60W Class-A Amplifier (part of the 'System A' series of articles)

By Stan Curtis

Class A Power

There is one amplifier configuration that is universally accepted as the ideal for audio use: Class A operation. Many early amplifiers operated in Class A, but as output powers rose above 10W the problems of heat dissipation and power supply design caused most manufacturers to turn to the simpler, more efficient Class B arrangements and to put up with the resulting drop in perceived output quality.

The System A applies the unchallenged excellence of Class A operation to the design of a reference amplifier free of the aberrations of commercially available models. Class A biasing is recognised as the ideal operating mode for an amplifier, offering the uncompromising accuracy demanded by dedicated audiophiles. The superiority of this amplifier depends on the output devices being constantly operated in their linear region, above cut-off and below saturation. Such operation results in the smoothest transfer function and the widest bandwidth.

The System A amplifier has a clarity and a tonal response that produces a superior perspective of depth with a sense of reality: instruments appear in precise position out of a silent background. The musical 'naturalness' of this amplifier is due to its lack of the constrictions of commercially desirable circuitry and the single-minded approach to a no-compromise sound quality.

Why Class A

The amplifier has an excellent technical performance even when operated in the conventional, but less desirable AB mode. With an open loop (i.e. no overall negative feedback) distortion of around 0.1% (1 kHz) and a frequency response stretching well outside the audio band, the use of the large amounts of negative feedback (found in most commercial competitors) is completely unnecessary. However, extensive correlation between measurements and subjective performance using a wide variety of amplifier types led to the conclusion that Class A biasing is the optimum for audio amplifier performance.

When biased to Class A, the transistors are always turned on, always ready to respond instantaneously to an input signal; Class B and AB output stages require a rnicrosecond or more to turn on. Thus Class A operation permits cleaner operation under the high-current slewing conditions that occur when transient audio signals are fed into difficult loads.

The continuous operation of the output stage in the linear collector region results in a more desirable distribution of distortion harmonics than is possible in Class B or AB because the non-linearities in the transfer curve are smoother and free of the abrupt transitions of class B and AB. The gradual non-linearities resulting from Class A operation produce distortions of low orders; primarily second and third harmonics. These lower order harmonics tend to be far less offensive to the ear than high order harmonics, being far more musical in nature (they are predominant in the harmonic spectra of most musical instruments). Higher order harmonics tend to 'harden' the overall sound. Such is the linearity of the Class A Amplifier that a mere 22 dB of gain reduction is made in the form of negative feedback.

Each amplifier is a completely separate self-contained mono unit. The use of mono amplifiers, while costly in terms of components, provides the maximum stereo signal separation under dynamic operation with complete freedom from cross-modulation effects, giving an improvement in subjective depth and accurate instrument imaging.

A glance at the photographs will also explain why each amplifier is made as a mono-block. A stereo version would be just too heavy, unwieldy and hernia-inducing for even the most dedicated audio fanatic (but if you know different...). Ideally each power amplifier can be located next to its respective loudspeaker and connected to it by very thick but short leads, thereby avoiding the losses associated with loudspeaker cables (30 A cable is suitable).

Protection - A Racket?

This Class A power amplifier is totally free of the usual protection circuits with their unavoidable colourations, distortions, and current-limiting characteristics. Instead we use an output stage having an exceptional power capability for an amplifier of such a low rating. With its substantial heatsinking this amplifier is capable of sustained operation with difficult loads.

The System A amplifier maintains complete control over the driven loudspeaker throughout its operating cycle. The true Class A operation avoids the inherent phase irregularity and inadequate current-sinking ability of comparable Class B and AB designs. The provision of an extremely low-impedance power supply gives the Class A amp a short-term current delivery and, equally important, current-sinking capability far in excess of any known Class AB power amplifier of similar rated output power.

Amp of Substance

The output stage is quite substantial, using a total of six 250 W power transistors. Fairly ‘old-fashioned' power transistors have been used (the MJ4502/802 family) in preference to some of the higher performance devices now available. They have been chosen because the die used to mount the semiconductor junction is of a large area; the device is quite rugged and can handle high currents. The short-term current capability of the output stage is, in fact, of the order of 90 A, somewhat in excess of the current capability of the wiring!

