hi-Fi Tube Amp:
Remake of the Dynaco ST-70

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Physics 398 EMI

I. Introduction

Being an audiophile, most of my previous projects have involved using audio in some form or another. Thus the idea of building an amplifier for this class came as a natural choice for me. In fact, I have always wanted to build one. Specifically, building a tube-amp intrigued me, as I have always preferred the warm, rich sound of tubes compared to solid-state devices. The next step was to decide what type of tube amplifier I wanted to build.

My goal was to build a simple tube amp, which would allow me to understand the concepts of amplifier design. I could then use this knowledge to build future amps which would become progressively more complex. Also, I wanted to build something that would be useful to me. Being a drummer, I had no need to build a guitar amp. I first decided to build a headphone amp. Since only minimal amplification was required, I determined that only one gain stage was really needed, and thus the circuitry would be simple. Upon looking at various circuits I could implement, it became clear that by adding only a little more circuitry, I could build a much more powerful amp. I finally decided to build a stereo hi-fi amp that could drive low impedance speakers. Again, not much gain is needed, since the amp would take line-level voltages as an input. The amp would be fairly simple to implement, and also be useful as I could use it to drive my stereo system at home.

Next I began to look for the proper circuit to implement. Originally I thought of taking a guitar amp circuit and converting it for high fidelity operation. However, after looking through the web, I found plenty of schematics of high fidelity amps that had fairly simple circuits. One amp in particular that had a wealth of information on the web was the Dynaco ST-70. This amp was originally made in 1959, and over 300,000 units were produced. The original schematic and pictures are shown in Appendix A. I found that this amp is a favorite of audiophiles because of its simple yet efficient circuit design. The ST-70 is still readily sold on auction sites such as eBay and a host of mod kits are available for it. Taking into account its popularity and availability, I decided to reproduce this amp in all its glory.

II. Construction of the Amp

A. Parts

The first step in making the amp was to obtain the parts. Since this amp was popular on eBay, I decided to look there first and see if I could buy a broken down ST-70 and then restore it. However, because of the popularity of this amp, I was not able to win any auctions because the prices became unreasonable. I decided that it would be easier just to buy all the parts separately and assemble them all together. I was able to buy brand new direct drop-in replacement transformers (two output transformers, one power transformer) for the ST-70 off a seller using eBay. These transformers can be found at the following web site: http://www.handwoundtransformers.com/dyna.html.

One important decision to make was to choose what type of driver circuitry I wanted. I was not inclined to use the original ST-70 design, as it required a circuit using two 7199's as driver tubes, which are currently hard to find. As noted before, there are many mod boards available for this amp, which use tubes that are more readily available. I found one particularly useful website for deciding on what circuitry to use, located at http://www.netaxs.com/~vkalia/st70.html. From this site and others, I decided that my best option was to go with the Triode Electronics Board, because it was similar to the original ST-70 circuitry, and it had gotten really good reviews from everyone who had used it. This board used two EF86's, and one 12AU7, all of which are currently in production. Using this board also helped me save time: I did not have to wire up all the circuitry because most of it was already laid out on a PCB (I did have to solder all the parts on the board, however).

After looking at the Triode Electronics site, located at http://store.yahoo.com/triodeel/, I found that I could also buy a power supply board with parts. Again this was mainly done because of time consideration, as I knew there was a lot of work to be done to build an amp from scratch. After researching, I found that the new power supply board was actually a much better design than the original circuitry that Dynaco used for the ST-70. It also allowed for use of either solid-state rectification or tube rectification. The power supply required the original ST-70 choke. I found a direct replacement for this choke at Welborne Labs, located at http://www.welbornelabs.com/.

I had most of the major parts now, except the tubes. I bought a brand new matched quad of JJ-Tesla EL34's on eBay, and I bought the EF86's, along with sockets, from Triode Electronics. I found a spare 12AU7 in the physics lab. The GZ34 rectifier tube was not needed, as I initially decided to use solid-state rectification. All other parts were found in the physics lab (or from Steve), or purchased in the ECE store. An analysis of costs is shown in Appendix B. The total amp cost came out to about $379. However, if I had not bought the driver board and power supply board, and instead wired everything myself, the cost would have come to $299.

