GLASS AUDIO

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READING GLASS

Welcome to this special new place where those of us with a warm, nostalgic, and satisfying predilection for the vacuum tube can meet to swap ideas, designs, experiences and discoveries. We're still a relatively small group but we haven't as yet made a whole lot of noise about ourselves. I hope all of you have been talking to your friends about this new enterprise. The larger the congregation, the livelier the service.

Contributing Editor **Joe Curcio** offers us the best of solid-state and tube technology in an update of the classic Dynaco Stereo 70. This newest incarnation has tight control for voltages, something we yearned for in the early days but never did because a tube-type

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A VACUUM TUBE POWER AMPLIFIER WITH SOLID-STATE REGULATION

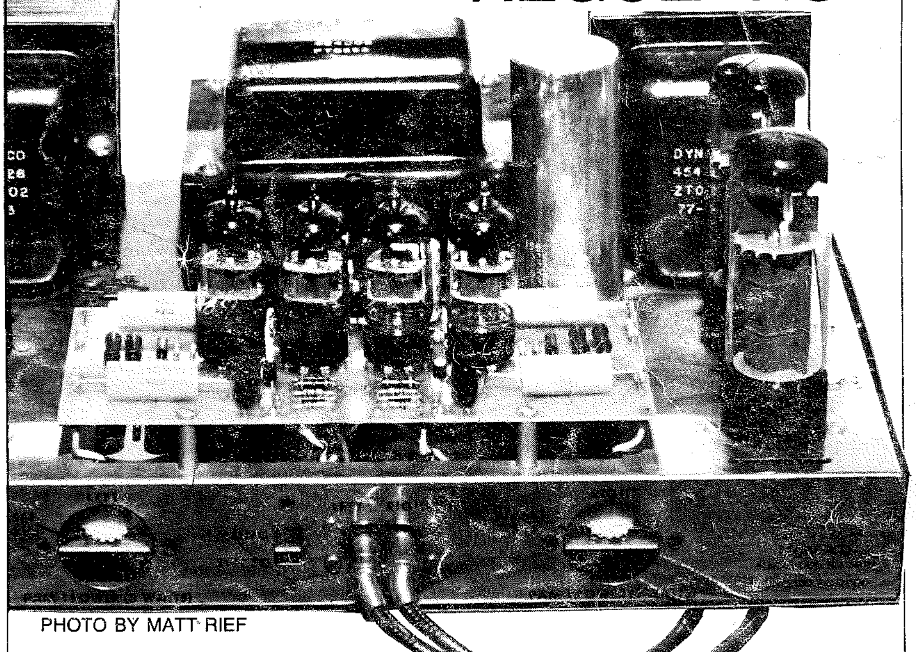

PHOTO BY MATT RIEF

by Joe Curcio

When my original pre-preamp (*TAA* 5/84) and "Daniel" preamp (*TAA* 2/85) designs were published, I had planned to quickly follow those articles with a similar, no compromise vacuum tube power amplifier. Although the power amplifier I present here is long overdue, I believe you will find it worth the wait.

During that time, I tried a number of design concepts in the "idea" stage, which have proven to be very successful. The design presented here embodies most of those concepts and has been refined as a package to subjectively excel in definition, dy-

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Vacuum Tube Power Amp

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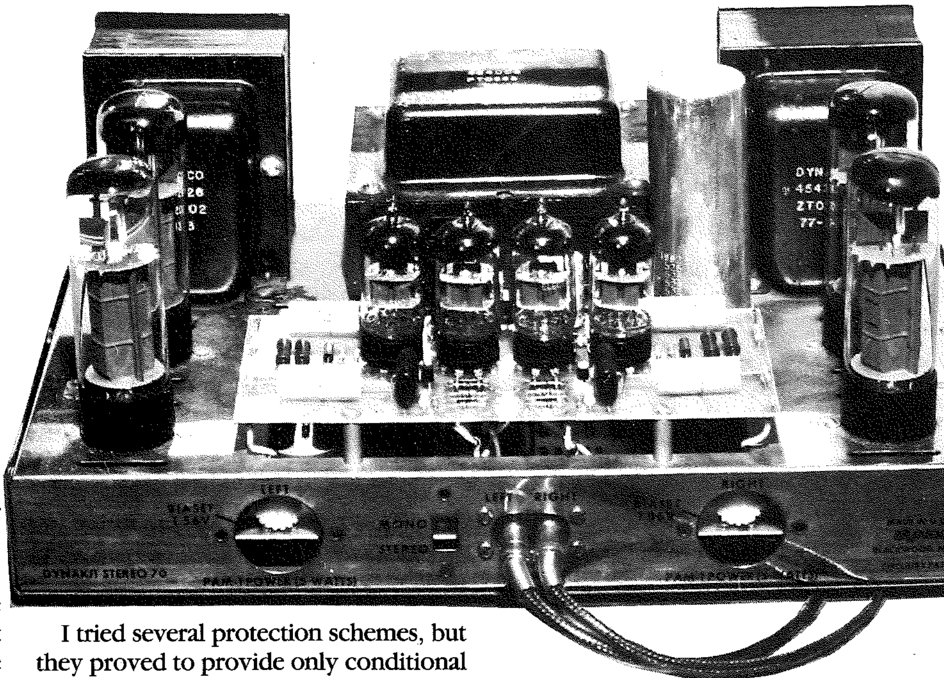
namics, and imaging.

The floating bias configuration of the regulators combined with the high voltage swing potential of the driver stage allows the circuitry described to be applied (with operating voltage considerations) to any number of basic tube power amplifiers. A description of the general application, however, would involve a discussion that would extend beyond the scope of this article. Therefore, I have chosen to describe a specific amplifier application. The Dynaco ST-70, widely available and a good source of high quality transformers, emerges as my candidate.



You might safely assume that the Dynaco ST-70 has been the recipient (and frequently the victim) of more modifications than any other commercial audio component. Ranging from capacitor upgrades in both the driver stage and/or power supply, to driver stage rework and rebiasing, most modifications are designed to reinforce the original design.

My design is much more extensive—using only the original transformers and hardware. I completely replaced the driver stage with an all triode design in which the voltage gain and phase splitting are accomplished within the same stage. The original power supply now serves only to input a bank of servo-controlled regulators. The majority of the circuitry is contained on two circuit boards, physically configured to reside within the ST-70 chassis (see *Photo*).

As you know from my previous articles, I am a strong advocate of highly regulated/servo-controlled power supplies. In prior designs, I used floating op amp, high-voltage regulators. These designs were both sonically neutral and extremely reliable. Direct application of this topology to the high-voltage/high-current requirement imposed by the output stages of vacuum tube power amplifiers results in a reliability problem. I identified the failure mechanisms to determine whether the original design could be protected or a complete redesign would be necessary.

I tried several protection schemes, but they proved to provide only conditional reliability, that is, they would not withstand some atypical but nonetheless possible situations, such as 3-second power line interruptions or shorted elements in the output tubes. I soon realized that a new regulator was necessary. After building and testing several devices, I finally devised a design that seemed insensitive to both line and load attack. I constructed several prototypes and sent them to various "real world" laboratories. The overall consensus was that the resultant regulator is not only more reliable, but sonically superior to the earlier design. Since then, approximately 25 copies of the version presented here have been built and perform without problems.