The power supply is equally substantial, using a 500 VA toroidal mains transformer and two massive computer grade reservoir capacitors. These components are expensive but essential. The rest of the construction is equally massive with a steel chassis supporting six very large heatsjnks. However construction is straightforward provided that the builder has strong arm muscles, and circuit alignment simple - there are but two adjustments - quiescent current and DC offset voltage nulling

Specification

Biasing mode:	Class A
Rated power:	60 W RMS into 8R (20 Hz to 20 kHz)
Transient delivery:	150 W into 8R
Harmonic and intermodulation distortion:	less than 0.06% at rated power output (20Hz to 20 kHz), decreasing monotonically with decrease in power. Distortion is virtually unmeasurable at small signal levels.
Frequency response:	10 Hz -1dB 120kHz -6dB (ref 0 dB at 1 kHz)
Power bandwidth:	5 Hz to 60 kHz
Hum and Noise:	100 dB below 24 V RMS output (CCIR)
Sensitivity:	700 mV RMS for 60 W into 8R
Negative feedback:	the open loop gain is reduced by 22 dB by the application of overall negative feedback
Transient intermodulation distortion:	zero

How It Works

This amplifier is basically simple, as can be seen from the block diagram (Fig. 1). Conventional complementary emitter-followers are driven by two separate voltage amplifiers arranged such that one handles the positive-going signals and the other the negative-going signals. A moderate amount of overall negative shunt feedback is then applied to stabilise the gain. To maintain a balanced and symmetrical treatment of the signal the performance of each 'sub-amplifier' should be the same. Furthermore these amplifiers have been designed to operate independently, without the need for the balancing signal currents from their 'mirror image' halves required in many so-called balanced amplifiers.

The simplified circuit (Fig. 2) shows that each sub-amplifier consists of two voltage-gain stages. This stage is of a novel arrangement previously used in a Meridian amplifier and subsequently in amplifiers by Lecson and Syntec. In the redesigned form here, the first stage consists of a complementary two-stage common emitter (Q1, Q5) whose gain is about x 2.3. The second stage is a current mirror stage (Q13) which drives the voltage across a load resistor tied to 0 V. The gain of this stage is about x 200. Thus the overall open loop voltage gain is of the order of x 460 and so, as the closed loop gain is x 26.7, the reduction due to negative feedback is x 17.2 or about 24dB.

Looking now at the final circuit (Fig. 3) it will be seen that the input amplifiers are powered from +/-15 V supply rails derived from resistor-zener regulators (R14-ZD1, and R15-ZD2). The current through the first stage (Q1) is held constant at about 0.36 mA by a floating regulator stage (Q3, Q4) which also provides temperature compensation. The gain of this stage is set by emitter resistor R4 which provides some local negative feedback. The second stage (Q5) is loaded by two series cascode transistors (Q6, Q7), the first having its base tied to ground and the second having its base tied to the -15 V rail. Thus the maximum collector voltage swing on Q5 is greatly reduced, so reducing the effect of the base-collector capacitance (Miller effect) which would reduce this stage's high frequency bandwidth. In summary, the presence of Q6 and Q7 improves the bandwidth and linearity. The load on Q7 is one half (Q12) of the current mirror and can be visualised as a resistor in series with a forward-biased diode. The second half of the current mirror is a common-emitter stage (Q15, Q16), a simple voltage amplifier except that its collector current equals (or 'mirrors') the collector current of the other half (Q12). This stage is made up of two transistors in parallel which share the current. This arrangement was found to improve the linearly of the stage. The other 'sub-amplifier' (Q2 to Ql4) works in exactly the same way but with opposite polarity.

The output stage uses the conventional Darlington emitter follower arrangement but with three parallel pairs of driver and output transistors. A transistor (Q17) is wired across the bases of the pre-driver transistors (Q18. Q19), providing a bias voltage to set the standing current in the output stage. Q17 is mounted on the heatsink with the aim of keeping this current constant regardless of temperature. Preset resistor PR2 is used to set the value of this current.

It will be seen that both the current mirror stages are driven from power supply rails that are different from those feeding the output stage. The same supply could be used but the signal in the current mirrors would clip well before the output stage, reducing the available output power. In fact the supplies to the current mirrors are made sufficiently high that these stages are still operating in their linear regions when the output stage clips.

The output DC offset voltage is set to zero by preset PR1 in the input stage. In theory there should be no DC offset at the output but, because of component tolerances and consequent mismatching, there always is. PR1 is arranged to make the current in the first stage of one 'sub-amplifier' either higher or lower than in the other and so null out any residual offset

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A simple low-pass filter is created by an R-C network at the input (R2, C2) to reduce the bandwidth of the signal below that of the open loop amplifier and thereby eliminate the generation of any transient intermodulation distortion.