B. Layout / Assembly

The next step was to layout and assemble all the parts on the chassis. The original Dynaco chassis was 9.5" x 13" wide, and 6.5" tall. The chassis I used was bigger than all these dimensions, so there were no spacing problems with laying out all the parts. I followed the layout of the original ST-70 for the most part: the EL34's along with driver board were in the front, while the two output transformers and the power transformers were in the back.

Five sockets (4 for the EL34's, 1 for the optional GZ34) were punched out using the 1 1/8" chassis punch. The driver board required a big rectangular hole underneath it, this was accomplished by Steve using his jigsaw. Holes were also punched out or drilled for the RCA jacks, transformer screws, speaker terminals, power switch, power cord, bias pots, choke, and fuse holder. The hardest part was punching out a big square hole for the power transformer. Ben Juday helped me out by using his plasma cutter to carefully cut out a square hole that would properly seat my transformer. Special care had to be taken not to cut the transformer wires while inserting the transformer into the hole.

Overall this step took the longest time, as it took a while to figure out exactly where each hole had to be cut out. Figures 1 and 2 show my amp and its layout. There were no major problems throughout this step and the layout turned out looking really nice, as shown by the figures.

Figure 1 – Front of Amp

Figure 2 – Back of Amp

C. Wiring

After laying out all the parts on the chassis, it was finally time to wire everything together. The proper layout of the wiring is critical in order to eliminate hum and other noise. Again I used pictures of the bottom of ST-70's on eBay (one is shown in Appendix A) as my guide for laying out the wires. One figure I found particularly useful for this was found in Curcio Audio Engineering's ST-70 Driver board instructions, located at http://www.curcioaudio.com/ST7-DVR-DOC.pdf. Figure 3 is shown below. This figure was most hopeful in figuring out where wires from transformers went and also how unused pins of the sockets were utilized. All heater (filament) wires were twisted to cancel out 60 cycle hum. Shielded coax cable was used from the input to the driver board to reduce any noise. The specifics of the wiring relating to the Triode Electronics Board is detailed in the next section. Figure 4 shows the actual wiring of my amp.