Since the output stage voltage regulator required development time, I took the opportunity to consider new driver stage "ideas brewing in the recesses." I auditioned a number of different topologies, including cascade and cascode inputs with split load phase inversion, and several variations of the "Williamson" circuit.

The constant current cascode differential amplifier emerged as the clear winner (and by no small margin). I refined this configuration through successive auditions and it now provides the greatest degree of dynamics, image and definition, in my experience. Independent reports from the field concur that this driver stage/power supply combination, when used with a Dynaco ST-70 transformer complement (*Fig. 1*) and operated within its power range, is sonically equal or better than commercial products costing up to several thousand dollars. As I previously mentioned, you can adapt this circuit to higher power output stages with a few power supply alterations.

The Driver

The driver stage's purpose is to provide a dual asymmetrical output signal of sufficient amplitude to meet the input level demands of the output stage. Balance must be preserved at both frequency extremes and be relatively insensitive to tube parameter differences, caused by aging and unit-to-unit variation. In addition, the circuit must be dynamically stable after overall loop feedback has been applied (if used). No single circuit configuration exists which is the best choice for meeting all these requirements; rather, the demands of the output stage must be factored into the choice of driver stage parameter optimization.

For example, for many years Audio Research used a popular technique of feedback around the output stage (transformer secondary to output tube cathodes). This reduced the distortion and linearized the output stage at the expense of requiring a greater peak voltage swing in the driver stage (which Audio Research provided). The indiscriminate application of this technique to a power amplifier, however, without the necessary correction to the driver stage (as has been suggested as a "general" improvement technique), may actually degrade dynamic performance.

To meet the voltage gain requirements two stages of triode amplification will be necessary. Given a choice of cascode or cascade, I have chosen the cascode configuration primarily because of its inherent direct coupling.

The lack of an interstage coupling ca-

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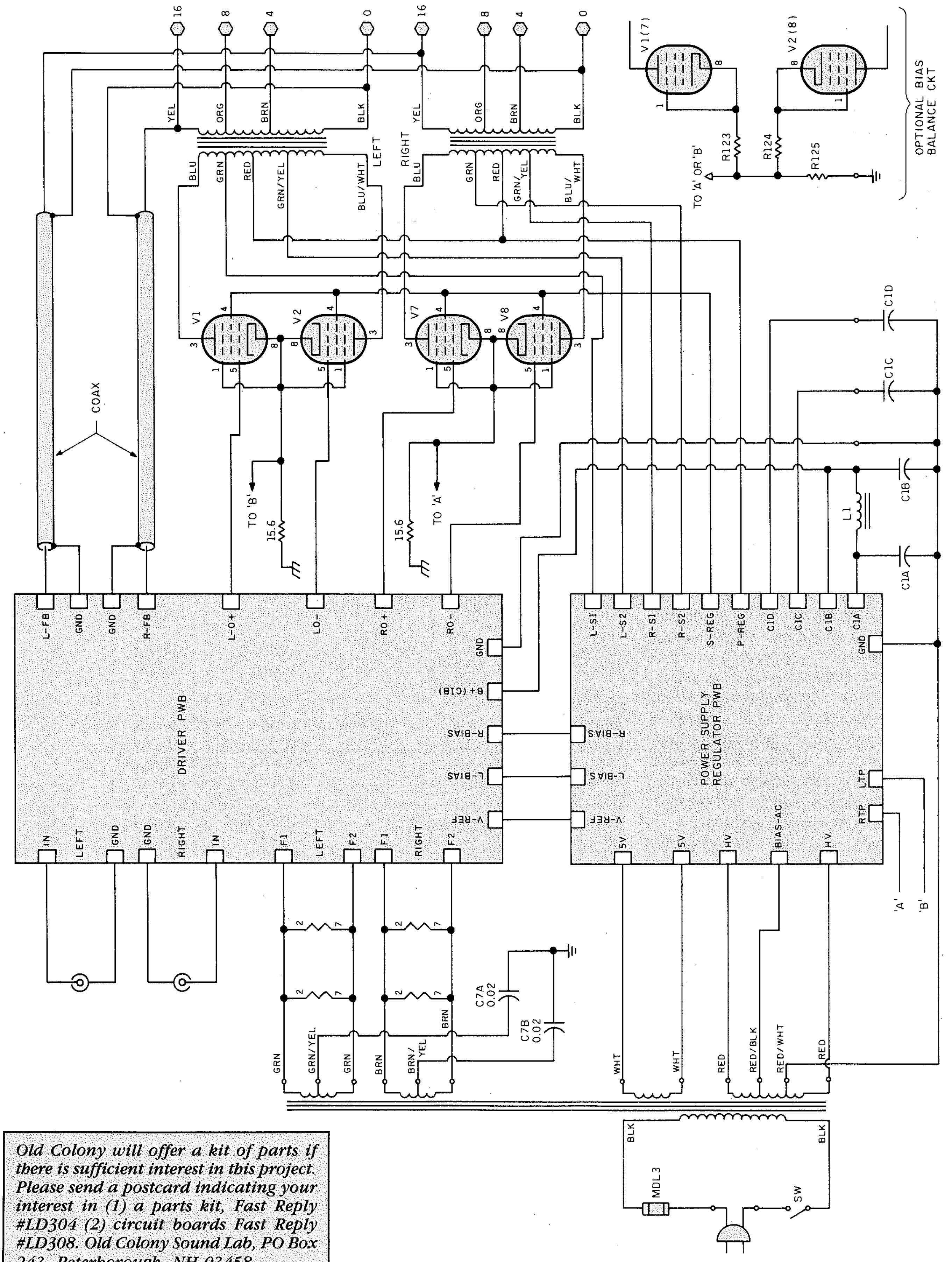


Old Colony will offer a kit of parts if there is sufficient interest in this project. Please send a postcard indicating your interest in (1) a parts kit, Fast Reply #LD304 (2) circuit boards Fast Reply #LD308. Old Colony Sound Lab, PO Box 243, Peterborough, NH 03458.

FIGURE 1: Wiring Diagram—Stereo-70.

pacitor increases low-frequency stability. One of my earlier versions of an ST-70 modification used a cascode gain stage, direct-coupled to a split load phase inverter (the same phase splitting technique of the original Dynaco driver stage). This configuration was very stable, but suffered from an output swing limited to one-third the supply voltage.

What we needed (if possible) was large swing potential (with dynamic balance) and direct coupling. In *Radio-Electronics* (September 1955) article and again in *Wireless World* (June 1956), L. B. Hedge described the "long-tailed cascode pair" configuration, in which a differential amplifier was configured using a pair of cascode "sides." This elegant circuit offers the most direct solution to the demands of the output stage. The degree to which it can function as a true differential amplifier (and therefore an effective phase splitter), depends on the signal coupling from cathode to cathode. This, in turn, depends on the biasing impedance being as high as possible at this point. To approximate a current source, Hedge specified a large value resistor (47kΩ) returning to a negative voltage supply.

The additional power supply (a major drawback of his approach) has even greater economic consequences today, given our insistence on highly regulated supplies. Through the use of a transistor current source, we can realize a high source resistance without the negative voltage requirement. This current source contributes significantly to this circuit's effectiveness as a phase splitter.

