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"THE MUSIC-LOVER 12"

by B. J. SIMPSON

INTRODUCTION

This design started off when I felt the need for a good quality amplifier of modest but adequate power output, using components which are available locally, and specifically intended for the home constructor. The target was a stereo main amplifier with about 5 watts in each channel, a stereo tone control and preamplifier unit, followed at a later date by a radio tuner unit.

As can be imagined, quite a lot of thought was given to the general form these units would take, to the way they would be constructed, and the question of economy. A decision was taken early on in the exercise to power all the units from one integrated power supply, on the grounds that this would be a cheaper solution to the power problem than the construction of separate power sections for all the units.

It was also decided that the single power supply unit and the stereo main amplifier would be built on two standard 8″ x 10″ aluminium chassis in "dead front" form, i.e., with no controls on them. They could therefore be stowed away in any convenient location, thus assisting the problem of fitting the system into the chosen room.

At the same time, the preamplifier was to be constructed in a specially-constructed aluminium chassis fixed behind a dummy front panel. In this way the unit is suitable mounting rack fashion into a large cabinet housing all the gear, or in a similar fashion could be mounted into a smaller cabinet holding only the preamplifier. The preamplifier carries all the controls for the complete system, and is the only unit therefore to which access is required whilst the system is in use.

Whilst the preamplifier chassis is a specially constructed unit, the geometry of which is dictated by the necessity for an efficient layout and complete screening of the circuitry, the actual mechanical construction of the chassis is quite simple. At all times the idea of home construction has been to the fore, and tools and processes not normally available to the home constructor have been avoided. In this way, the preamplifier chassis is actually a simple unit consisting of flat aluminium plates bolted together with short lengths of ¾″ or ½″ aluminium angle.

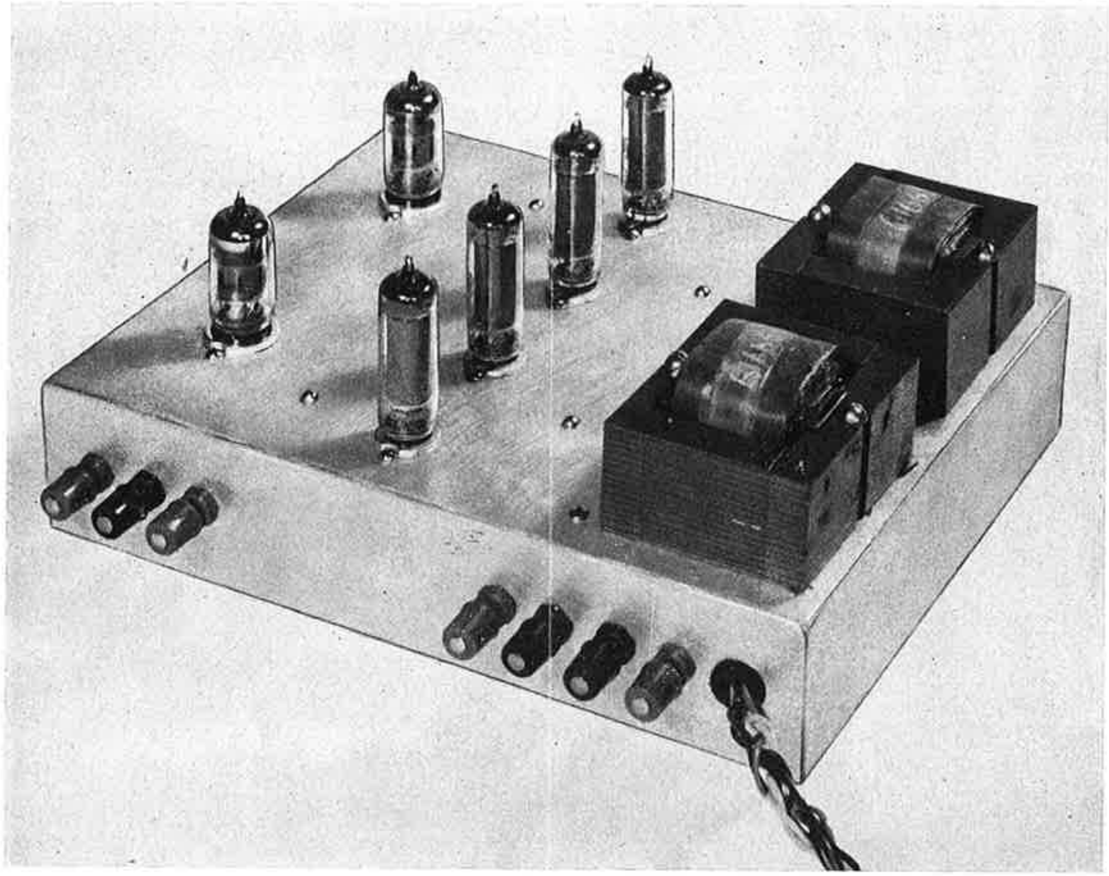
It is intended that the radio tuner unit will be built behind a dummy front panel as in the case of the preamplifier unit, but here of course a much less elaborate chassis will be required. Initially only the standard broadcast band will be covered.

In this first article on the subject, the stereo main amplifier and the combined power supply units will be dealt with. Details of the preamplifier and the radio tuner units will follow at a later date.

PERFORMANCE

As we are discussing this month only the main amplifier channels of the system, remarks on performance will be restricted to those pertinent to that section. Data on the preamplifier will be reserved until the full description of that unit is published.

One of the usually accepted standards for high fidelity performance is that the amplifier will deliver the stated power at 1% total harmonic distortion or better. This stems from the fact that it is widely accepted that the minimum aurally



Top view of the stereo main amplifier.

detectable level of distortion is about 1%. In any case it forms some sort of criterion.

As it turned out, by the time this unit had been worked on a little, it was found to deliver 6 watts at better than 1% total harmonic distortion with both channels fully driven and with sine wave input at 1 Kc. In fact, in the model, 6 watts output was obtained for 0.6% total harmonic distortion, so that the figure claimed is very conservative, and makes ample allowance for slight variations in components and similar factors. Intermodulation distortion is 1.5%. Cross talk between the two channels of the main amplifier is acceptably low at 40 db down with one channel fully driven. The noise level is 72 db below full output.

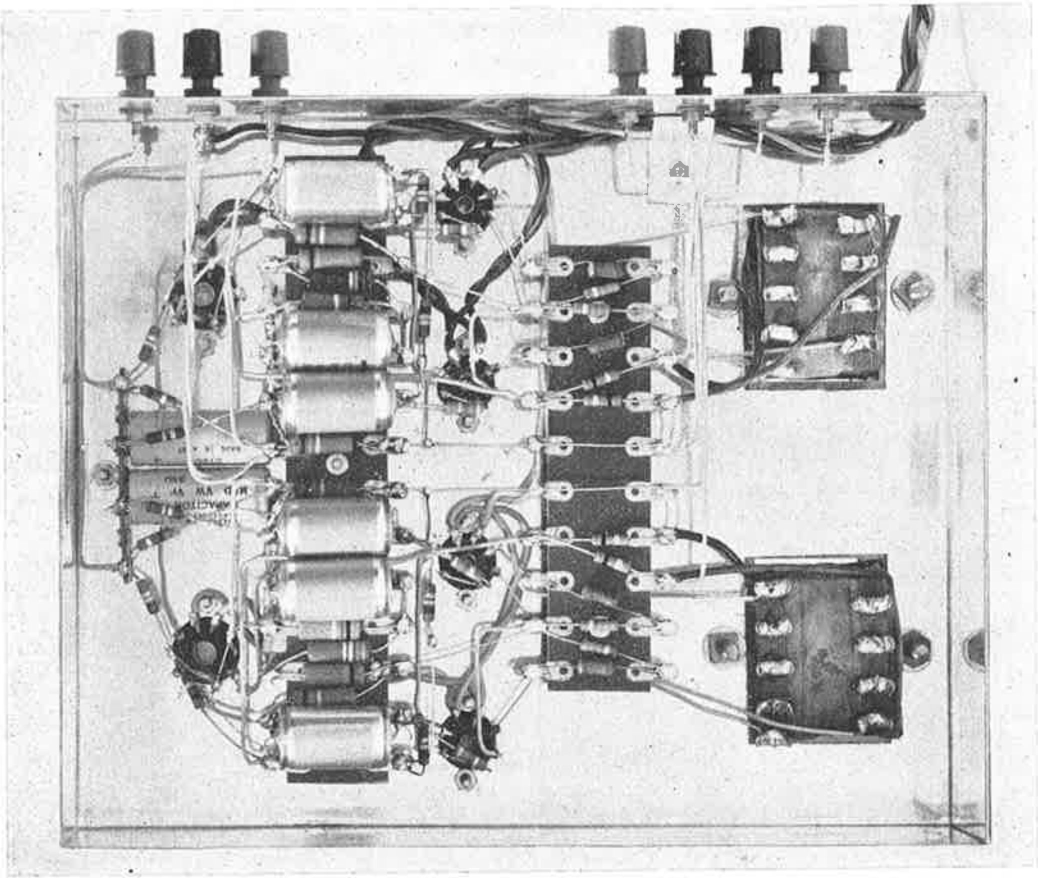
To deal with the response characteristic of the main amplifier, we could say that the response is 15 to 15,000 cps +0—3 db. This however does not tell the whole story. In fact the unit's response is flat from 15 cps through 5,000 cps, falling 0.5 db at 7,500 cps, 1.5 db at 10,000 cps, and 3.0 db down at 15,000 cps. This tells a better story. These figures, as is customary, were taken at the 1 watt output level. As a matter of interest, the response curve is substantially the same at the 6 watt output level, a much more severe test.