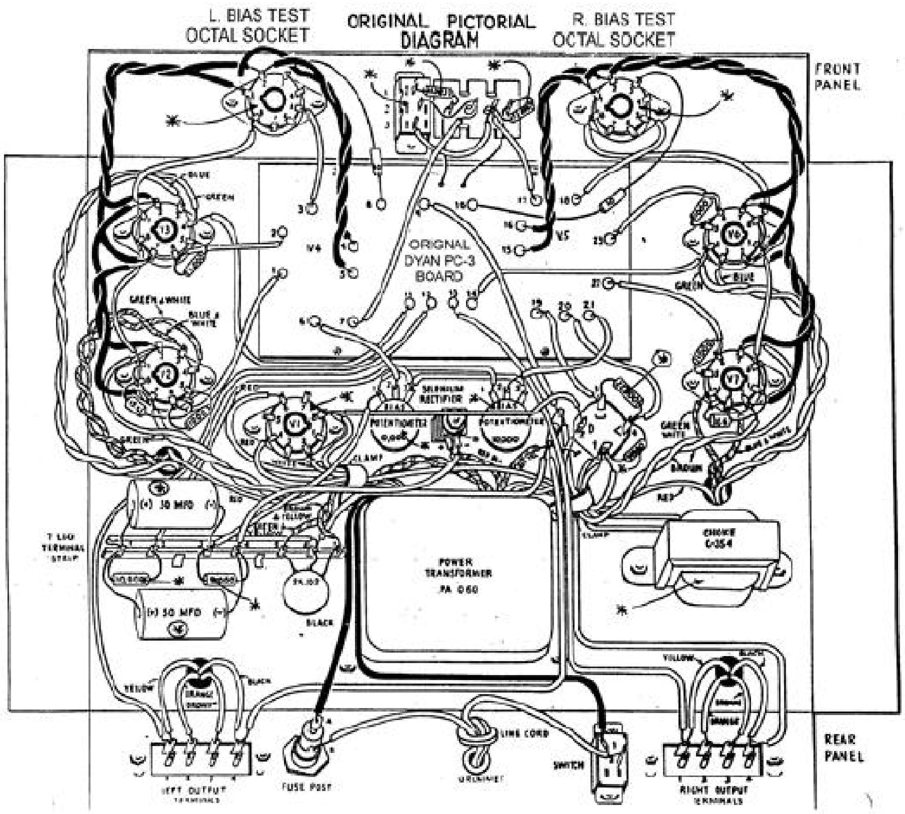


Figure 3 – Drawn Layout of the ST-70 Amp

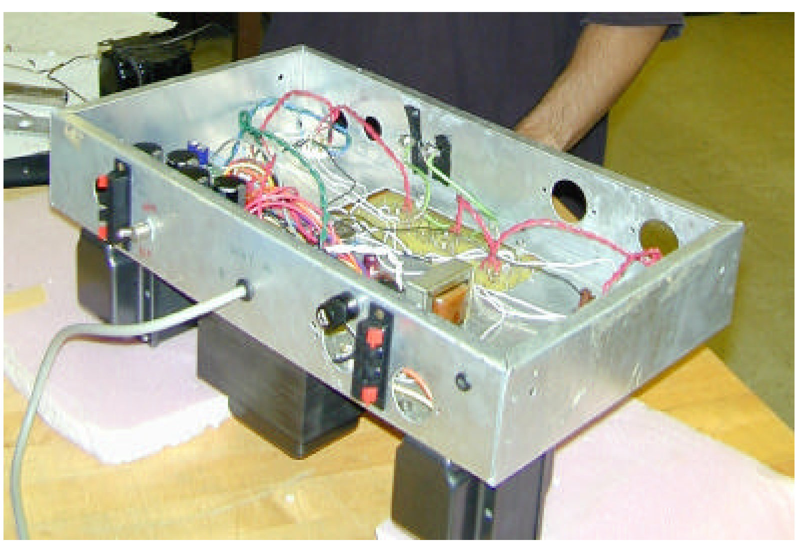


Figure 4 – Actual Layout

III. Analysis of the ST-70 / Triode Electronics Driver Board

Appendix C shows the schematic of the Triode Driver board. The schematic essentially the same as the original ST-70 driver board (shown in Appendix A), only with slight modifications to accommodate the EF86 driver tubes and the 12AU7 phase splitter. From the research I've done, most people noted that this board produces less noise and distortion than the original, while having a better overall frequency response.

Looking closer at the schematic, the circuit begins with the audio input from the RCA jack. The signal then goes into the first gain stage by being sent to the grid (pin 9) of the EF86 driver tubes. The EF86's are pentodes, which allow for high frequency operation and a high gain (actual values will be discussed in the next section). After this stage, the signal is outputted into the 12AU7 (pin 2 and pin 7). This stage is configured in a Cathodyne phase splitter configuration. This part of the circuit acts to invert the phase of the signal coming out of pin 3 (pin 8) 180 degrees with respect to the signal coming out of pin1 (pin 6), which will later be used for the push-pull operation of the output transformers. Before this happens, these two signals are then sent to the grid of the EL34 output tubes (again pentodes), where it is further amplified before being sent to the transformers. The output transformers convert the amplified signals into values that the speakers can handle (actual values discussed in next section).

There are a few modifications I made to the circuit shown in Appendix C. I removed the mono switch that connects both 470K resistors, as I found no need for this. All spots marked with a square for "preamp power takeoff points" have been removed. Thus, points 3, 8, 10, and 18 have no connections, and also resistors R12 and R112 have been removed from the board. Finally, the 15.6 ohm bias resistors were replaced with 10 ohm resistors.