The power supply has to deliver two split rails. The main supply to the output stage is nominally +/-40 V at 4 A, derived from the main transformer windings and rectified by bridge rectifier BR1. This rectifier can get very hot so it is bolted onto the chassis. The secondary supply is a low-current +/-50 V to power the voltage amplifier stages. The output from the extra windings is rectified by BR2 and fed to smoothing capacitors C12 and C13. These capacitors are not wired between supply and ground but between the two supplies; this layout reduces their voltage rating.

The mains supply is fed to the transformer via an on-off switch, a fuse, and a thermal cut-out switch. Two neon indicator lamps are used. LP1 is connected between live and neutral and is the ‘power' indicator; LP2 is connected across the thermal cut-out. If this cut-out opens the full supply voltage is applied across LP2 which then illuminates as an 'over-temperature’ indicator. (This indicator has never operated yet in the prototypes.) Care should be taken to adequately sleeve and insulate all mains wiring and terminals to ensure safe and reliable operation.

Parts List

Resistors	
R1	47k
R2,10,26,27	1k0
R3,22	10k
R4,9	560R
R5,11	3k9
R6	12k
R7,8,23	2k7
R12,13	120R
R14,15	680R 4W
R16,17,28,29,32,33,36,37	100R
R18,19,20,21	200R
R24,25	22k
R30,31,34,35,38,39	0R22 2W5
R40	10R 1W
R41	10R 2W (not wirewound)
R42	5k6
R43	18k
R44	300R
PR1	20k miniature preset
PR2	2k2 miniature preset
	All resistors 1/4W, 5% except where stated
Capacitors	
C1	10u 35V tantalum
C2	1n0 polystyrene
C3	100p polystyrene (22p - see update)
C4,5,9	100u 6V3 tantalum
C6,7	100p miniature ceramic
C8	220n polycarbonate
C10,11	15,000u 50V electrolytic (Sprague
C12,13	36D)
	470u 63V electrolytic
Semiconductors	
Q1,4,8,9,10,17,18	
Q2,3,5,6,7,19	MPSA06
Q11,13,14	MPSA56
Q12,15,16	MPSA93
Q20,24,28	2N6515
Q21,25,29	BD379
Q22,26,30	BD380
Q23,27,31	MJ802
ZD1,2	MJ4502
	15V, 1W3
Miscellaneous	
SW1	
TS1	DPST mains switch
LP1	Thermal cut-out switch
LP2	Red neon
FS1	Orange neon
FS2	1.25" 5A – 10A (to suit loudspeaker)
	20mm 3.15A

Construction

The constructional layout shown in the drawings and photographs should be followed as closely as possible. (With such high currents flowing down the cable forms, problems can easily occur if too many changes are made). The heatsinks and the power supply components are assembled onto the base-plate and wired up in accordance with the wiring diagram. The recommended wire types and gauges should be adhered to. Any bare wire ends should be sleeved using silicone rubber sleeving. This may seem an extravagance but your opinion will change shortly after a short-circuit wipes out £18 worth of transistors! A substantial soldering iron will be needed to solder together the power supply components. The use of a low-power iron will usually result in a selection of dry joints on these connections.

The coil L1 is wound onto the body of R40. This is not a critical procedure - about 17 to 20 turns of enamelled copper wire should do nicely. The gauge can be anything you have to hand, from 20 to 26 swg. Use some lacquer or epoxy to hold the wire in place on the resistor, scrape the enamel off the ends of the wire and solder them close to the resistor. The whole thing can now be soldered in place on the board.

Particular care should be taken in mounting the power transistors. Good quality insulating washers and bushes should be used and a generous smearing of thermal paste is essential. These transistors should be bolted to the heatsinks very tightly to ensure good thermal contact at all temperatures.

Assembly of the printed circuit board is straightforward enough using the component overlay as a guide. As usual, particular care should be taken to confirm the polarity and alignment of all capacitors, diodes and transistors; and to avoid putting mechanical strain on any of the components. After assembly the board should be checked on the copper side for dry joints and solder bridges. Such defects on power amps usually result in an expensive bang so don't skip this admittedly tedious chore.

One final point regarding construction. Once the amplifier has been completed and tested, it should be switched on and allowed to reach its normal operating temperature (about 20 minutes). The amplifier should then be switched off and all the screws tightened up. Differences in thermal coefficients of expansion can result in some of the screws becoming slightly loose, particularly those holding the heatsinks to the top and bottom covers.