The input signal level required to load the amplifier to the full 6 watts output is of the order of 1250 millivolts.

THE MAIN AMPLIFIER

The basic prescription for the main amplifier followed mainly standard lines, in that the design called for two beam power valves preceded by a phase splitter and a voltage amplifier. These days of course the function of phase splitter and voltage amplifier are usually combined in a multi-unit valve, and this is what happened in this case. Two basic requirements still remain to ensure good quality: these are a good output transformer and enough negative feedback to flatten the response curve of the amplifier. As the amount of useful feedback that can be obtained is still partly a function of the output transformer, we tackled that problem first.

The Component Design section of M.S.P. was approached with the request for a suitable



Underside view of the stereo main amplifier.

transformer, and they came up with a very good one, on which the performance of the complete amplifier depends. In the original design, as shown in the photographs, the transformers had some experimental taps; these taps are not required in the final design, and should therefore be ignored in the photographs.

The valve chosen for the final stage in the main amplifier was the 6AQ5, operated in class AB1 with fixed bias. The valve chosen for the phase splitter and voltage amplifier was the 6U8. The triode section of this valve, which forms the phase splitter, is conventional in form, but the pentode section voltage amplifier is used in an unusual starved-current direct-coupled arrangement. The direct coupling reduces phase shift in the feedback loop and helps to make the amplifier very stable.

The feedback arrangements are also a little unusual. Feedback is taken from the voice coil winding of the output transformer in the usual way, but is applied to the grid of the voltage amplifier. This system sprang in part from the fact that the more conventional insertion of the feedback voltage into the cathode circuit of the voltage amplifier was complicated by the operation of the valve in a starved-current mode.

The system chosen works very well. Further, it readily lends itself to simple readjustment for different voice coil impedances, and to experimental adjustment of the amount of feedback used. This is not to suggest that the amount of feedback should be experimented with in every case, because the percentage chosen already strikes a good compromise. Experimentation is not recommended unless the necessary equipment is on hand to evaluate results.

In addition to the main feedback circuit, there are three sources of feedback in the 6U8 stage. The screen of the pentode section is fed from the triode cathode. Not only does this provide a very convenient method of energising the screen, but also provides dc feedback to the screen. A 2.2 pf capacitor provides negative feedback at very high frequencies of the order of 15 Kc and over, between cathode of the triode and the pentode control grid. This capacitor reduces ringing when testing on square waves without appreciably affecting performance at the higher frequencies. Feedback is also provided between the plate circuit of the pentode and the cathode of the triode; this reduces plate loading in the pentode section and improves the low-frequency performance of the amplifier.

The usual RC combination is applied across each half of the output transformer primary, largely as a precautionary measure. It will be noted that the time constant of the RC filter is perhaps a little shorter than usual, but is adequate for the purpose, and removes any possibility of supersonic signals either degrading the amplifier performance or damaging the output transformer.

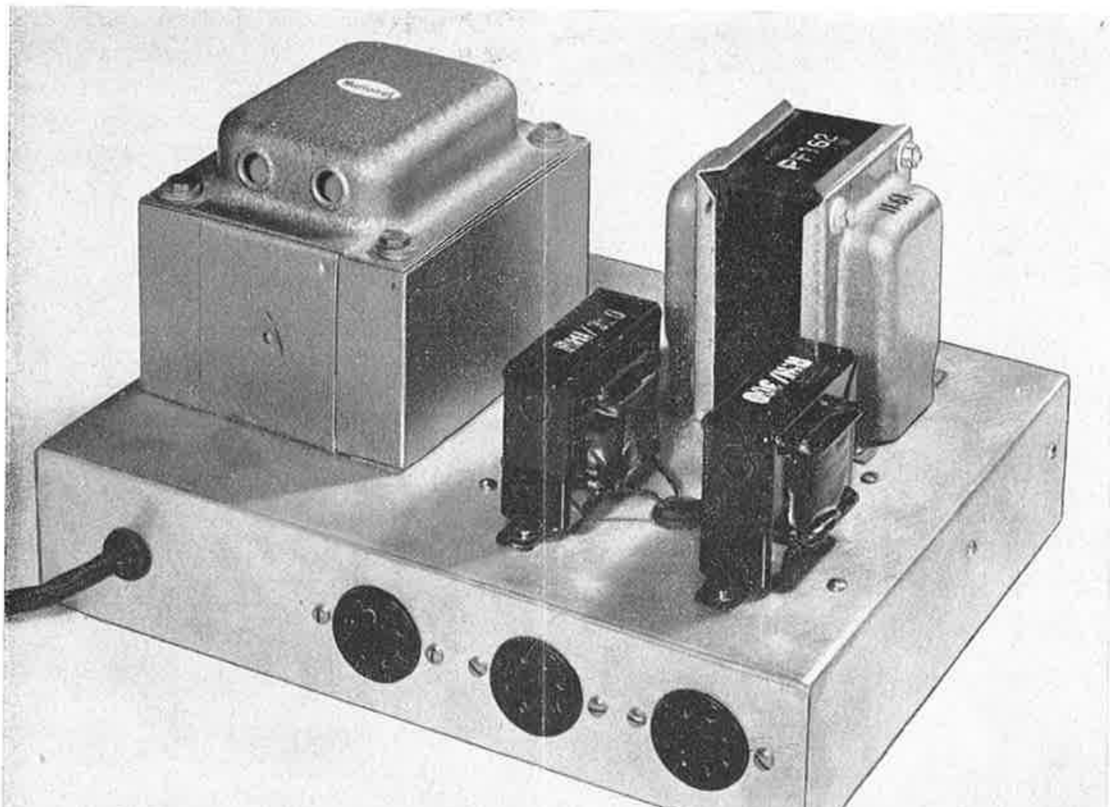
The grid stoppers in the 6AQ5 circuits were not really necessary, but were included as a matter of good practice, the cost of the components being insignificant. The question will doubtless be asked why the more economical cathode bias was not used instead of fixed bias. The answer here is a simple one, the matter of performance: with a 250 volt B+ supply, the maximum permitted with the 6AQ5, I was unwilling to lose 15 volts, 6% of the available voltage, with the consequent lowering of performance. If a somewhat poorer performance in terms of power output and fidelity can be tolerated, then cathode bias could be used and show a slight saving in cost.

The rest of the main amplifier is straightforward and requires no comment. The mechanical arrangement and layout of components is shown in the accompanying photographs and diagrams, and no difficulties can be seen in putting the unit together. Whilst the layout is not critical, it is suggested that adherence to the layout shown will save the trouble of planning a new one.