IV. Results

Before laying out the transformers on the chassis, I took measurements of their characteristics. The measurements are shown in Appendix D. For the output transformers, both measurements of voltages and inductances were taken. From the inductance charts (Tables 1 and 3), we can see that there was very low short circuit inductance. This means that there is not much leakage in the transformers, thus indicating their high quality. Doing some math we can derive the following equation: Zpri / Zsec = Loc(Pri) / Loc(Sec) = (Npri / Nsec)^2. Thus I calculated the turns ratio for 1Khz values for the 4 ohm, 8 ohm, and 16 ohm outputs. I also calculated the turns ratio using the voltages I recorded in Table 2 using the equation Vpri / Vsec = Npri / Nsec. These values and their comparison is shown below:

Ratio of Turns Npri / Nsec	Right Trans/ Inductance	Right Trans/ Voltage	Left Trans/ Inductance	Left Trans/ Voltage
4 Ohms	30.6	30.3	30.3	30.3
8 Ohms	22.9	22.2	21.3	22.0
16 Ohms	14.5	15.6	15.3	15.6

Thus we can see that the two methods of measurement agree fairly well and the left and right transformers are pretty well matched. The choke and the power transformer were also measured, as shown Tables 4 and 5, respectively. Both measured out close to their ratings.

Now that the transformers checked out, I was ready to test out my power supply circuit. Testing was done after soldering all the components and wiring the power transformer leads and choke leads to the board. There were no tubes attaches and thus no load. The amp turned on without any problems, which was a relief. The B+ voltage measured at 514V and the bias voltages measured at –47.8V and –32.8V, which were all close to the expected values given in the Triode information sheets. Next I wired up everything else in the amp. After inspecting the circuit, Steve fixed some cold solder joints, and then we powered it on. At first try, the power tubes were glowing, but one of the driver tubes and the 12AU7 were not glowing. Upon further inspection, Steve found that one of the filament voltage wires had a cold solder joint, and after fixing this, all tubes were glowing. We then hooked up some speakers to the output and then set the bias voltage. The Dynaco specs called for 100mA of current through each pair of EL34's, so 50mA through each EL34. So we set the bias point voltage to 1.00V, which with a bias resistor of 10 ohms came out to 100mA. Then we hooked up a CD-player to the input, and listened for audio. To my surprise, the amp was working perfectly; there was absolutely no hum and the sound coming out was perfectly clean! We also recorded some voltages, listed here:

Voltages	Left (side)	Right (side)
Bias grids	-39.7V	-38.5V
Plate	464V	463V
Screen	466V	466V

Although everything sounded good, the power tubes seemed to be running to hot, so Steve recommended that we lower the current so the EL34's would last longer. We then set the bias point for half of what we had before, 25mA through each EL34. This made the EL34's run a little cooler, and the amp still sounded great. We took further measurements of voltages, listed here:

Voltages	Left (side)	Right (side)
Bias grids	-45.2V	-45.2V
Plate	483V	482V
Screen	484V	483V