Transistor Q101, with its associated base and emitter components, serves as the current source; biased into the proper quiescent operating mode from the voltage present at the output of the driver stage. A large AC component at these points is out of phase and therefore cancels to zero (effectively). The remainder of the driver circuitry is a very conventional self-bias cascode circuit on each "side."

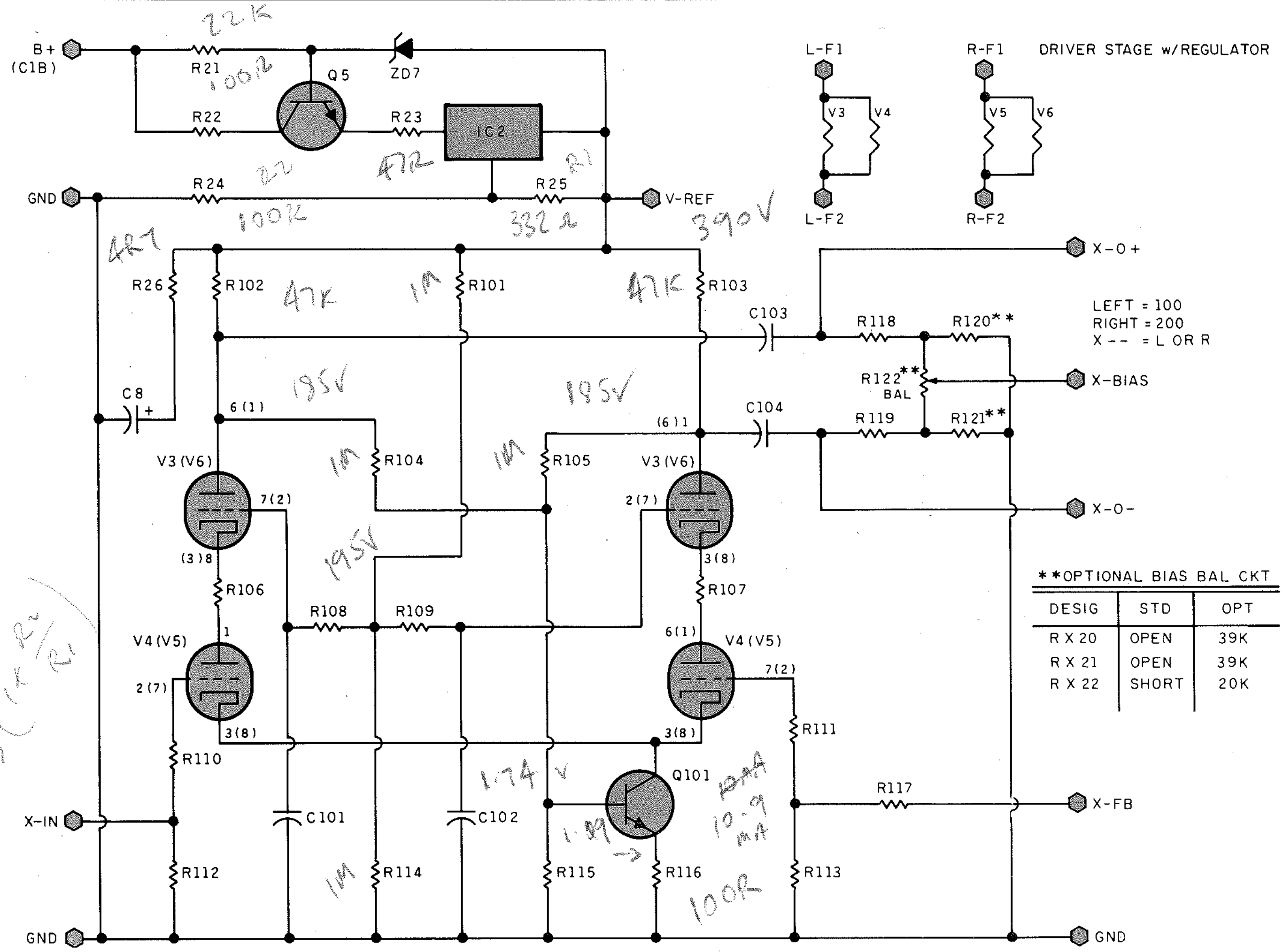
Output

The output stage is reconfigured from the original "ultralinear" circuit (in which the screen grids were fed from the output transformer primary winding) to the fixed screen circuit (fixed supply voltage). The voltage supplying the screens is tightly regulated, playing a major role in the sonic formula.

The output tube bias voltage is derived from a fixed-zener regulated sup-

ST-70 PARTS LIST — *optional bias balance circuit

Item	Description	P/N	Source	Quantity
Capacitors				
C1 a-d	30, 3x20μF Quad	298906	ST-70	1
C2, 3	100μF, 16V electrolytic	20NH100	Mouser	2
C4	0.1μF, 600V Mylar (Sprague 6PSP10)	926-2168	Allied	1
C5	47μF, 100V electrolytic	19AX047	Mouser	1
C6	47μF, 50V electrolytic	20NR047	Mouser	1
C7 a, b	.02μF ceramic	224403	Dynaco	1
C8	10μF, 450V electrolytic	19FF010	Mouser	1
Cx01, 02	0.1μF, 250V polypropylene	23PQ410	Mouser	4
Cx03, 04	0.47μF, 400V polypropylene		ST-70	4
D1-15	1000PIV	333-1N4007	Mouser	15
F1	3A slow blow fuse	504-MDL-3	Mouser	1
IC1	dual bi-FET op amp	551-UPC812C	Mouser	1
IC2	adjustable +V-reg	551-UPC317H	Mouser	1
L1	Choke	423354	ST-70	1
Q1,3,x01	NPN SS transistor	333-KN4400	Mouser	4
Q2	HV/Hi-power transistor	D1341	MCM	1
Q4, 5	HV/Med power transistor	511-TIP50	Mouser	2
Resistors				
R1	not used			
R2	75Ω, 6W	ME285KNA620-75	Mouser	1
R3	1kΩ, 6W	ME285KNA620-1K	Mouser	1
R4, x08,x09	3.3MΩ, ½W	29SJ500	Mouser	3
R5, 7	10kΩ, ¼W	29SJ250	Mouser	2
R6, 8	470Ω, ¼W	29SJ250	Mouser	2
R9	39Ω, ½W	29SJ500	Mouser	1
R10, 11, 26	4.7Ω, ½W	29SJ500	Mouser	2
R12-15 x18, x19	470kΩ, ½W	29SJ500	Mouser	8
R16	1kΩ, ½W	29SJ500	Mouser	1
*R17, *18, 21	22kΩ, ½W	29SJ500	Mouser	3
R19, 20	25kΩ, ADJ Bias (Bourns 3352H-1)	754-8210	Allied	2
R22, 116 x06, x07	100Ω, ½W	29SJ500	Mouser	6
R23	47Ω, ½W	29SJ500	Mouser	1
R24	100kΩ, 3W	P100KW3	Digi-Key	1
R25	332Ω, 1%, ½W	29MF500	Mouser	1
Rx01, x04 x05, x12	1MΩ, ½W	29SJ500	Mouser	8
Rx02, x03	47kΩ, 3W	P47KW3	Mouser	4
Rx10, 11	33Ω, ½W	29SJ500	Mouser	4
Rx13	1kΩ, 1%, ½W	29MF500	Mouser	2
Rx14	352kΩ, 1%, ½W	29MF500	Mouser	2
Rx15	4.75kΩ, 1%, ½W	29MF500	Mouser	2
Rx17	47.5kΩ, 1%, ½W	29MF500	Mouser	2
*Rx20, *x21	39kΩ, ½W	29SJ500	Mouser	4
*Rx22	20kΩ, adjustable (Bourns 3386F)	754-3211	Allied	2
Rx23, x24	1.8Ω, ½W	29SJ500	Mouser	4
Rx25	15.6Ω, 5W	120150	ST-70	2
Miscellaneous				
(1) SW1 DPDT slide switch, 576S5022CD03-0			Mouser	
(1) T1 PA-060, 464006 (ST-70)				
(2) T2, 3 A-470, 454326 (ST-70)				
(4) V1, 2, 7, 8, EL34/6CA7			Triode	
(4) V3-6, 6DJ8/6922 (Siemens)			Triode	
(2) X1, 3 TO-220 heatsink, 33HS222			Mouser	
(1) X2 TO-3 heatsink, HS103-1.25			Allied	
(25) X4 PWB terminals			Concord	
(8) X5 spacer 4-40x1 inch, 839-2337			Allied	
ZD1-4 not used (91V, 5W zener diode)				
(1) ZD5, 15V, .5W zener diode, 570-1N4744A			Mouser	
(1) ZD6 30V, .5W zener diode, 570-1N4751A			Mouser	
(1) ZD7, 6.2V, .5W zener diode, 570-1N4735A			Mouser	