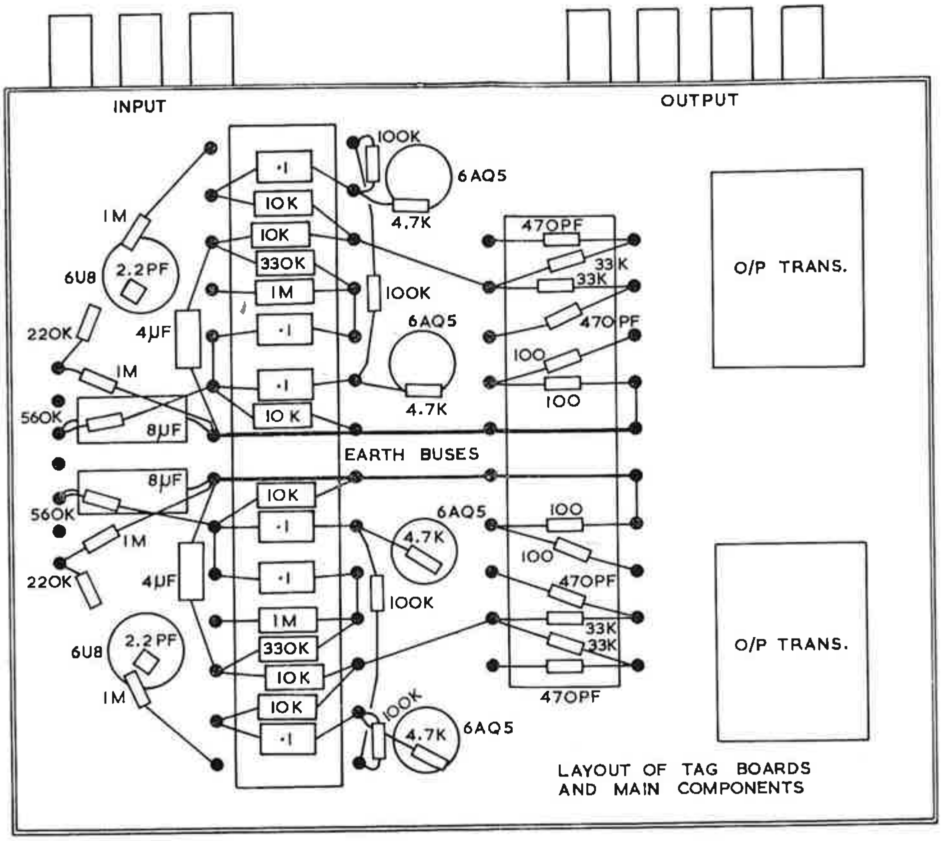
The system of interconnections between the power supply and the other units of the system is at the builder's discretion. In my case I used a simple and cheap octal plug with a plastic screw-on cover, together with standard octal sockets. The sockets are mounted in the power unit, whilst the plugs terminate multi-way leads attached to the individual units. Terminals or any other system could be used instead, but a polarised plug removes the danger of wrong connections.

THE POWER SUPPLY

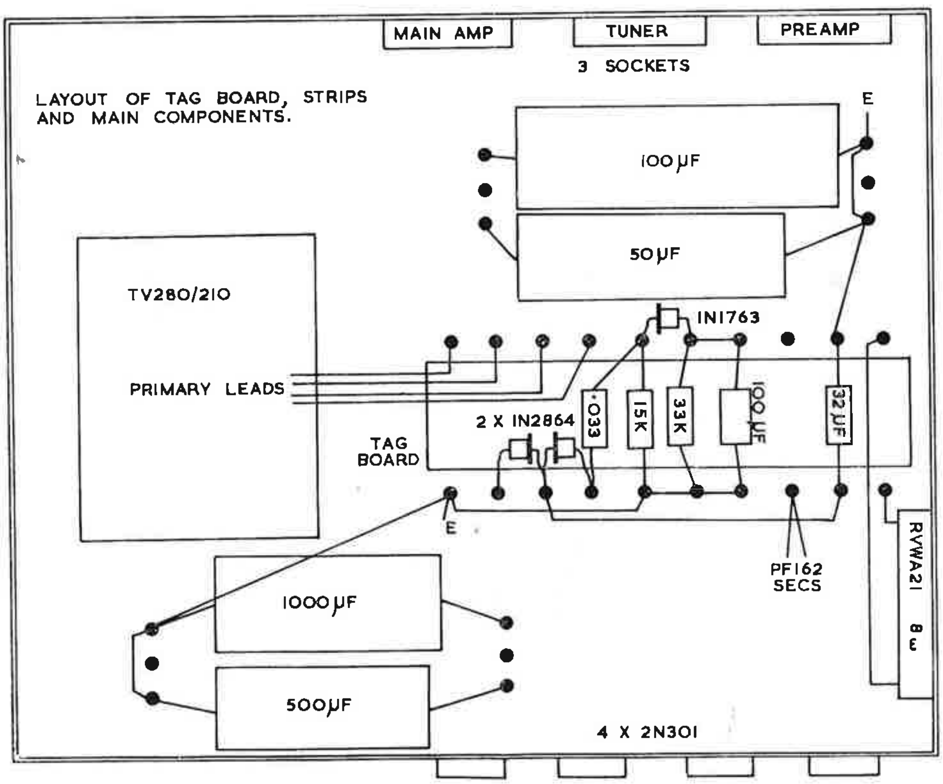
As previously mentioned, the power supply unit is intended to cater for all units of the



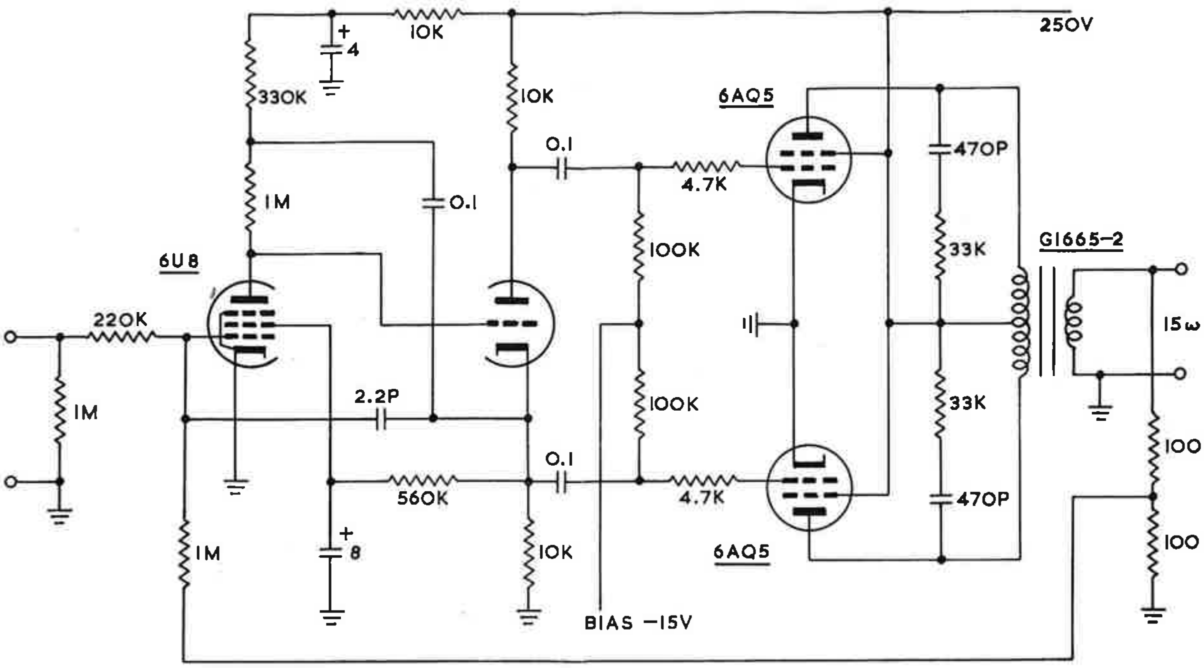
Top view of the power unit.



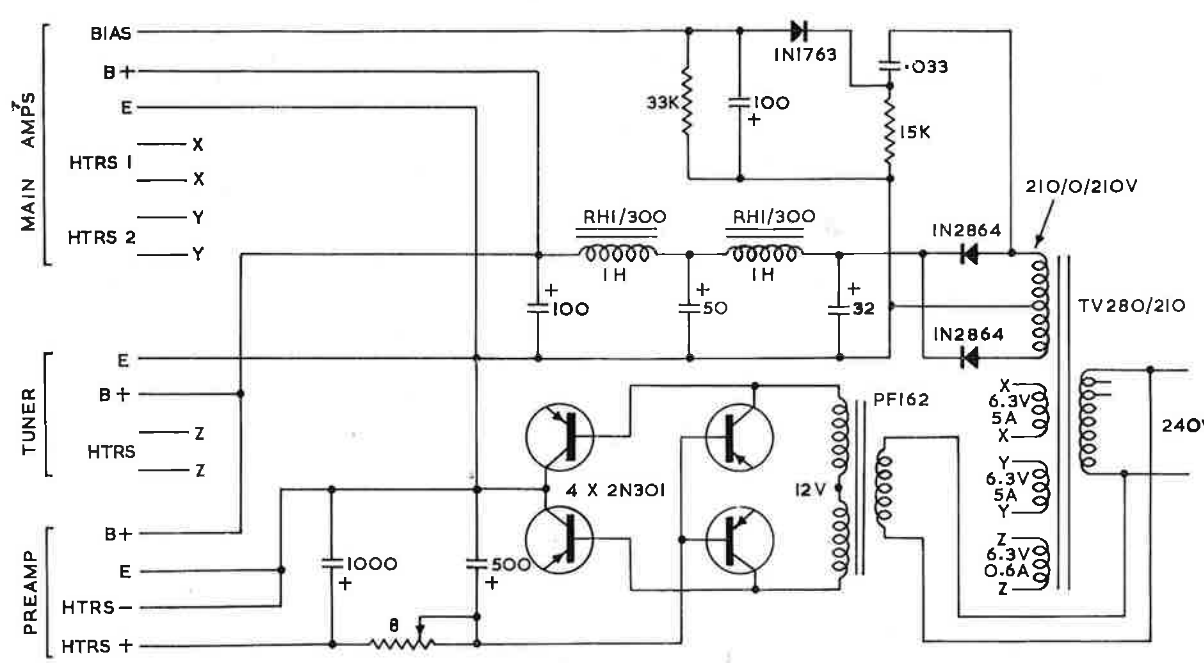
Component layout in the stereo main amplifier.