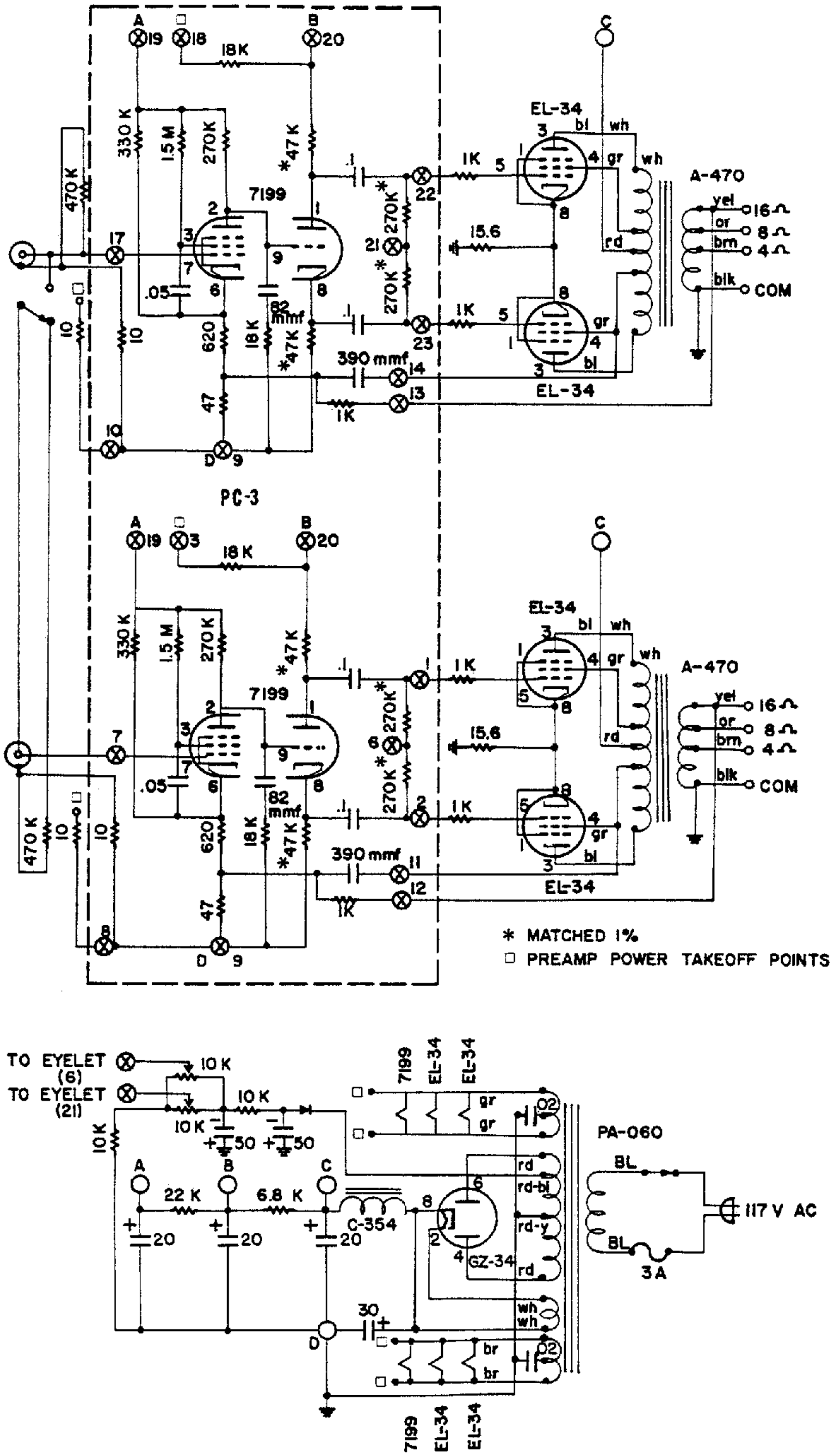
We also measured the voltages at various stages of the op-amp, in order to determine what type of gain the amp was producing at these stages. Table 6 shows the results of these measurements From this, we can calculate the gain at each stage, by dividing by the input voltage of 50mV. The converted gain is found by multiplying the original gain by the turns ratio for the 4ohm load (30.3). This will give us the gain on the other side of the transformer. We can see that the amp has a very nice frequency response, as it has a fairly consistent gain throughout the range of frequencies that we measured. The gain through the first stage (after EF86) is approximately 13.5, while the final gain (after EF86 and EL34) is approximately 200. Dividing these two numbers out, we find that the gain of the EL34's alone is approximately 14.8. The phase inverter stage was not included in the measurements as it should have unity gain.

V. Conclusion

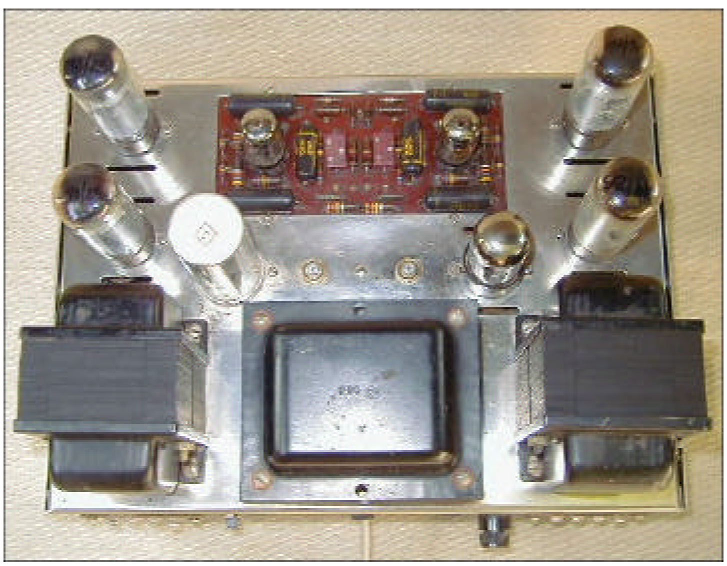
Overall, this was a very satisfying project. I built the amplifier from scratch, and in the end, it came out sounding perfect. I now have an amp that I can use, maintain, and cherish for a long time. I fully intend to build around this amp by adding a pre-amp circuit for it, and also some efficient speakers. Thus my goal is to have a stereo system totally built from scratch. Another goal I have is to start building my own amps using my own designs. Hopefully this project will serve as the building block for many future amps to come.