**OPTIONAL BIAS BAL CKT

DESIG	STD	OPT
R X 20	OPEN	39K
R X 21	OPEN	39K
R X 22	SHORT	20K

FIGURE 2: Schematic—driver stage with regulator.

ply which feeds two possible bias control circuits. Both circuits provide control of the operating current of the output tubes, however, the optional circuit allows current trimming/balance of each output tube. If you wish to incorporate the optional bias balance circuitry, cut the foil shorting R122 and R222 on the driver circuit board and follow the charts indicating the correct use of R120/R220, R121/R221 and R17/R18 (*Fig. 2*). In addition, you must include R123/R223 and R124/R224 at the cathode of *each* output tube to independently measure each output tube.

Power

The original Dynaco power transformer is retained. A full-wave center-tapped rectifier feeds a capacitor/inductor filter to provide the primary "raw" B+ power. All high-voltage regulator inputs are supplied from this point. This is identical to the original ST-70 circuit with the exception of solid-state rectification.

A tap on the high-voltage secondary winding feeds a half-wave capacitor input filter. This negative supply (approximately 60V DC) is zener-regulated to provide the fixed output tube bias.

Filaments are energized by two separate, identical center-tapped windings; one for each channel with the center tap referenced to ground through a small value capacitor. The respective right and left channel driver stage tube filaments are also fed from these windings.

Three regulators control high voltage for the output tube plates, output tube screens and the driver board. The "plate" and "screen" regulators are nearly identical, differing only by the series pass element and, therefore, current capacity. They are servo-controlled op amp configurations differing from my previous designs—the circuit operational current is not derived from the high voltage bias, but rather, from a separate "floating" supply. The original rectifier tube filament windings are used in a voltage doubler configuration to provide the plus/minus supply voltage for the dual op amp. R9 references the "zero" point of the plus/minus supply to the output of the screen regulator so the op amp always sees an operational voltage that is centered about its own output voltage.

Reference voltage for the plate and screen regulators can be either "zener" derived or obtained from the output of the independent driver regulator. You should use the driver regulator as a reference in this application. In other designs of perhaps higher voltage, use the zener string configuration (the circuit board has provisions for the components). In either case, the chosen reference is filtered through a long time-constant RC filter to reduce low-frequency modulation. The diodes and series resistors surrounding the op amps either redirect or provide limiting to the high-voltage currents surrounding the low-voltage active devices (*Fig. 3*). This is especially important in redirecting high voltage capacitor charge or discharge paths.

Regulated high voltage is self-contained on the driver board and is realized with a conventional LM317 floating regulator. The operation of this regulator has been described in this and other publications (the National Semiconductor 1982 *Voltage Regulator Handbook*).

De-construction

Since you will be starting with an amplifier that may have been assembled more than twenty years ago (and possibly with questionable construction techniques), the first step is to completely disassemble the original amplifier.

The hardware you will retain includes the four octal sockets, the input connector (RCA phono), speaker output terminals, fuse holder, power switch, power cord, and the 7-pin terminal strip. If any parts look dirty, worn, corroded or otherwise questionable, I strongly suggest you replace them. An attempt at cost cutting now can result in runaway output tubes (dirty pin 5) or other more extensive problems and headaches in the future. Therefore, carefully remove and clean all solder and wire remnants from the terminals of the salvaged hardware.

The electrical components we retain include the transformers, choke, filter capacitor (four-section electrolytic), 15.6Ω output tube cathode bias resistors, and the 0.02μF dual ceramic capacitor. The electrolytic capacitor is the most likely to be defective. Any of the four sections could be defective. A dead (pun intended) giveaway is a brown powdery substance at the base of any of the lugs or around the diameter of the phenolic (near the phenolic aluminum intersection). If you see this, just replace it, since if it's not defective now, it soon will be.

The probability of a defective transformer is small, however the power transformer is the more likely candidate for failure. An easy go/no-go test of the power transformer is to apply AC line voltage to the primary through a ½A fuse with all the secondaries disconnected. If the fuse survives, the transformer is at least not shorted. If you think the chassis needs to be cleaned (and most do), then remove these items also. Otherwise, just remove and clean all solder/wire remnants from the filter capacitor. Be careful: solder "balls" can