Testing and Set-up

This amplifier is straightforward to test providing a logical sequence is followed. The first test is without the main PCB fitted and without the power transistors connected to the power supply. Check that there is no leakage between the collector of any power transistor and heatsink using a high-resistance range of your meter. Next check the output transistor junctions (base-collector. base-emitter, collector-emitter and so on) at the PCB end of the wiring loom. If all is well the power transistors can be forgotten for the moment.

Next, the power supply. Fit a mains fuse; switch on and check that the voltage across the reservoir capacitors is +/-40 V (within 2 V). Allow these capacitors to discharge and then fit the PCB assembly, connecting all the wires except those to the power transistors. Both the presets should be set to mid-travel and the power again switched on. The secondary supply rails can now be measured and should be about +/-50 V. The output DC offset voltage (junction of R28, R29) should be measured and should be adjustable to zero by turning PR1. If the offset voltage cannot be adjusted you have a fault on the board.

If all is well disconnect the supply and again wait for the power supply to discharge. Now connect up the power transistors to the PCB but with a current meter (able to measure greater than 3 A DC current) in series with the positive supply to the three collectors (Q22, Q26 and Q30). Ideally a voltmeter should be connected between the output rail and ground. Say a short prayer and switch on. You should find that PR2 (turned clockwise) will increase the current and PR1 should still adjust the DC offset voltage. Adjust the current to about 1 A and, using a loudspeaker and convenient signal source, quickly check that the amplifier works. If it does, the amplifier can be set up properly; but be warned that this takes several hours.

Set the current to 3 A and allow the amplifier to heat up. The current will vary so adjust it gradually every 10 minutes or so until it is stable. The DC offset can now be nulled to zero but as this can interact with the current some alternate adjustments will be needed. After a couple of hours the amplifier should be stable and ready for use.

Update (ETI February 1986)

1. The sound quality is improved by using 1% 1/4W metal film resistors throughout.

2. With most good loudspeakers it is worth removing the Zobel network (C8, R41) and replacing the output choke (L1, R40) with a 10 W wirewound 0R22 resistor.

3. There will be some difficulties in setting up the amplifier unless zener diodes ZD1 and ZD2 are close tolerance types or closely matched to each other.

4. Capacitor C1 can be left out or, if there is a danger of offset voltage at the pre-amplifier output, replace it with 1u0 100 volt polyester.

5. Capacitor C3 should be replaced by a 22p 100 V polystyrene type.

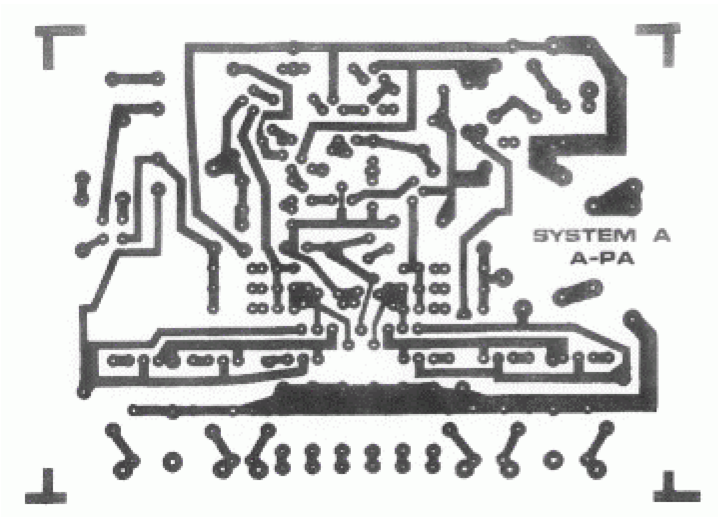
6. When setting-up the standard current, the case should be as complete as possible since this affects thermal equilibrium.

7. The heatsinks should be chosen to allow the amplifier to run at a case temperature of between 40 and 50ºC. Since each output transistor dissipates 40W, each should be bolted to a heatsink having a rating of less than 1ºC/W.

8. The power supply wiring, the output wires and the wires to the output transistors should be as thick as practically possible (at least 2.5 mm).

9. Constructors will find it worth resetting the standing current and DC offset voltage after the amplifier has been in use for about ten hours.