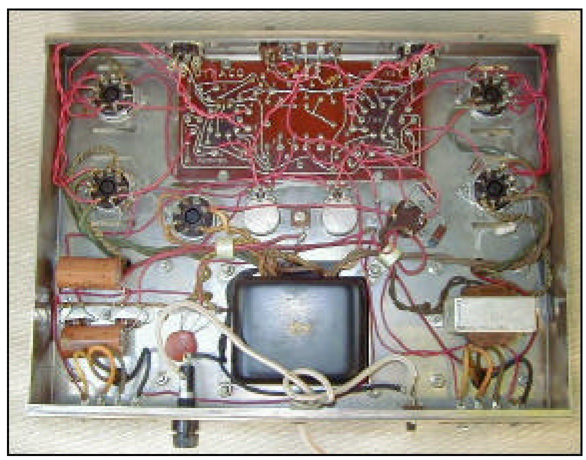
Finally, I would like to give thanks to Ben Juday for helping me with cutting holes in my chassis, and extra special thanks to Steve for helping me with everything. I've definitely learned more from this Physics 398 class than any other class. Steve's knowledge of guitars, amps, and everything related is incredible, and his enthusiasm for teaching everything he knows makes the class enjoyable and informative at the same time. Again, thanks for everything.

Appendix A – Original ST-70 Schematic, Pictures




BIASET
1.56V
PREAMP POWER
MONO
STEREO
LEFT RIGHT
INPUT
RIGHT
BIASET
1.56V
PREAMP POWER
DYNAKIT STEREO 70
DYNA COMPANY
PHILA. PA.
MADE IN U.S.A.
CIRCUITRY PATENTED