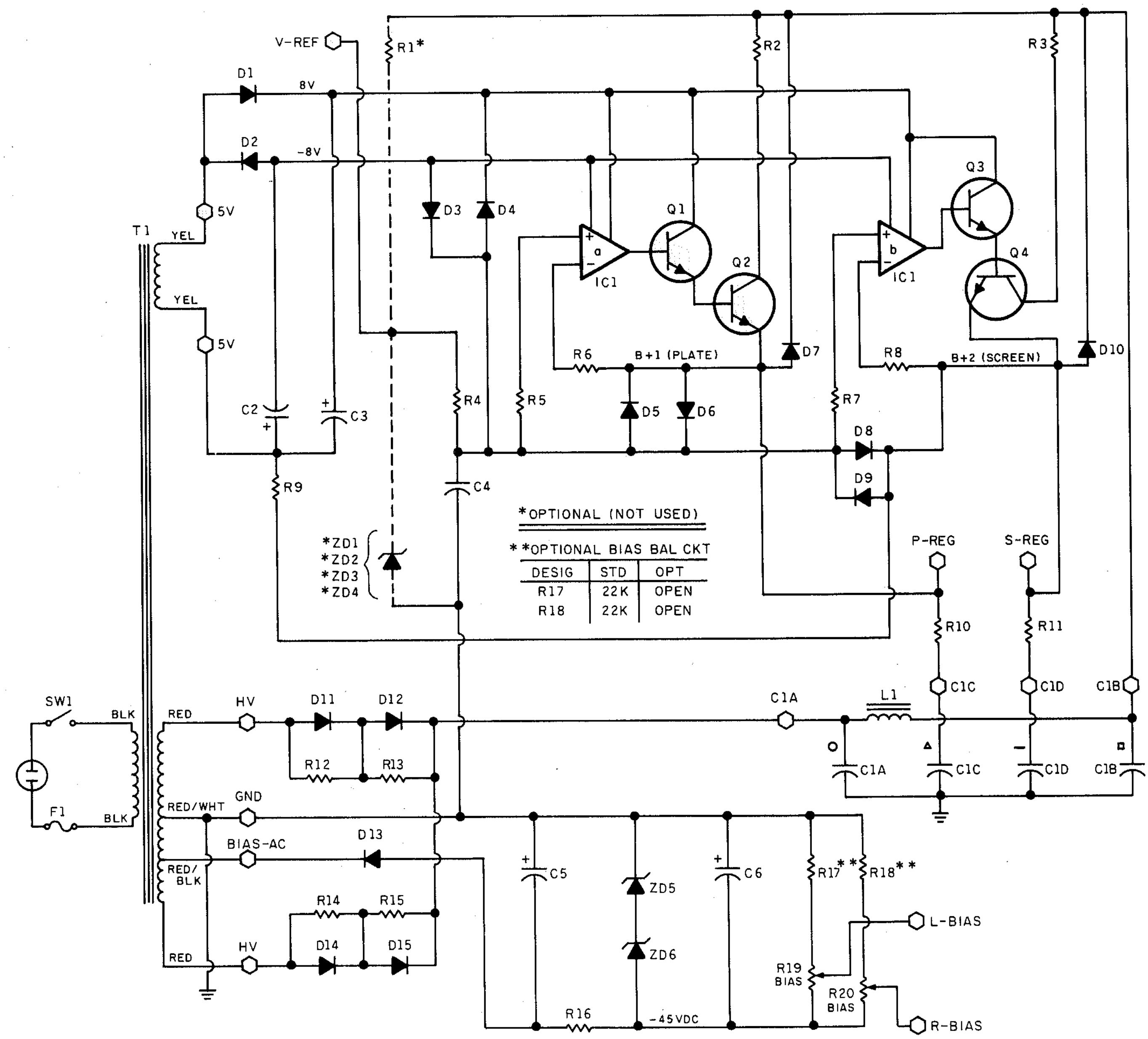


FIGURE 3: Schematic—power supply with plate, screen and bias regulators.

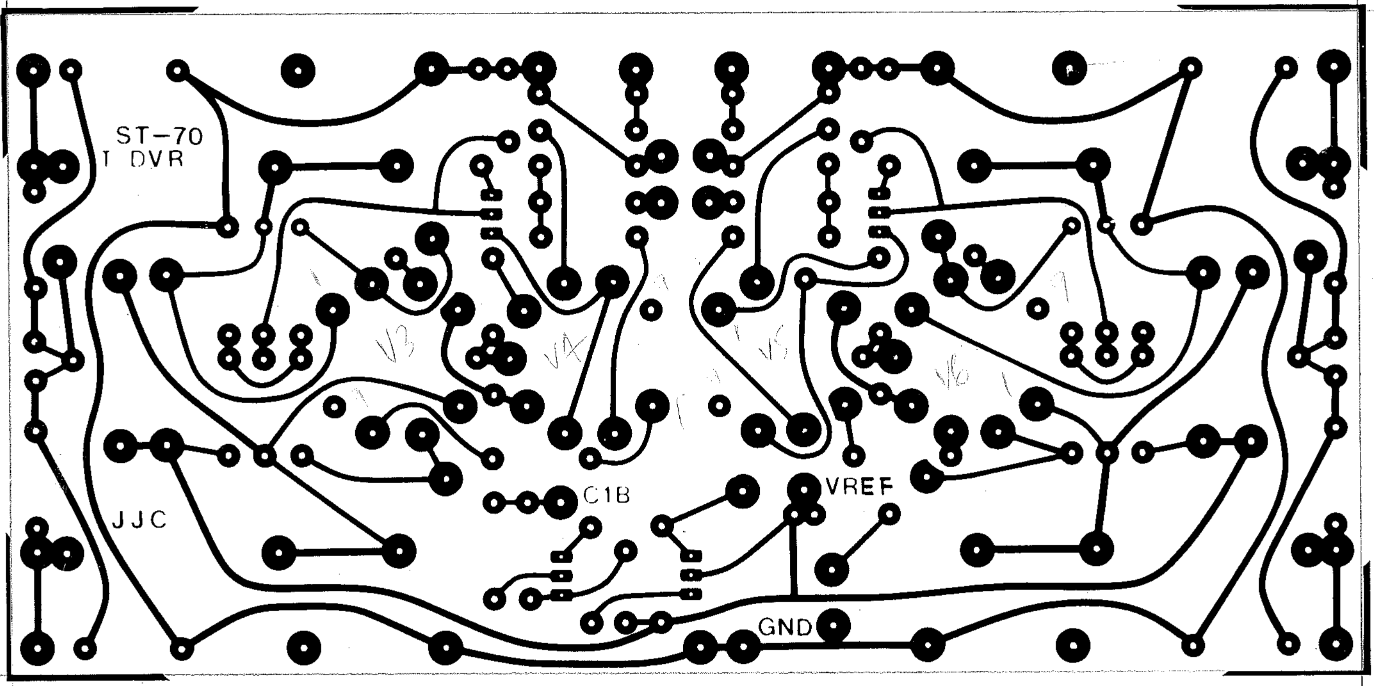


FIGURE 4a: Circuit pattern—Stereo-70 driver and regulator.

accumulate and lodge in the area between the phenolic and aluminum capacitor case, only to dislodge and cause havoc later.

Remove and discard the bias pots, selenium rectifier and 7199 driver board. Since the original wiring/insulation quality is questionable, I see little reason to save the original wire (unless you have difficulty obtaining new wire, which should be Teflon insulated, 18 AWG, non-magnetic).

Board

Using the component placement diagram (*Fig. 4*) makes the construction of the driver circuit board straightforward. Double-check all components with specified polarity (diodes, transistors, and electrolytic capacitors) for proper orientation. Since the 47kΩ, 2W plate resistors (R102/R202, R103/R203) will become warm in normal operation, allow space, approximately ¼-inch, between these resistors and the board.

The power supply/regulator circuit board component placement diagram is shown in *Fig. 5*. Most components on this assembly have a designated polarity, therefore proceed carefully and double-check your work. The current-limiting resistors (R2 and R3) must be spaced approximately ⅜-inch above the board surface. Normally they do not generate much heat, however, during a sustained short condition, they become quite hot and may become the sacrificial element.

The plate regulator series pass transistor (Q2) may become hot (130°F) in normal operation depending on the AC line voltage, therefore, its heatsink (TO-3) should be spaced approximately $\frac{1}{16}$-inch above the board.