Figures



The pcb foil pattern

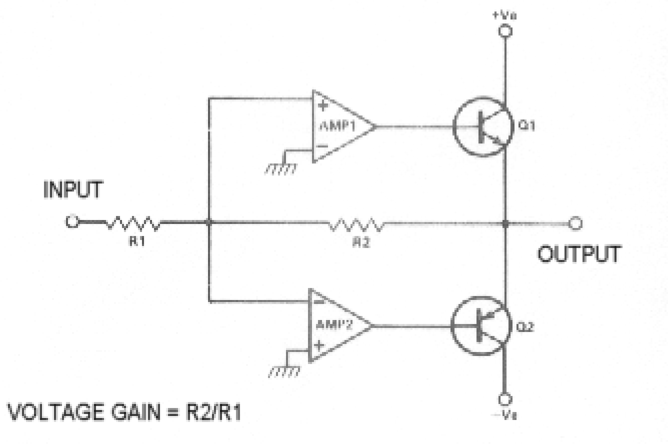


Fig. 1 Simplified block diagram of the power amp.

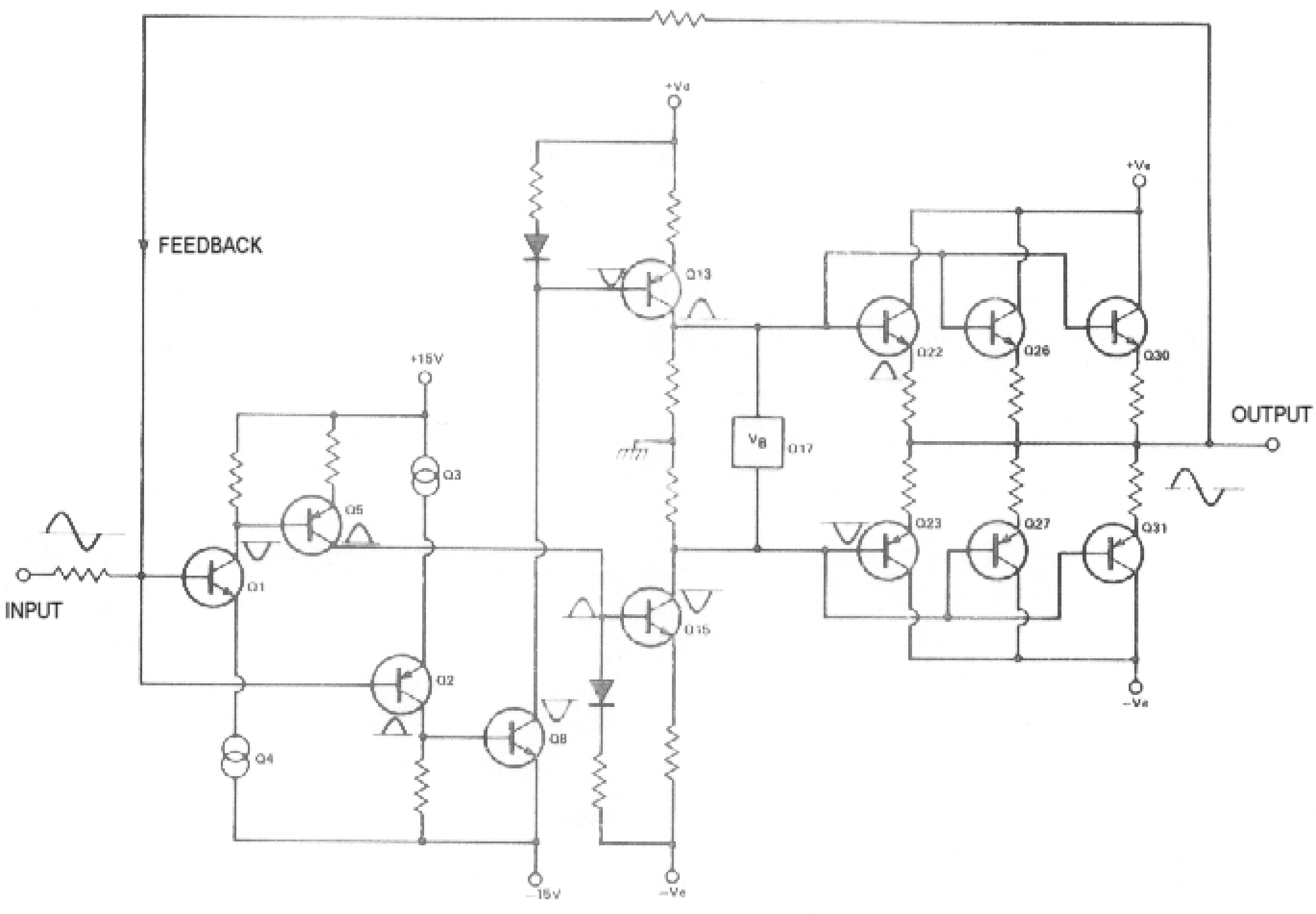


Fig. 2 A ‘flow chart’ circuit diagram illustrating the operation of the System-A amp.