Component layout in the power supply unit.



Circuit diagram of one channel of the stereo main amplifier; two identical channels make up the complete amplifier.



Circuit diagram of the integrated power supply, which provides power for all the component parts of the system.

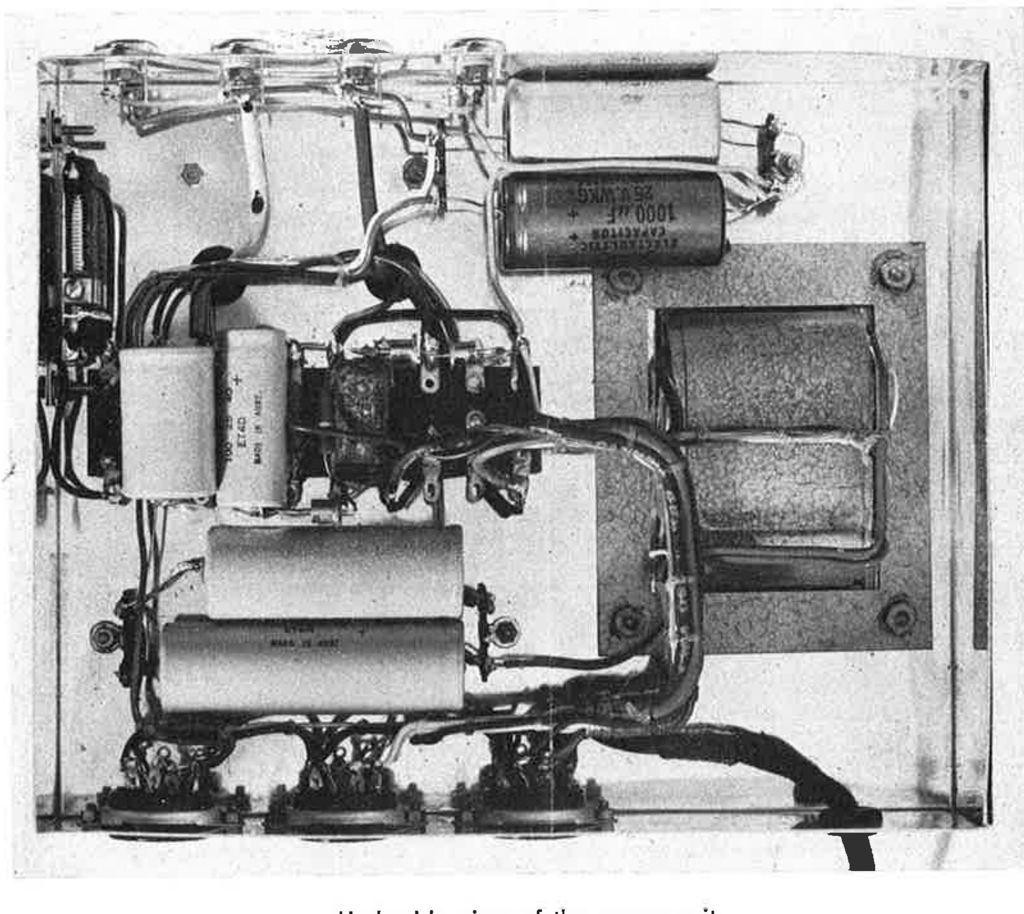
system. Further, as a precaution against hum in the low-level stages of the preamplifier, it was decided to employ dc throughout in that unit. The power supply therefore has to provide a B+ supply at 250 volts, a bias supply of −15 volts, a 6 volt dc supply for the heaters in the preamplifier, and the necessary 6.3 volt ac supplies for the heaters in the rest of the system.

A lot of thought was given to the best way of providing these supplies economically and using standard parts if possible. Separate heater supplies for the two channels in the main amplifier were thought desirable in case balancing about ground was required to reduce hum. Where two separate channels are fed from the same heater supply, the optimum balance point for one channel rarely seems to coincide with that for the other channel.

It was not possible to find one standard mains transformer that would give what was required, and it was hardly to be expected. The final solution, as shown in the accompanying diagrams, uses two mains transformers which are standard items and readily available. The first transformer is a TV280/210; this item gives 210/0/210 volts at 280 ma in the B+ winding, two 6.3 volt 5 amp windings and one 6.3 volt 0.6 amp winding. The other transformer is a filament transformer, with two 6.3 volt 3 amp windings, one of which has a centre tap.

The 210/0/210 volt winding on the TV280/210 transformer is used with two 1N2864 silicon diodes in a full-wave rectifier arrangement, using a two-section LC filter to provide a B+ supply for the entire system at 250 volts. The chokes used are standard 1 henry units, type RH1/300. The two 5 amp heater windings are used for the two channels in the main amplifier, where they are underrun. The 0.6 amp heater winding on this transformer is reserved for the heater supply in the radio tuner unit.

The bias supply for the main amplifier unit is derived from one side of the B+ winding on the TV280/210 transformer, a fairly common practice. A 1N1763 silicon diode half-wave rectifier is fed from an RC voltage divider connected straight across the winding. The rest of the bias circuit consists simply of a load resistor and capacitor filter. This is a very cheap and simple way of providing a low voltage at negligible current and should be used more often.



Underside view of the power unit.

The remaining part of the power unit is the dc heater power for the preamplifier. This is provided by the PF162, with the two windings connected in series aiding, and with the centre tap of one of the windings unused. The 12.6 volt output is rectified in a bridge rectifier arrangement, consisting of four 2N301's in which the collectors and bases only are used. Readers will remember that a similar arrangement was used in the low voltage transistorized power supply recently described in these pages. The output of the bridge rectifier is applied through a simple RC filter in which the resistive element is adjustable; the resistor is adjusted for 6 volts dc on the heaters of the preamplifier valves.

The power supply section is also built on a standard 8″ x 10″ aluminium chassis. The layout is shown in the accompanying photographs and diagrams. Only a small amount of heat is developed in the 2N301's, and their attachment to the skirt of the chassis as shown is sufficient provision for heat sinking.

PARTS LIST FOR MAIN AMPLIFIER

Valves

4 Super Radiotron 6AQ5
2 Super Radiotron 6U8

Transformer

2 M.S.P. Sample type G1665-2, 10K ohms plate to plate, 15 ohms secondary.

Resistors

4 100 ohm $\frac{1}{2}$ watt
4 4.7 ohm $\frac{1}{2}$ watt
6 10K ohm 1 watt
4 33K ohm $\frac{1}{2}$ watt
4 100K ohm $\frac{1}{2}$ watt
2 220K ohm $\frac{1}{2}$ watt
2 330K ohm 1 watt
2 560K ohm $\frac{1}{2}$ watt
4 1M ohm $\frac{1}{2}$ watt
2 1M ohm 1 watt

Capacitors

2 2.2 pf ceramic 500 V.W.
4 470 pf ceramic 500 V.W.
6 0.1 mf paper 400 V.W.
2 4 mf electrolytic 300 V.W.
2 8 mf electrolytic 300 V.W.

Miscellaneous

Chassis, valve sockets, terminals, tag strips, connecting plug, assorted hardware.

PARTS LIST FOR POWER SUPPLY

Semiconductors

4 AWV 2N301 transistors with mica washers
2 AWV 1N2864 silicon diodes
1 AWV 1N1763 silicon diode

Transformers

1 TV280/210. 210/0/210 volts at 280 ma, 2 x 6.3 volts at 5 amps, 6.3 volts at 0.6 amps
1 PF162. 2 x 6.3 volts at 3 amps

Inductors

2 RH1/300 filter chokes, 1 henry at 300 ma

Resistors

1 8 ohm wirewound adjustable, 30 watts, FRWA21
1 15K ohm 1 watt
1 33K ohm 1 watt

Capacitors

1 0.033 mf paper 1000 V.W.
1 32 mf electrolytic 300 V.W.
1 50 mf electrolytic 350 V.W.
1 100 mf electrolytic 300 V.W.
1 100 mf electrolytic 25 V.W.
1 500 mf electrolytic 25 V.W.
1 1000 mf electrolytic 25 V.W.