I recommend you insert two 6-32 screws from the conductor side of the board, using "star" washers to ensure a reliable electrical connection, secured by a $\frac{5}{16}$-inch nut on the component side. These will serve as the spacers. Drop the heatsink and then the transistor onto these screws, then the retaining nuts (¼-inch). Unless you are using this regulator board in an alternate application (requiring a different plate/screen regulator output than is specified here), you should omit the 5W zener reference diodes (ZD1–4 and resistor R1).

Chassis

Before you begin to reassemble your amplifier, remember that the effort you expend now in careful construction practices will have both sonic and aesthetic rewards afterward. Most of the connections you will be making involve high impedance/high level signal conductors susceptible to mutual coupling. Almost all contain lethal voltage levels. Dress your wires carefully (against the chassis) and solder thoroughly. Always check the insulation following the soldering operation to determine if it has been compromised. I strongly recommend Teflon insulation.

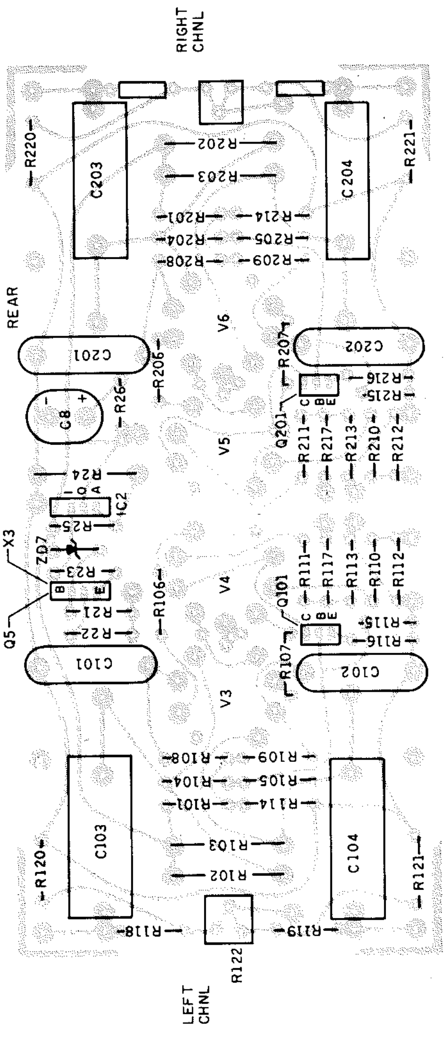


FIGURE 4b: Component layout.

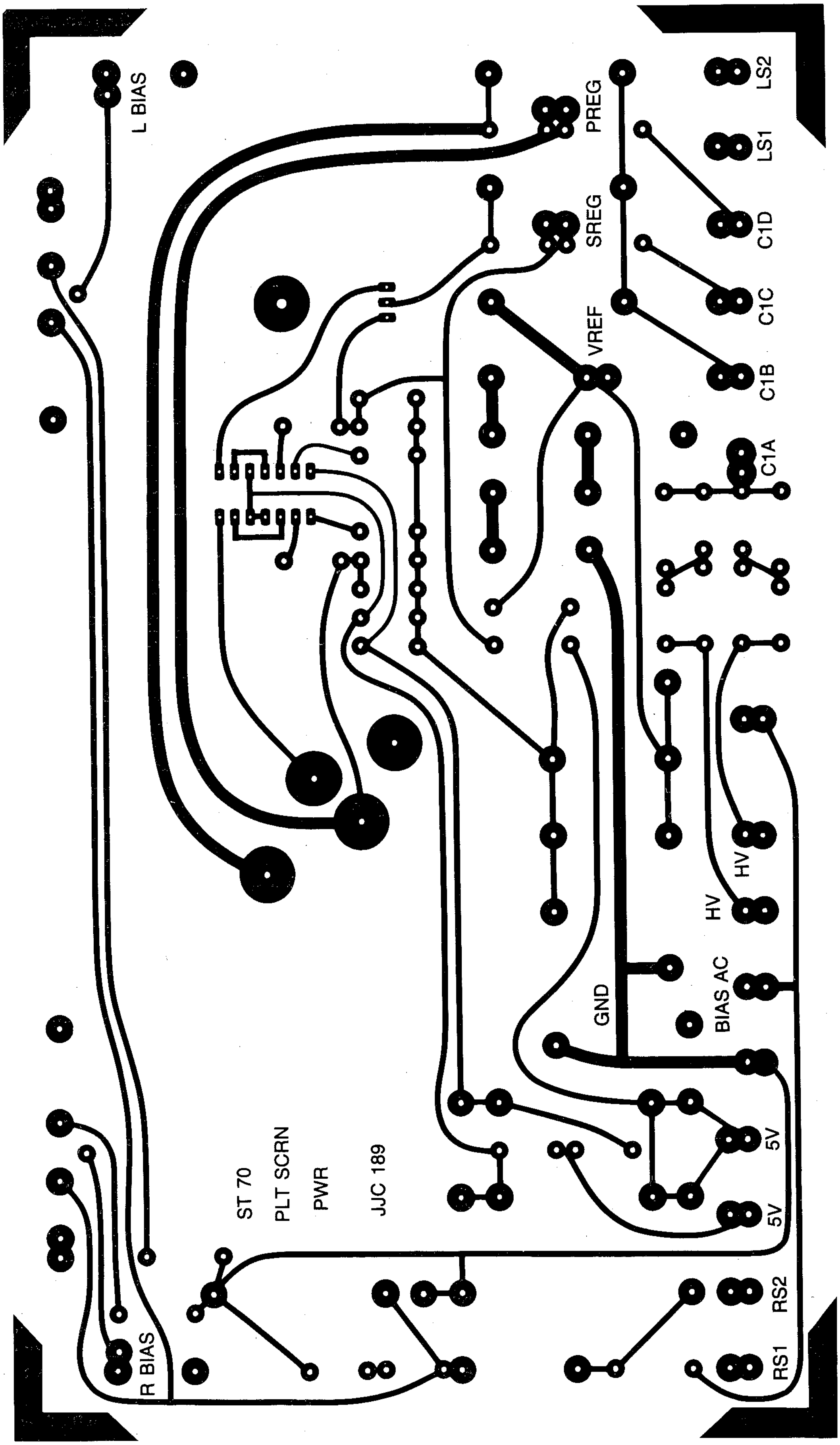


FIGURE 5a: Circuit pattern—Stereo-70 plate and screen regulator and master power supply.