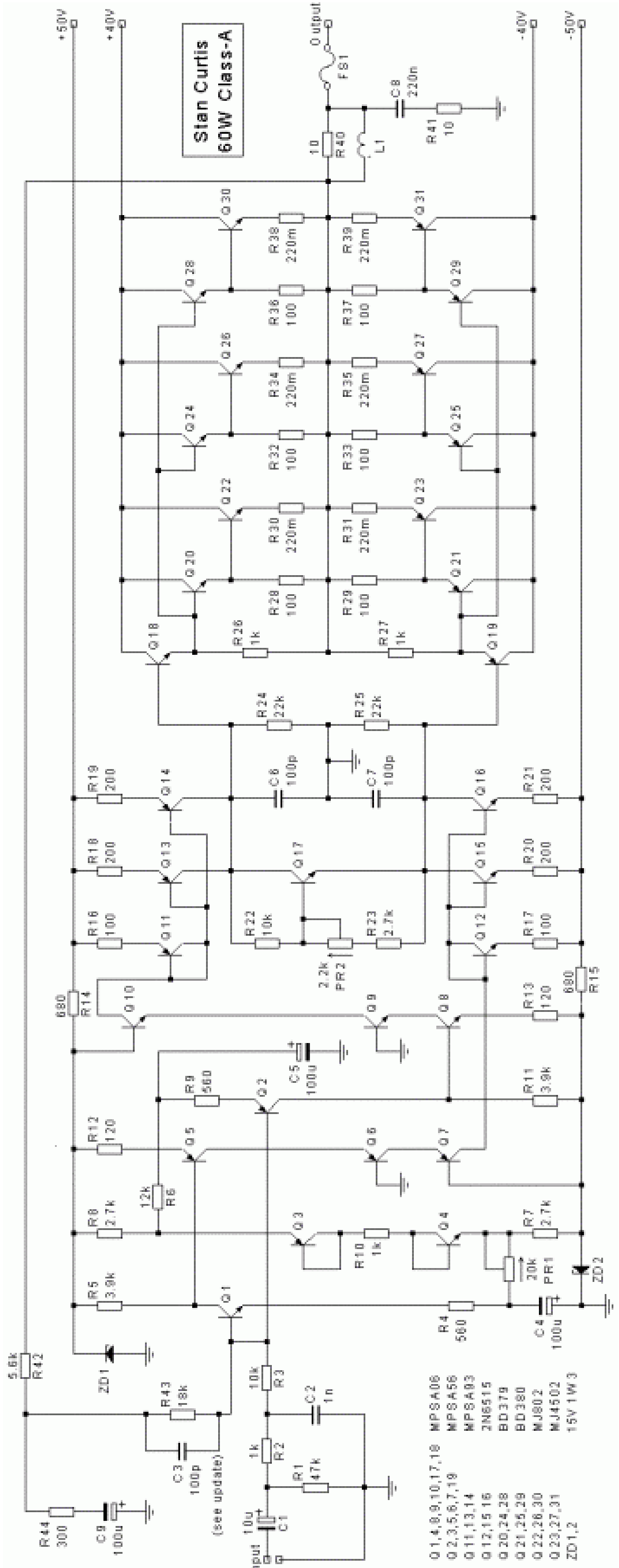


Fig. 3 The complete circuit diagram for the System-A power amplifier. Note that the output transistors are mounted remotely from the main PCB.