Miscellaneous

Chassis, tag strips, connecting sockets, assorted hardware.

Transistors As RF Power Amplifiers

By J. B. Fisher, WA2CMR/6

RCA Semiconductor and Materials Division

Recent advances, particularly the advent of the high-frequency "mesa" device and the use of silicon, have brought transistors to the point where they may usefully serve as drivers for high-power-output valves, or as power stages themselves. To effect a smooth transition from valve to transistor circuit design, however, the experimenting amateur should be aware of the major differences between the two devices. Some of the important considerations for rf power amplifier design are discussed below.

Class of Operation

The transistor is a natural class C amplifier because the emitter-base contact potential must be overcome before collector current will flow. A transistor connected as shown in Figure 1 is automatically biased in the class C region. As shown by the curves of Figure 2, a positive voltage of 0.3 volt for germanium types or 0.6 volt for silicon types must be applied to the base before collector current starts to flow.

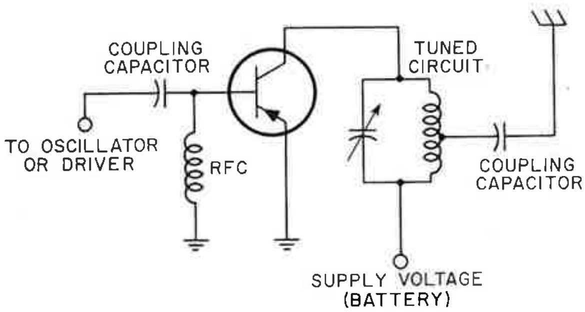


Fig. 1—A transistor connected as shown is automatically biased in the class C region.

For class B operation, the transistor is forward-biased to the point where collector current just begins to flow. For class A or linear operation, additional forward bias is applied until the desired collector current is drawn.

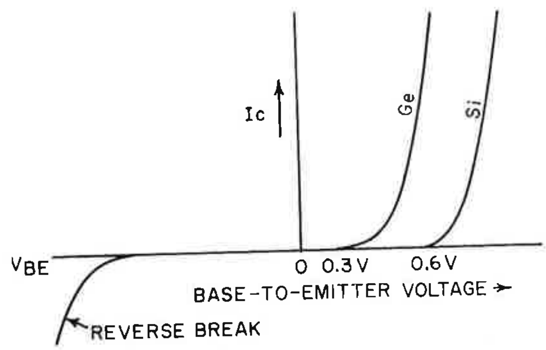


Fig. 2—Before collector current will flow, a positive voltage of 0.3 volt or 0.6 volt respectively must be applied to the base of germanium or silicon types.

The circuit for class A or class B operation is shown in Figure 3. The emitter resistance R_3 helps to stabilize the transistor and reduces the possibility of "thermal runaway" in the event of overheating.

"Base-leak" bias may be developed as shown in Figure 4. As base current is drawn, capacitor C charges to the voltage developed across R. If the time constant of RC is long, as compared to one cycle of the transmitted frequency, the charge is retained for this time. This procedure requires additional driving power to the transistor, however, and does not appreciably increase efficiency.

Care must be taken to insure that the base is not driven too far in the reverse direction. Such "overdriving" could damage the transistor or cause loading of the preceding stage.

Matching

For maximum power output and gain, both the input and output of a transistor circuit should be matched. This procedure differs from valve-circuit design, in which the grid input is usually considered as a high impedance and no attempt is made to match into it.

The input impedance of grounded-emitter stages decreases with increasing power output and is lowest for high-power transistors. Typically, this impedance ranges from 1,000 ohms in the milliwatt region to about 5 ohms for power of 1 watt or more. Grounded-base input impedance is always low, usually in the range from 100 ohms down to about 5 ohms.

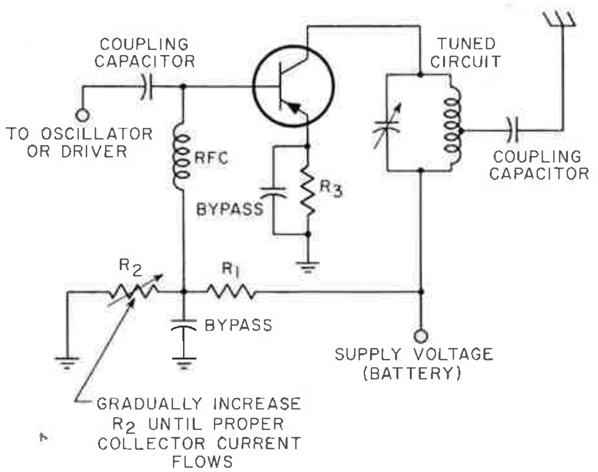


Fig. 3—Schematic of class A or class B amplifier.

Output or collector impedance R_{out} is best obtained from the power required P_{out} and the supply voltage E, as follows:

$$R_{out} = \frac{E^2}{2\,P_{out}}$$

This equation is not exact, but it does provide an approximate figure for design purposes. The output is always capacitive. This capacitance is generally designated by the manufacturer as C_{ob}. The input is usually capacitive at frequencies below 50 megacycles, but may become inductive at higher frequencies.*

*Detailed information on matching was given in "Silicon VHF Transistors—An Application Guide," Radiotronics Vol. 26, Nos. 5 and 6.

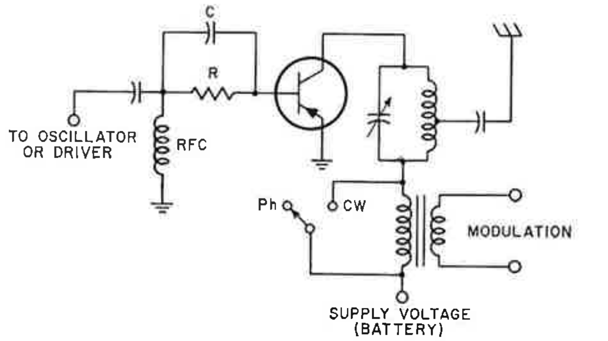


Fig. 4—"Base leak" bias and collector modulation.

Efficiency

If a transistor is operated well below its alpha cutoff frequency (the frequency at which the forward current gain is 0.707 times its low-frequency value), the theoretical maximum efficiencies for its class of operation can nearly be achieved. For example, the circuit shown in Figure 5 has provided better than 90% efficiency at 50 megacycles with an output of 1 watt. Efficiencies close to 75% can be obtained in class B stages, and nearly 50% in well-designed class A stages.

Neutralization

The greatest similarity between valves and transistors is in the area of neutralization. The feedback capacitance, sometimes referred to as $C_{b'c}$, is equivalent to grid-plate capacitance in valves. This capacitance is the major cause of self-oscillation within the transistor.

If the transistor is operated in the common-emitter configuration, this capacitance feeds back a small portion of the collector signal to the base. If this signal is sufficient to overcome base losses, the unit will oscillate. This situation is equivalent

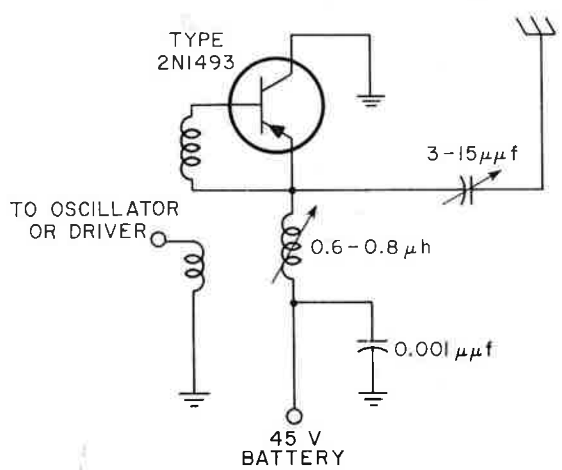


Fig. 5—Schematic of class C, grounded collector, common emitter amplifier.

to that observed in grounded-cathode operation of triodes. In well-shielded radio-frequency amplifiers, it should be possible to operate the transistor at frequencies up to one-third to one-half its alpha cutoff frequency before neutralization is required.

The common-base configuration, like grounded-grid valve operation, is less subject to self-oscillation because the phase shift between input and output is minimized. At frequencies close to alpha cutoff, however, even this configuration should be neutralized.

Neutralization is accomplished by cancelling out the effects of $C_{b'c}$. Typical neutralization circuits are shown in Figure 6. If the transistor is operated class A, C_n may be adjusted by applying the drive to the output tank, with dc voltages on, and tuning for minimum rf at the input tank. For class C operation, C_n is made approximately equal to $C_{b'c}$, and is then adjusted for best stability of the amplifier with drive.