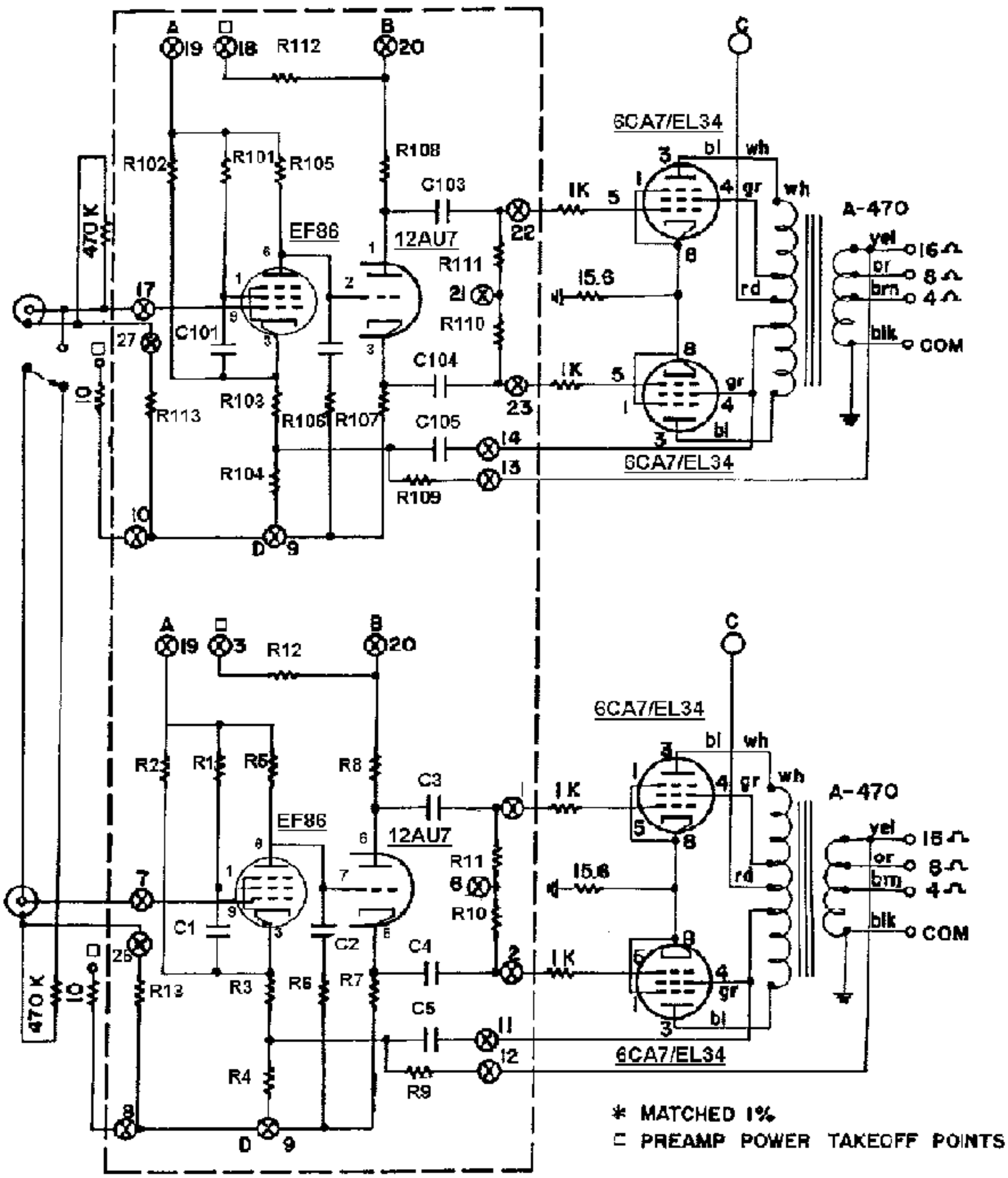




Appendix B – Total Costs (not including Tax, Shipping charges)

Item	Cost
2 Output Transformers	$100
1 Power Tranformers	$50
4 EL34 Tubes	$45
2 EF86 Tubes	$26
1 12AU7 Tube	Free
Triode Electronics Driver Board w/ Parts	$75
SDS Labs Capacitor Board (Power Supply Board) w/ Parts	$50
4 Gold Octal Sockets	$12
C354 Choke	$15
2 10K Pots	$4
2 RCA Input Terminals	$2
Line Cord, Fuse Post, Fuse, Switch, Wire, 1 Octal Socket	Free
Steve's Help	Priceless!
Total Cost	**$379**
Total Cost w/o Boards	**$299**

Appendix C – Triode Electronics Driver Board Schematic



Appendix D

Primary Inductances / Resistances (RIGHT Output Tranfsormer)									
Loc	**120 Hz**	**1 kHz**	**10 kHz**			**Doc**	**120 Hz**	**1 kHz**	**10 kHz**
red-blue	5.12	6.65	-			red-blue	.056	.195	-
red-white	5.13	6.44	-			red-white	.049	.184	-
blue-white	54.0	24.5	-			blue-white	.357	.152	-
Lsc	**120 Hz**	**1 kHz**	**10 kHz**			**Dsc**	**120 Hz**	**1 kHz**	**10 kHz**
red-blue	20.1m	19.0m	15.01m			red-blue	16.5	1.46	.315
red-white	19.8m	19.0m	17.9m			red-white	9.13	1.19	.200
blue-white	35.5m	33.0m	34.6m			blue-white	14.1	1.88	.255
Secondary Inductances / Resistances (RIGHT Output Tranfsormer)									
Loc	**120 Hz**	**1 kHz**	**10 kHz**			**Doc**	**120 Hz**	**1 kHz**	**10 kHz**
4 ohms	69.8m	26.1m	-			4 ohms	.454	.149	-
8 ohms	189m	46.6m	-			8 ohms	.510	.141	-
16 ohms	-	116m	-			16 ohms	-	.185	-
Lsc	**120 Hz**	**1 kHz**	**10 kHz**			**Dsc**	**120 Hz**	**1 kHz**	**10 kHz**
4 ohms	55u	48.9u	46.5u			4 ohms	-	1.93	.295
8 ohms	85u	77.7u	74.1u			8 ohms	14.1	1.88	.293
16 ohms	156u	133.5u	126.1u			16 ohms	14.0	1.87	.295