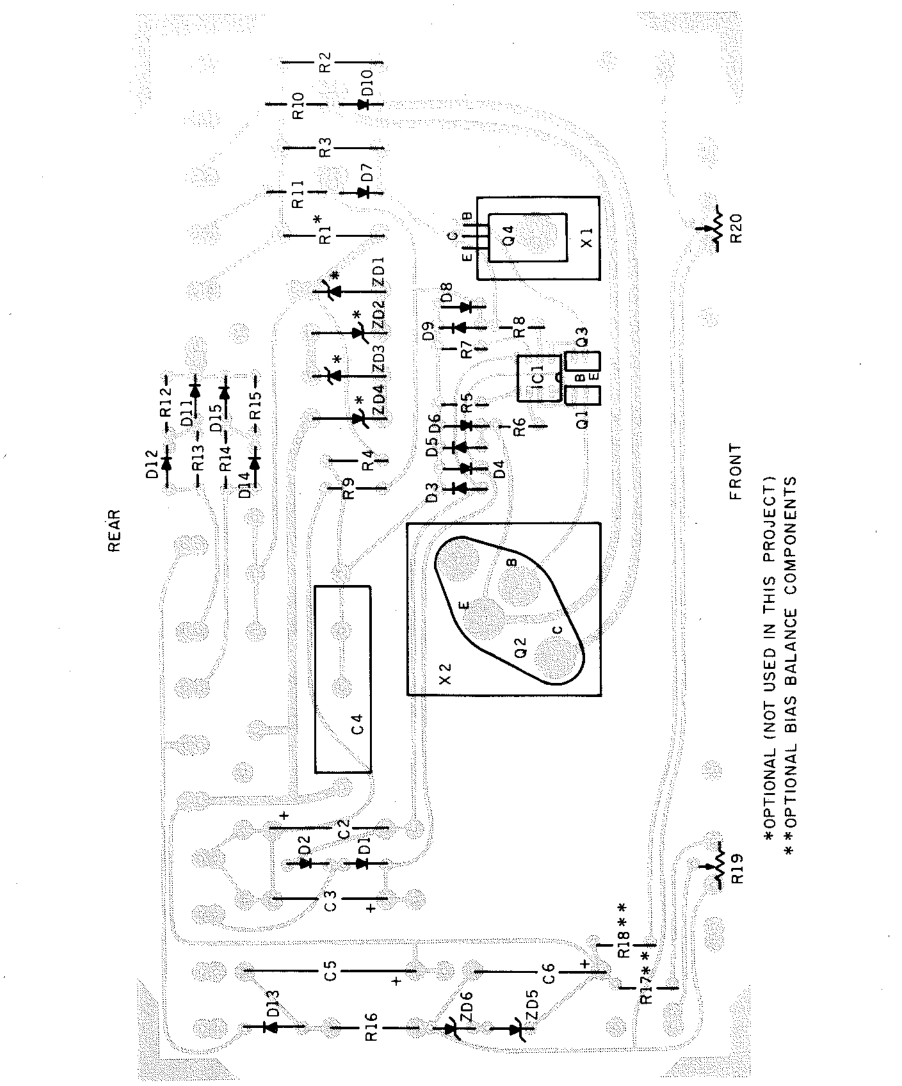


FIGURE 5b: Component layout.

After you have cleaned and restored/replaced the hardware, you may reinstall it on the prepared chassis (*Fig. 6*). Also install the eight 1-inch spacers (four on top and bottom). The front spacers (nearest the input connectors) share a common mounting hole. Use male/female 4-40 threaded spacers at these locations. The other two driver board spacers occupy the remaining mounting holes of the original driver board. Mount a below-chassis spacer at the position of the original rectifier tube's socket-mounting hole nearest the chassis center. Mount the remaining below-chassis spacer at the position of the ground lug adjacent to the quad capacitor filter. Retain the ground lug and tighten securely.

You should connect a solid bare wire between this lug and the nearest case terminal of the quad cap. This is the star ground point for the amplifier: all chassis ground connections will be made to this short (¾-inch) wire except the 15.6Ω (R125/R225) current-sense resistors. If previously removed, reinstall the filter choke (located under the right channel output transformer). Connect it to section A and B of the quad filter cap (C1). Attach a 5-inch wire to each of the four sections of the quad filter capacitor (I prefer four different colors for easy identification later) dressed toward the rear of the amplifier. Reinstall the 7-pin terminal strip at its original location. Finally, connect an 8-inch black wire to the ¾-inch ground wire and route it along the chassis' left side.

The output tube sockets should have the locating tab (between pins 1 and 8) "pointing" toward the outer chassis edge. On each side (channel) connect the following to the output tubes:

1. Connect pins 1 and 8 together on each of the four output tubes. Connect the 1/8 pin junction of the front tube to 1/8 junction of the rear tube.
2. Attach the 15.6Ω bias resistor (R125/R225) to the rear tube 1/8 junction with the remaining end terminating at the tube ground lug.
3. Attach a 5-inch wire to the front tube 1/8 junction, dressed toward the front of the amplifier.
4. Connect pin 4 of the front tube to pin 4 of the rear tube. Connect pin 4 of the rear tubes together. Connect a 5-inch wire to the right channel rear tube, dressed toward the rear of the chassis.
5. Connect pin 2 of the front tube to pin 2 of the rear tube. Connect an 8-inch wire to pin 2 of the front tube, dressed toward the front of the chassis.
6. Connect pin 7 of the front tube to pin 7 of the rear tube. Connect an 8-inch wire to pin 7 of the front tube dressed toward the front of the chassis.
7. Lightly twist together the two 8-inch wires from Steps 3 and 4 and direct them along the chassis front (near the top) toward the center.
8. Output tube pins 3 and 5 remain unterminated for now, as well as pin 6.

Preparation and Installation

Prior to installing the replacement driver stage circuit board, attach the following:

1. Connect a 5-inch wire to each of the four (two per channel) output terminals (outer corner of circuit board).
2. Connect a 7-inch wire to each of the two (one per channel) bias terminals (center outer edge).
3. Connect a 3-inch wire to each of the four (two per channel) input terminals (center front of circuit board).
4. Connect a 5-inch red wire to the B+ in terminal and a 6-inch black wire to the ground terminal of the circuit board (near center rear). Connect a 12-inch white wire to the driver regulator output. Lightly twist these three wires together.
5. Connect an 18-inch shielded coax cable center lead to the FB terminal of the circuit board. Connect the shield to the input ground point.

Install your new circuit board on the four 1-inch spacers previously installed. Orient the board so the regulator section is nearest to the power transformer. Now feed the wires that originate at the driver circuit board through the rectangular cutout in the chassis. In some cases this opening may have a sharp burr which should be removed (light emery paper will do). Make the following connections:

1. Trim to length and connect the 5-inch wires from Step 1, to pin 5 of the nearest output tube. Dress these wires

so they are as close to the chassis as possible.

2. Connect the 7-inch bias wires later.

3. At the RCA input connector, cut the center tab (not ground) to a length of ⅛-inch beyond the end of the cylindrical section. Trim to length and connect each of the 3-inch wires from Step 3 to these terminals, which is a one-to-one physical correspondence. Simply extend and connect each wire one at a time to ensure the correct connection. The solder connection should be made on the outside surface of each center pin (which has been cut). Carefully clean all flux residue with acetone.

4. Trim to length and connect the red wire to the "B" terminal of the filter capacitor (C1). Similarly trim and connect the black wire to the bare grounding wire. Connect the white wire later.

5. The shielded cable should be routed along the inside front and then along the side edge of the amplifier chassis toward the output transformer. It will be connected later.

6. Connect the twisted pair of filament supply wires (from pins 2 and 7 of the output tubes) to the F1 and F2 connections of the circuit board for each channel. Dress these wires along the center of the rectangular cutout and along the chassis.

Transformers

Install the output transformers in their original positions (the transformer with the longer primary leads is the left unit). Make the following lead connections for each (channel) of the output transformers:

1. Connect the black secondary lead to the C terminal of the output connector. Also connect the shield of the shielded cable (from the driver circuit board) to this point.