Heat Transfer

Heat transfer is an important problem in transistor-circuit design, although it is seldom encountered with valves. Some means should be employed to remove heat from the transistor, especially when its maximum collector dissipation is approached. Heat transfer may be accomplished by solidly attaching or mounting the transistor case to the chassis or heat radiator. If the collector is internally tied to the case, the circuit shown in Figure 5 may be used. In this circuit, the collector is at rf and dc ground potential, although the transistor is operating in the common-emitter configuration.

Modulation

Modulation may be applied to the collector, base, or emitter of a transistor, as it may be applied to the plate, grid, or cathode of a valve. The efficiencies and percentages of modulation available from each type are very similar to those available in valves. Collector modulation is shown in Figure 4.

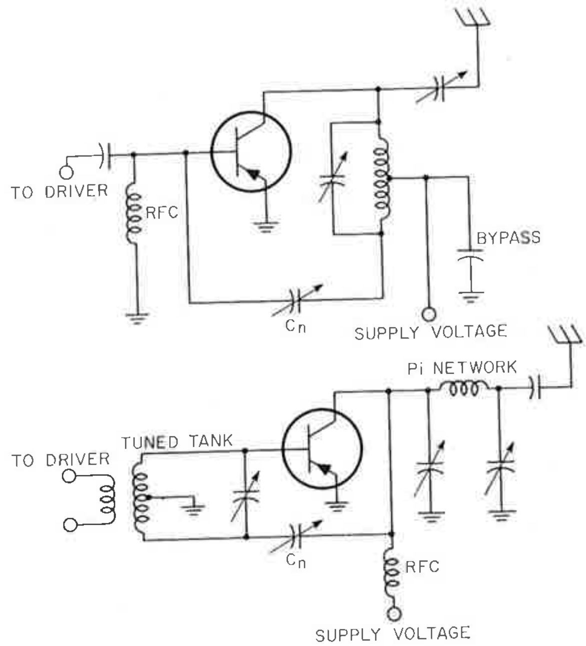


Fig. 6—Typical neutralization circuits.

Power Output

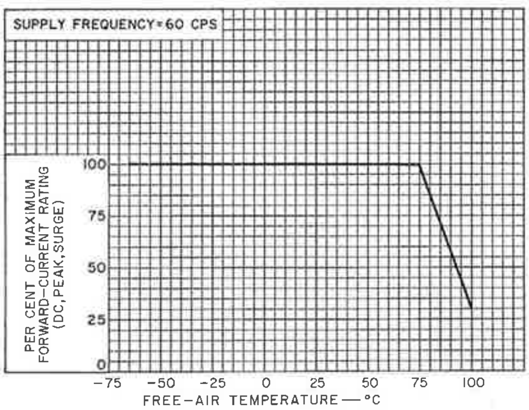
The amount of power available from a transistorized transmitter is determined by the type of transistor used. There are some low-cost germanium power transistors available with reasonably high alpha cutoff (about 7.5 megacycles) that should work well on 80 metres. With a pair of these (e.g., 2N1905's), a well-designed circuit will develop approximately 15 watts at 80 metres directly from a 12-volt storage battery. A new type now in development will put out 18 watts on 10 metres and 10 watts on 6 metres. Developmental types are limited in distribution and are relatively high in cost; but the amateur can look forward to their general availability in the not-too-distant future.

(With acknowledgments to RCA)

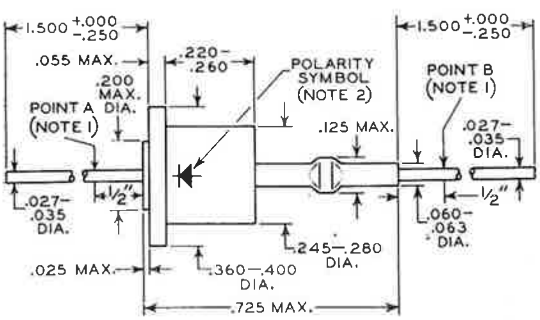
AWV AS3

SILICON DIODE

The AWV AS3 is an hermetically-sealed silicon rectifier of the diffused junction type and is a general-purpose component. This rectifier uses the popular "top-hat" type of case with axial leads. The AS3 has a peak inverse voltage rating of 800 volts and a maximum dc forward current rating of 500 ma with resistive or inductive load.



Rating Chart



DIMENSIONS IN INCHES

92CS-9728R1

NOTE 1: DO NOT DIP SOLDER BEYOND POINTS A AND B.
NOTE 2: ARROW INDICATES DIRECTION OF FORWARD (EASY) CURRENT FLOW AS INDICATED BY DC AMMETER.

Dimensional Outline

MAXIMUM RATINGS
(Absolute-Maximum Values)

	Resistive or Inductive Load	Capacitive Input Filter	
Peak Inverse Voltage	800	800	v
RMS Supply Voltage	560	280	v
Forward Current*			
DC	500	400	ma
Peak Recurrent	—	5	a
Surge, for "turn-on" time of 2 ms	—	35	a
Ambient Temperature Range:			
Operating		−65 to 100	°C
Storage		−65 to 175	°C
Lead temperature for 10 sec max.		255	°C

*For ambient temperatures up to 75° C. For operation at higher ambient temperatures, see rating chart.

CHARACTERISTICS. (At T_a=25° C)

Minimum instantaneous forward voltage drop at dc forward current = 500 ma	1.2	v
Maximum reverse current at maximum peak inverse voltage	10	μa

SILICON CONTROLLED RECTIFIERS

Among the many semiconductor devices that are available to us today is the silicon controlled rectifier, a type of unit which finds its main application in industrial circuits, where it is used for motor control and similar functions. In this type of application it fills a requirement which in the past has been catered for with various types of thyratron and similar valves.

The application of the silicon controlled rectifier falls into two basic modes, dc power control and ac power control. In the former type of application, the unit functions as a normal rectifier with the exception that the power delivered to the load is controlled by the rectifier under the influence of an external controlling signal. In ac power control circuits, the amount of ac power supplied to a load is controlled, again by an external signal, by causing the unit to conduct over only a portion of each cycle.

Basic Arrangement

The silicon controlled rectifier is a p-n-p-n device, that is, it has three p-n junctions. The rectifier opposes current flow in both directions until a small current is made to flow between the cathode and a third or switching electrode. When the switching current is applied, the forward resistance of the rectifier falls to a value comparable with that of a normal silicon rectifier having the same order of current rating.

To explain the operation of the silicon controlled rectifier, let us look first at a p-n-p arrangement, seen in Fig. 1. This uses two p-n junctions, so arranged that the device opposes the flow of current in both directions. This type of device is widely used in semiconductor work, and according to the geometry and type of doping used in the semiconductor material, could represent a transistor or a symmetrical zener diode. So this configuration presents no problem.

To travel from the three-layer two-junction arrangement of Fig. 1 to the silicon controlled rectifier, all we have to do is to add a further layer and a further p-n junction. We then have the configuration shown in Fig. 2, which can be used either as a conventional rectifier, a switch or a relay.

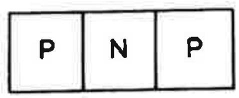


Fig. 1

To study the operation of this four-layer rectifier, let us bias the junctions as shown in Fig. 3 with a battery, a load, and a meter to show current flow. The junctions have been numbered one to three in the diagram for ease of reference. With this arrangement then, the leakage current through junction 2 allows forward current to flow through junctions 1 and 3. This small forward current is carried by minority carriers, that is, by electrons in the "p"-type material, and holes in the "n"-type material.

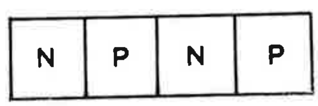


Fig. 2

The percentage of these minority carriers which reaches junction 2 from each side forms the "alpha" of the respective parts of the rectifier. Whilst the actual value of alpha in any device must necessarily depend on many factors, the most significant is the magnitude of the current flowing. When the sum of the alpha of the left-hand three layers and the alpha of the right-hand

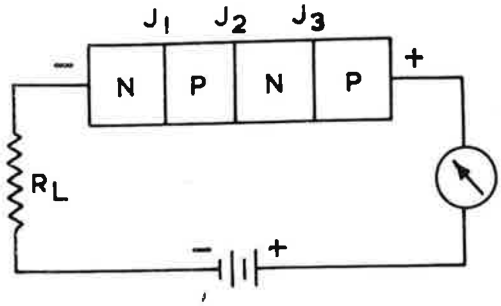


Fig. 3

three layers approaches unity, current through the complete unit is limited only by the external circuit. In order to cause conduction in the unit therefore, the leakage must be increased.

From our experience with conventional rectifiers, we know that this can readily be done by increasing the voltage applied across the middle junction. A rise in temperature will of course also increase the leakage current.