Table 1

Voltages	Right	Left
Blue/White (Plate to Plate)	1.000V	1.001V
Grey/Green (Screen)	.432V	.433V
Black/Yellow (16 ohm)	64.0mV	64.0mV
Black/Orange (8 ohm)	45.0mV	45.5mV
Black/Brown (4 ohm)	32.0mV	33.0mV

Table 2 above

Table 3 below

Primary Inductances / Resistances (LEFT Output Tranfsormer)									
Loc	**120 Hz**	**1 kHz**	**10 kHz**			**Doc**	**120 Hz**	**1 kHz**	**10 kHz**
red-blue	5.40	7.69	-			red-blue	.056	.206	-
red-white	5.36	7.40	-			red-white	.045	.210	-
blue-white	56.0	27.7	-			blue-white	.329	.162	-
Lsc	**120 Hz**	**1 kHz**	**10 kHz**			**Dsc**	**120 Hz**	**1 kHz**	**10 kHz**
red-blue	22.2m	20.3m	15.5m			red-blue	9.83	1.39	.321
red-white	20.8m	20.1m	20.1m			red-white	8.79	1.12	.189
blue-white	40.2m	37.3m	37.6m			blue-white	12.6	1.69	.263
Secondary Inductances / Resistances (LEFT Output Tranfsormer)									
Loc	**120 Hz**	**1 kHz**	**10 kHz**			**Doc**	**120 Hz**	**1 kHz**	**10 kHz**
4 ohms	82m	30m	-			4 ohms	.471	.163	-
8 ohms	-	61m	-			8 ohms	-	.200	-
16 ohms	-	118m	-			16 ohms	-	.185	-
Lsc	**120 Hz**	**1 kHz**	**10 kHz**			**Dsc**	**120 Hz**	**1 kHz**	**10 kHz**
4 ohms	63u	58u	55.5u			4 ohms	-	1.63	.238
8 ohms	104u	96.7u	93.5u			8 ohms	11.8	1.55	.228
16 ohms	165u	154u	148.4u			16 ohms	12.6	1.65	.243

Magnetek C-24x choke
L= 0.957 H @ 1 kHz
L= 0.965 H @ 100 Hz
52.8 ohm DC resistance
Table 4

Power Transformer	**Voltage**	**Converted Voltage**
Black / Black (Input)	1.003V	122 VAC
Green 1 / Violet	25mV	3.05V
Green 2 / Violet	30mV	3.66V
Green1 / Green2	54.5mV	6.65V
White/ White	42.5mV	5.19V
Brown1 / Orange	25mV	3.05V
Brown2 / Orange	30.3mV	3.67V
Brown1 / Brown2	54.5mV	6.65V
Red1 / Yellow	2.905V	354.4V
Red2 / Yellow	2.885V	352.0V
Red1 / Red2	5.20V	634.4V
Grey / Yellow	0.478V	58.32V

Table 5

Voltages input 50mV	Left Side EF86	Right Side EF86	Left Side Speaker	Right Side Speaker
100 Hz	.615V	.604V	.362V	.368V
400 Hz	.738V	.715V	.344V	.351V
1000 Hz	.696V	.573V	.358V	.365V
5000 Hz	.766V	.738V	.344V	.351V
10000 Hz	.740V	.722V	.325V	.334V
15000 Hz	.678V	.666V	.294V	.303V
18000 Hz	.623V	.613V	.273V	.283V
Average	**.693V**	**.662V**	**.329V**	**.336V**
Gain	**13.86**	**13.24**	**6.58**	**6.72**
Converted Gain	**-**	**-**	**199.3**	**203.6**

Table 6