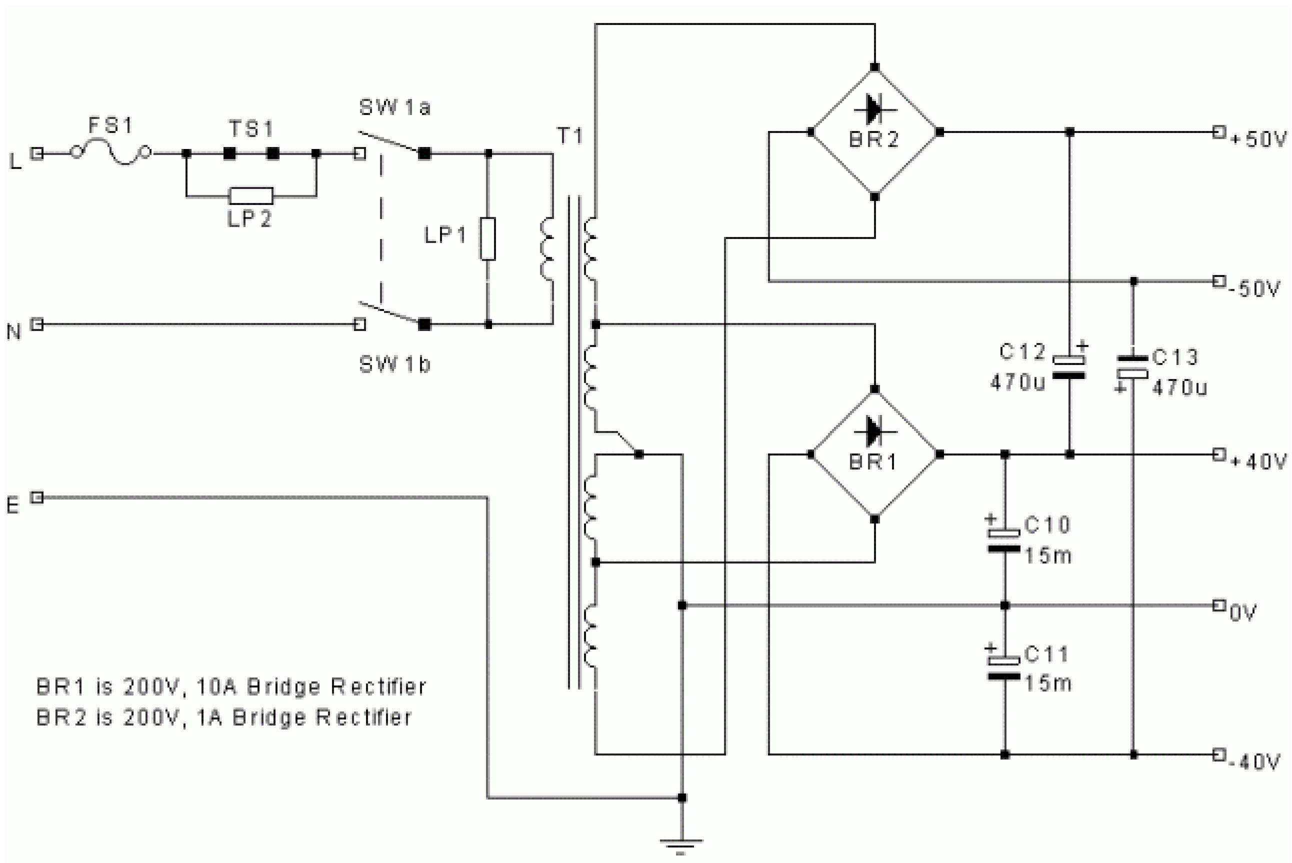


Fig. 4 The PSU circuit used to drive the power amps.

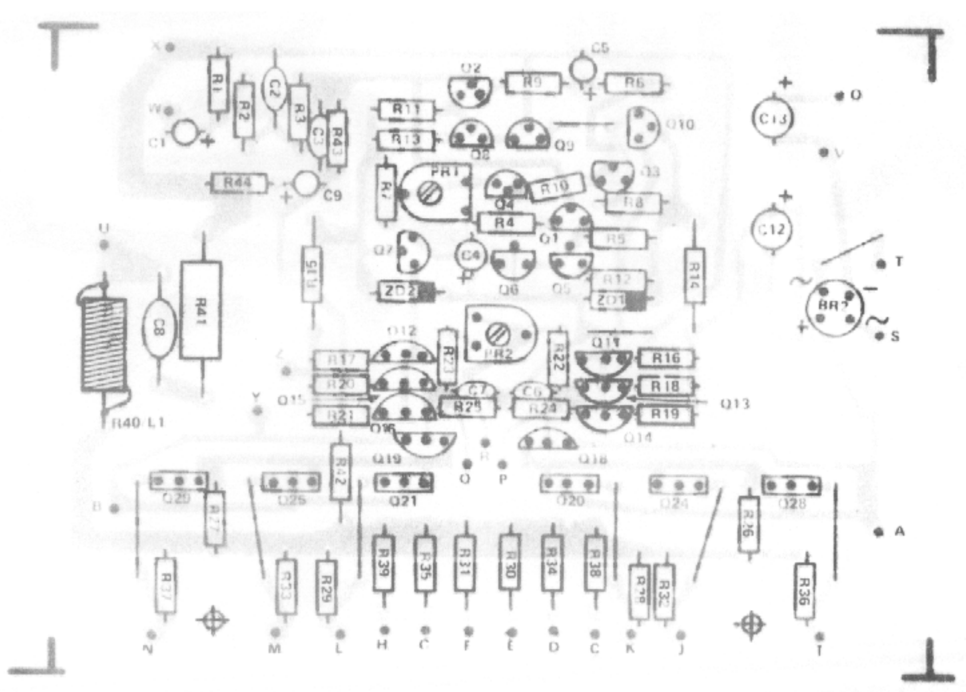


Fig. 5 Component overlay for the power-amp pcb.