It is interesting to see what happens when the polarity of the bias voltage shown in Fig. 3 is reversed. Now there are two leakage currents through junction 1 and junction 3, which will cause injection of carriers at junction 2. These carriers will affect the reverse characteristics of junction 1 and junction 3. The only effect in this case however is a slight increase in the currents at junction 1 and junction 3, because the value of the alphas involved is always much less than unity.

An increase of voltage and/or temperature to cause breakdown of the rectifier would be cumbersome and not very useful, so the four-layer unit is completed with the addition of an ohmic contact to the p layer between junction 1 and junction 2. The rectifier is now controlled by passing a current through junction 1. The effect of this current is to increase the alpha beyond the normal value, up to or beyond the point

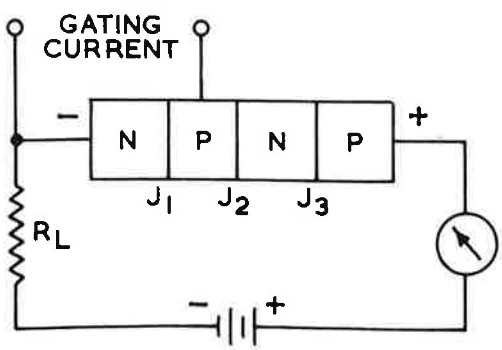


Fig. 4

where complete conduction is achieved. This arrangement is shown in Fig. 4.

Two Transistors

One useful and popular comparison used to explain the operation of the silicon controlled rectifier is that of liking it to two transistors, one a p-n-p unit and the other an n-p-n unit. When these two transistors are connected as shown in Fig. 5, it will be readily seen that the two transistors have a common n layer and a common p layer. If the two block diagrams shown in Fig. 5 to represent the two transistors are pushed together, we are back with the diagram shown in Fig. 4.

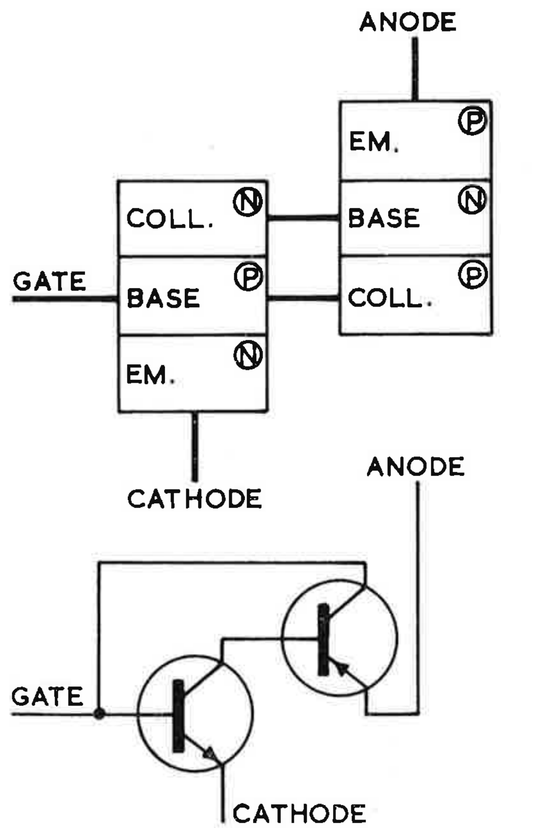


Fig. 5

With the two transistors connected as shown, the collector current of the p-n-p unit feeds the base of the n-p-n unit, and vice versa. A positive feedback loop has thus been created, so that when the product of the individual gains of the two transistors exceeds unity, the circuit will be self-regenerative.

In the "off" condition of the circuit shown in Fig. 5, the base of the n-p-n transistor is reverse-biased, so that only a very small leakage current will flow from cathode to anode. Compare the base of the n-p-n unit with the gate electrode shown in Fig. 4. At the level of the low leakage current, the current gains of the two transistors are very low also, so that their product is less than unity, and there is no conduction through the rectifier (ignoring leakage). The forward resistance of the unit is very high.

To bring about a low forward resistance and a substantial forward current flow, a small forward bias current is applied to the base of the n-p-n unit (the gate), so that the current gains of the two transistors rise. As the forward bias current is increased, a point is reached where the sum of the two transistor current gains exceeds unity. At this point, as previously mentioned, the circuit becomes self-regenerative. The current flowing from cathode to anode will therefore increase rapidly, until a stage is reached where the limiting factor on the forward current is the value of the external load.

It is important to realise that once the state of full forward conduction has been reached, the gate electrode has no further control on the current flow. The similarity with thyratron operation will readily be seen. As in the case of a thyratron, current flow from cathode to anode can only be halted either by the removal or reversal of the applied anode voltage, or by the reduction of the anode voltage below a minimum sustaining voltage.

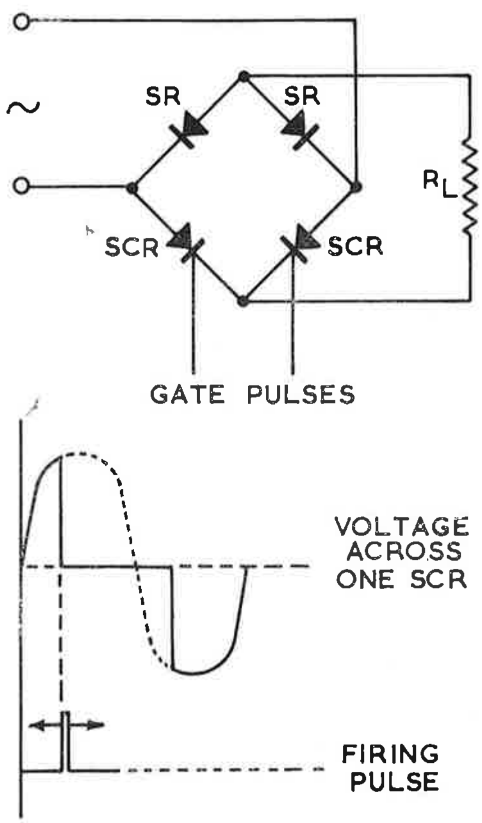


Fig. 6

Firing Circuits

Because the control current through the gate of the controlled rectifier can start the rectifier but cannot stop it, the process is often referred to as "firing" the rectifier. The gate current is supplied by an external circuit which provides a pulse to the gate at the appropriate point in the cycle of operation. These pulses can be of two types. One is a very narrow pulse, the leading edge of which is timed to arrive at the moment forward conduction is required; the other type of pulse used is similarly timed but of longer duration, being maintained during the full conduction period of the rectifier.

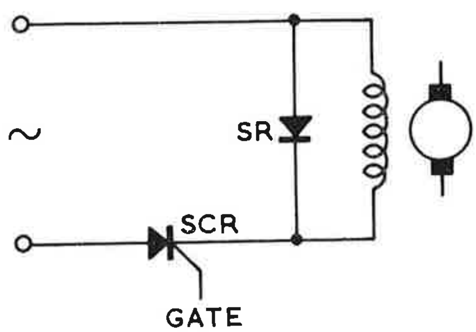


Fig. 7

The choice of the type of control pulse used is a design problem and will be passed over in this instance. It is a matter of which is best for the particular application. For example, where the load applied to the system is highly inductive, or where ac power control is to be used, use of the very short pulse method may be unsatisfactory as the rectifier may be shut off again when the gate pulse is removed, due to the fact that the load current has not had time to build up.

The main point to be remembered is that the rectifier is controlled by a firing pulse, and that the leading edge of this pulse is adjustable in time. If we imagine a simple half-wave rectifier system with a controlled rectifier, and if we vary the time at which the control pulse arrives with respect to the periodicity of the applied ac voltage, we have complete control of the power developed in the load.

Firstly, it is obvious that only that portion of each positive half cycle which occurs after the application of the gate pulse will actually cause current to flow through the rectifier and into the load. Secondly, if the gate pulse is not applied, or is so phased that it arrives during the negative half cycle, then no current will flow at all. Where more complex rectifier circuits are used, this basic concept still applies, except that there will be more than one controlled rectifier to consider.

DC Control

A simple arrangement using a bridge rectifier is shown in Fig. 6, used to rectifier the ac input and control the power passed to the load. It is interesting to note that with the exception of certain applications, cases such as the bridge configuration where more than one rectifier is always in series, only one of the rectifiers need be a controlled unit, and the other(s) in the series chain can be conventional types with similar forward characteristics.

Fig. 6 also shows the operation of one of the controlled rectifiers by displaying the voltage waveform across the rectifier, related to the firing pulse. As shown in the diagram, the incidence of the firing pulse coincides with forward conduction in the rectifier, and the drop of voltage across the rectifier effectively to zero. There is of course always a small forward voltage drop, but its value is insignificant in this context.