2. Connect the brown secondary lead to the "4" terminal of the output connector.

3. Connect the orange secondary lead to the "8" terminal of the output connector.

4. Connect the yellow secondary lead to the "16" terminal of the output connector. Also connect the center lead of the shielded cable (from driver circuit board FB terminal) to this point.

5. Connect the solid blue primary lead to pin 3 of the output tube nearest to the front of the amplifier.

6. Connect the striped blue primary lead to pin 3 of the output tube nearest the output transformer.

7. Route the red primary leads toward the filter capacitor but do not

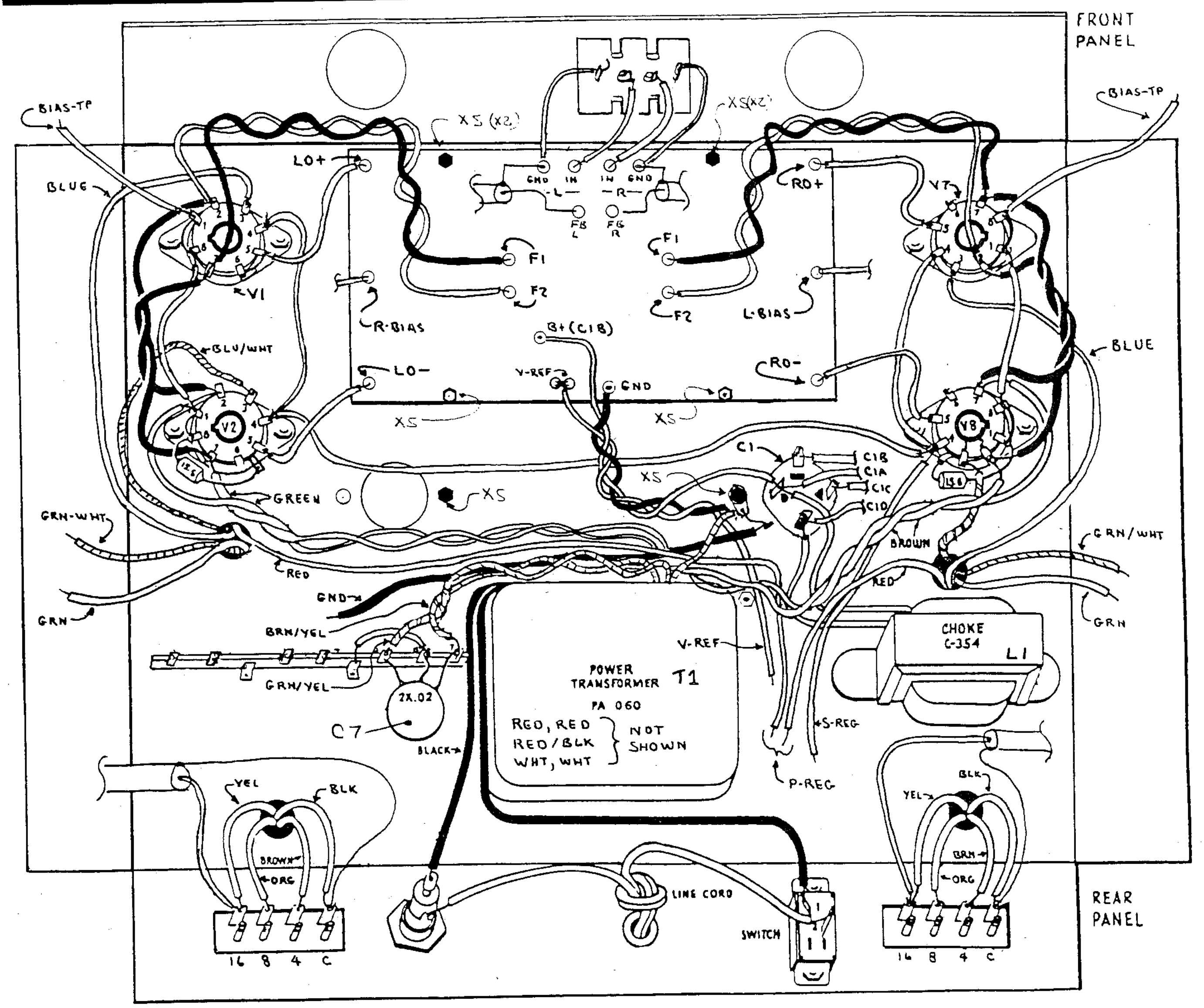


FIGURE 6: Wiring and installation.

connect at this time. Terminate the green and green striped primary leads later.

Reinstall the power transformer and make the following connections:

1. Connect one of the primary leads (black) to the power switch and the other to the fuse holder center pin (as in the original).

2. Connect the left channel filament windings (green) to the output pin terminals (2 and 7) of the output tube nearest the left output transformers.

3. Connect the right channel filament windings (brown) to the output pin terminals (2 and 7) of the output tube nearest the right output transformers.

4. Connect the red/yellow secondary (center tap) to the ground lug bare wire near the filter cap.

5. Connect one green/yellow secondary (filament center tap) to pin 5 of the 7-pin terminal strip.

6. Connect the other green/yellow secondary (filament center tap) to pin 7 of the seven pin terminal strip.

7. Attach the outer leads of the original dual 0.02μF ceramic disk capacitor (C7) to pins 5 and 7 of the 7-pin terminal strip. Attach the center lead to pin 6. Attach a 2-inch wire from pin 6 to the nearest mounting pin (adjacent to pin 5).

8. Extend the red/black (bias AC) lead by 4 inches.

9. The red (2), red/black (1), and yellow leads remain unterminated until later.

10. Connect the line cord to the remaining power switch and fuse-holder terminals.

Power/Regulator

Install the power supply/regulator circuit board on the four 1-inch spacers previously installed below the chassis. Note that the input terminals from the RCA input connector are snug against the front edge of the board. This is of no consequence but now you can see why the previous trimming procedure is required. Trim to length and carefully make the following connections:

1. The right BIAS lead from the driver circuit board to the "R BIAS" terminal pad.

2. The left BIAS lead from the driver circuit board to the "L BIAS" terminal pad.

3. Connect the four leads from the filter capacitor to the appropriate C1a, C1b, C1c, and C1d terminal pads.

4. Connect one of the two red power transformer secondary leads to one of the "HV" terminal pads. Connect the remaining red lead to the other "HV" pad.

5. Connect the red/black power transformer secondary lead (which you have previously extended) to the "BIAS-AC" terminal pad.

6. Connect one of the two white power transformer secondary leads to one of the "5V" terminal pads. Connect the remaining white lead to the other "5V" pad. These leads may have discolored to a yellow tint.

7. Connect both of the output transformer red leads to the "P-REG" terminal.

8. Connect both of the output tube screen leads (pin 4, both channels) to the "S-REG" terminal.

9. Connect the white wire from the driver circuit board regulator out to the "V-REF" terminal.

10. Connect the black Wire from the ¾-inch ground point to the "GND" terminal.

11. Connect the lead from the front output tube junction to the RTP/LTP terminals for both channels.

12. Connect the output transformer blue/white lead to one of the L-S1/R-S1