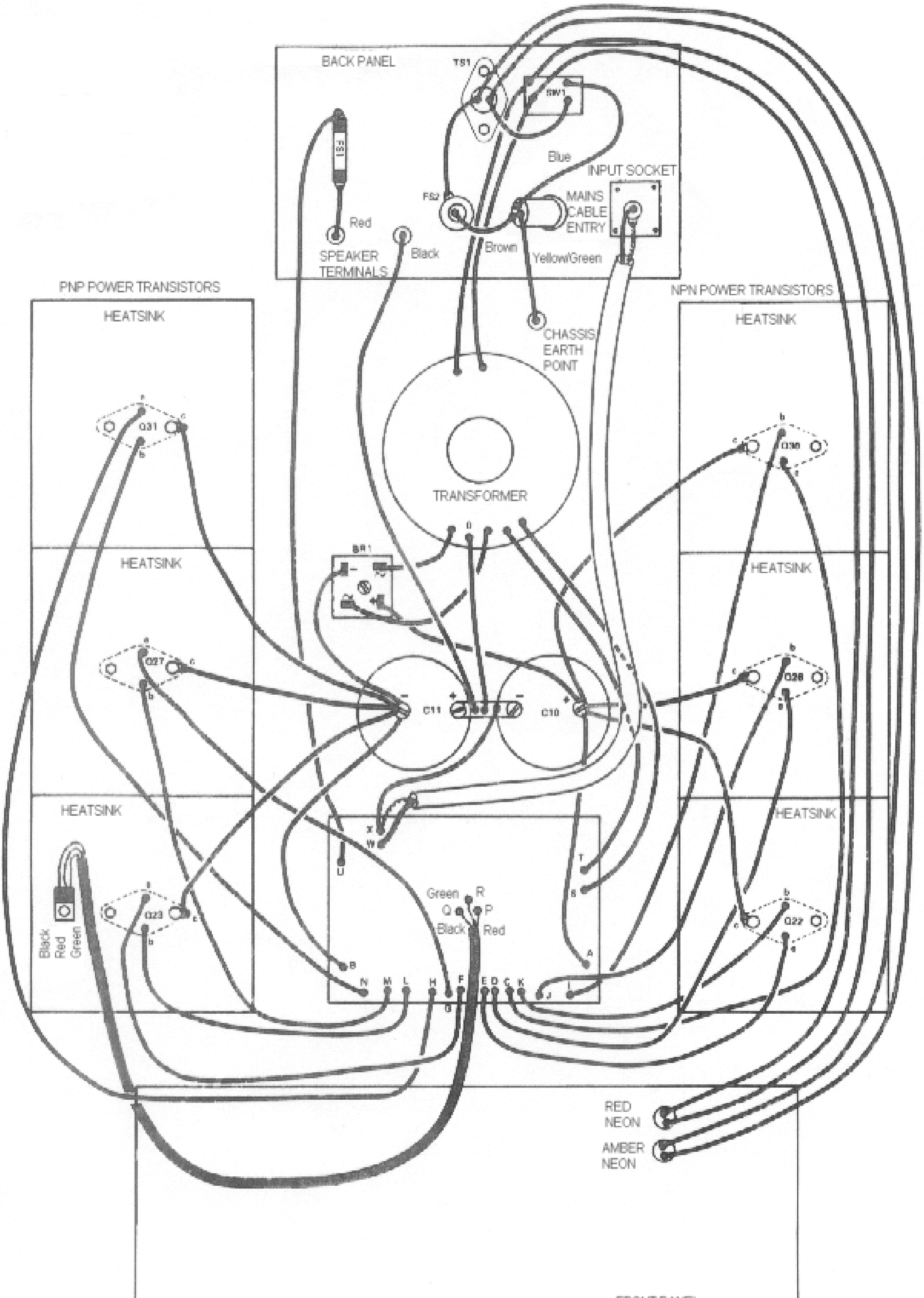


Fig. 6 A bird's eye view of the inside of the power amp with the case taken part and laid flat to show the wiring connections. With this diagram to identify point-to-point connections, and using the photographs as a guide to the layout of the looms, construction should be easy, albeit tedious. Make sure the wire carrying high currents is up to the job!