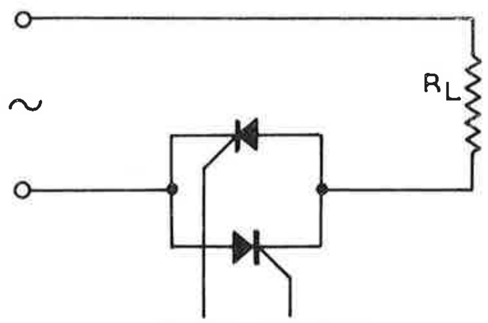


Fig. 8

The leading or left-hand edge of the conduction period, initiated by the firing pulse, can be moved forward or back in time with respect to the applied ac voltage by suitable phasing or timing arrangements, so giving complete control over the power flowing into the load. For the sake of clarity, the operation of only one rectifier is shown. The start of conduction in the second unit is indicated by the rise of voltage in the reverse direction across the rectifier under consideration.

A second application of dc control is shown in Fig. 7, a circuit widely used for supplying and controlling motor field currents. The controlled rectifier is a simple half-wave rectifier circuit, and the only point of interest is the use of the second diode, sometimes called a "flywheel" diode. The second diode, connected in shunt with the load, smooths the field current by using the back emf to maintain the field current when the controlled rectifier is not conducting.

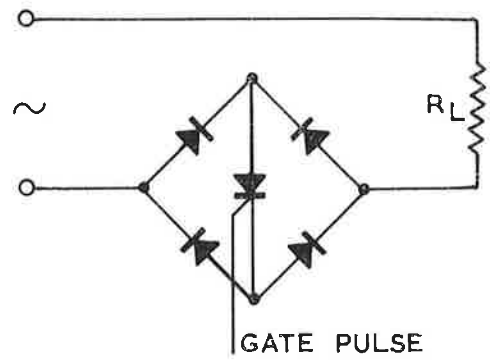


Fig. 9

AC Control

Two methods of controlling ac applied to a load will be briefly mentioned to complete the picture. The first method is shown in Fig. 8. It consists essentially of two controlled rectifiers connected back to back and supplied with suitably phased gating pulses. It will be seen that the rectifiers alternately control forward current flow on alternate half cycles. The waveform for each rectifier would follow from that given in Fig. 6.

The second ac power control method to be mentioned is shown in Fig. 9, and shows how power control can be achieved with the use of only one controlled rectifier. The controlled rectifier is fired into conduction at some point in each half cycle. Each time the rectifier is driven into conduction, it completes a circuit for forward current flow through two of the conventional rectifiers. The pairs of conventional rectifiers are used alternately on positive and negative half cycles. Note that the bridge configuration ensures that there is always a path which will give forward conduction through the controlled rectifier.

Summary

These few remarks only begin to tell the complete story on these versatile units, but their application, mainly in industrial equipment, is so specialised as hardly to warrant a more complete treatment in these pages. An attempt has been made rather to draw attention to the units and their mode of operation in a general way as a contribution to background knowledge.

NEW RELEASES

EEV BR1143

To enable high outputs to be obtained from relatively-compact rf induction heaters, the English Electric Valve Co., Ltd. have designed and produced an advanced type of industrial power triode, the BR1143. This is a forced-air cooled valve, and the figure of 20Kw anode dissipation quoted for design purposes allows a generous temporary overload capacity, thus making a very real contribution to the overall reliability of the complete equipment.

1N1612—1N1616

The announcement of these types with reversed polarity versions makes an addition of ten 5-ampere diffused-junction silicon rectifiers with JEDEC DO-4 package. These silicon rectifiers are designed to meet stringent environmental and mechanical requirements of critical military and industry power-supply applications. These rectifiers have PIV ratings of 50 to 600 volts.

2N398-A

This germanium p-n-p alloy junction transistor in the JEDEC TO-5 package is specifically designed for direct high-voltage control of "on-off" devices such as neon indicators, relays, incandescent-lamp indicators, and indicating counters of electronic computers. The 2N398-A has all the features of the industry-preferred 2N398 plus increased current, dissipation, and temperature ratings for use in those applications requiring such high ratings.

2N828

The 2N828 is an epitaxial transistor of the germanium p-n-p mesa type in the JEDEC TO-18 package. The 2N828 is designed especially for high-speed saturated switching applications in military and industrial equipment where high reliability and high packaging densities are important design considerations. The 2N828 meets the mechanical and environmental requirements of MIL-S-19500B and features: short storage time of 50 n sec maximum; high minimum gain-bandwidth product of 300 Mc min. at $V_{CE} = 1$ volt and $I_C = -10$ ma; low saturation voltages of -0.2 volt max. at $I_C = -10$ ma, $I_B = -1$ ma, and -0.25 volt max. at $I_C = -50$ ma, $I_B = -5$ ma.

2N955

The 2N955 is a germanium n-p-n double-diffused mesa transistor with a typical gain-bandwidth product of 1 KMc in the JEDEC TO-18 package, designed specifically for high-speed logic-circuit applications. The 2N955 combines rugged construction and inherent high electrical stability. This new high-speed transistor has been designed to meet the stringent electrical and mechanical requirements of military specifications.

2N2102

The 2N2102 is an n-p-n triple-diffused planar "universal" silicon transistor which can cover a majority of small-signal and medium-power applications in military and industrial equipment. The 2N2102 is a direct replacement for the 2N1613 family of transistors and features:

Breakdown voltage (BV_{CBO})—120 volts at $I_C = 0.1$ ma
Saturation voltages: ($V_{CE}sat$)—0.5 volt max. at $I_C = 150$ ma
($V_{BE}sat$)—1.1 volts max. at $I_C = 150$ ma
Output capacitance (C_{ob})—15 pf max.
Wideband noise figure—6 db max.
Maximum dissipation rating—5 max. watts

6DS4

The 6DS4 is a high-mu nuvistor triode intended for use as a grounded-cathode, neutralized rf amplifier in vhf tuners of TV and FM receivers. The exceptional performance of the 6DS4 in fringe areas and other locations where signal levels are weak is made possible by the following features: semiremote-cutoff characteristic which reduces cross-modulation distortion: excellent signal power gain, achieved by very high transconductance and excellent transconductance-to-plate current ratio: low noise factor, significantly better than tuner valves currently in use in TV receivers; and excellent stability and exceptional uniformity of characteristics from valve to valve.

8053

The new 2-inch diameter head-on type of multiplier phototube, type 8053 is the third of a trio of recently developed phototubes utilizing a venetian-blind dynode structure and having S-11 response. Like its prototypes, the 8054—a 3-inch diameter tube—and the 8055—a 5-inch diameter tube—, the new 8053 is intended specifically for scintillation counter applications. The 8053 may be inserted directly into the socket of either of its prototypes as the need for larger or smaller diameter multiplier phototubes arise.

8055

The 8055 is a new 5-inch diameter "venetian-blind" type multiplier phototube designed especially for scintillation counter applications requiring large diameter scintillators. The large area of the photocathode also makes this new tube highly useful in applications requiring good photon collection from distant or diffuse radiation sources. The 8055 is the 5-inch counterpart of the recently announced 3-inch type 8054.

8072, 8121, 8122

These beam power valves are not only small and compact, but very economical, and are "tailor-made" for mobile use. These rf power amplifiers, rated for CW and linear service, not only satisfy mobile power requirements, up to 500 Mc, but also provide three choices of cooling!

The 8072 is the conduction-cooled member of this family for low voltage mobile applications. With a plate voltage of only 700 volts, it will supply useful CW power of 110 watts at 50 Mc, 105 watts at 175 Mc, and 85 watts at 470 Mc.

The 8121 is the forced-air cooled variant (finned-type radiator for cooling in horizontal plane) with a maximum plate dissipation of 150 watts. With a plate voltage of 1500 volts, it will supply useful CW power of 235 watts up to 500 Mc—PEP power of 170 watts at 30 Mc.

The 8122 is the forced-air cooled version (louvred, high-efficiency radiator for cooling in vertical plate) with a maximum plate dissipation of 400 watts. With a plate voltage of 2000 volts, it will supply CW power of 300 watts up to 500 Mc—PEP power of 380 watts at 30 Mc.

8077/7054

The 8077/7054 is a shorter 9-pin miniature version of the popular 7054 power pentode designed specifically for use in very compact mobile communications equipment operating from 6-cell storage-battery systems. Featuring high transconductance (11500 μmhos), low interelectrode capacitance, and high power sensitivity, the 8077/7054 is particularly useful in class C radio-frequencies up to 40 Mc. It may also be used in modulator and audio-frequency power-amplifier applications.

Editor .... Bernard J. Simpson

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