HOME STUDY COURSE IN ELECTRONICS — 14

Power Supplies

Valve equipment power supplies — problems in using AC to heat valves — the indirectly heated valve — the full-wave rectifier, using valve diodes — smoothing and filtering with inductance and capacitance — the use of semiconductor diodes — the voltage-doubler rectifier — the half-wave rectifier — transistor equipment power supplies — the bridge rectifier — dynamic filtering and regulation.

For the sake of simplicity, most of our circuit discussion to date has assumed the provision of suitable DC supply voltages, without much emphasis on how such voltages are obtained. In this chapter, we explain how supply voltages are derived from the AC power mains.

In the early days of radio, receivers were invariably supplied from batteries. It was commonplace to use either an accumulator for the filament supply or a number of heavy-duty dry cells capable of supplying the requisite and often considerable filament current.

The grid bias voltages were taken from a special bias battery, not intended to deliver significant current, but with tappings at each cell junction to give voltages in 1½-volt steps to 4½ volts or 9 volts — to quote what were common figures

For the plate supply, so-called radio "B-batteries" were used. These were large and rather expensive banks of dry cells, usually made up in 45-volt blocks and tapped at 22½ volts. Two such B-batteries in series could supply 90 volts, while three in series were commonly employed to give 135 volts. How cumbersome and expensive these batteries were tends to be forgotten in these days of transistor receivers.

While the early sets were simple enough from the designers' point of view, the need to provide, attach, and conserve batteries was a constant worry to radio set users and it was natural that efforts should be made to cut the operating costs, at least. As a result, various gadgets appeared aimed at supplementing or replacing the expensive batteries.

Numerous chargers or "trickle chargers" were put on the market for recharging the filament accumulators. The chargers might deliver currents up to 3-odd amperes and would top up a discharged battery in a day or so. Trickle chargers were designed to be left on more or less continuously, keeping the battery full at all times and saving the hitherto regular trip to the local garage for a battery re-charge.

So-called "B-Battery Eliminators" were released, to replace the high-tension batteries altogether. These incorporated a transformer, rectifier and filter system, rather like a modern AC power supply. Various resistors and tapping points were included so that they could supply the requisite intermediate voltages at the order of current drain commonly encountered in battery sets of the day.

Some B-battery eliminators also included auxiliary circuits to provide negative bias voltages, although the cost of a bias battery was never a major item.

These various units enjoyed a limited degree of popularity, but the obvious objection of having gadgets and accumulators attached to the family radio provided strong incentive to produce self-contained receivers which could simply be plugged into the power point and operated therefrom just like any other electrical appliance.

Initially, the main difficulty was that of providing filament supply. For reasons we shall see a little later, AC from the power mains could not readily be changed to DC at the voltage and current needed to operate a number of parallel-connected filaments. And there were — and still are — two basic objections to applying AC to the filament of a directly-heated valve.

The first and perhaps most obvious objection is that because the filament has a certain voltage drop, the effective bias between filament and grid varies over its length. As a result if the filament is heated by the application of AC, an alternating voltage component tends to be superimposed upon the desired DC bias to modulate the plate current and cause hum. It is possible to cancel out most of this superimposed component by accurately centre-tapping the filament AC supply, and this was done with early receivers designed to be operated directly from the mains. But unfortunately this technique does not avoid the second problem.

Because alternating current falls to zero twice in every cycle, the temperature of the filament tends to vary cyclically when AC is used to heat it. This causes a corresponding variation in the number of electrons produced, and thus still tends to modulate the plate current to produce an undesirable hum (in this case at twice the AC supply frequency). In an attempt to overcome this problem the directly heated valves used in early AC receivers had special low-voltage high-current filaments made from thick wire and therefore thermally sluggish. However this was only partly successful.

A satisfactory solution to the problem only came with the introduction of valves having "indirectly heated" cathodes. Such valves were described in an earlier chapter.

With the development and release of valves having indirectly heated cathodes the major problem with all-mains operation disappeared and numerous receivers were released using them. It was still necessary to produce from the mains a pure DC supply for the valve plates and screens, but, as we shall see, this was not — and is not — a major problem.

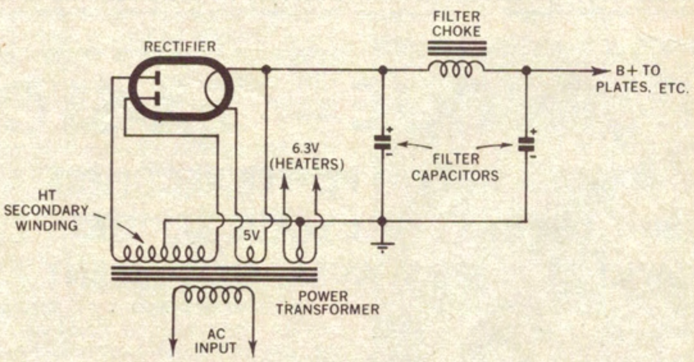


Figure 1: A typical power supply circuit using a valve rectifier as used in older receivers and amplifiers. Supplies using semiconductor rectifiers are more common in modern receivers.

In most radio receivers, amplifiers and other equipment using valves, the DC supply for the plates and screens is provided by a power supply circuit using a transformer and rectifier. In early equipment the rectifier used was a valve, usually a double diode. In more modern equipment silicon diodes are used.

Figure 1 shows a typical valve rectifier power supply circuit, whose operation we can proceed to discuss.

The heart of the supply is the power transformer, which is shown diagramatically as a number of windings adjacent to an iron core. The transformer is used to provide low voltage AC for the valve heaters as well as the plate supply.

The incoming power lead is connected across the primary winding, which will normally be rated to receive an input of 240 volts AC. It must be AC. A power transformer must not be connected across DC mains. If it is, it is almost certain to blow the fuses or burn itself up, or do both!

The reason for this is not hard to discover in that a transformer relies for its operation on a constantly changing magnetic field. As the alternating current from the power mains flows to and fro through the primary winding, it causes a strong magnetic field in the iron core to build up and collapse in cyclic fashion. The moving lines of force thus created induce current and voltage in the various secondary windings, obeying the laws of magnetism explained in an earlier chapter.

The alternating voltage developed across each secondary winding is almost exactly proportional to the ratio of turns between the primary and the secondary winding in question. Thus, if there are 1,200 turns on the primary winding, a secondary winding also having 1,200 turns would deliver the same 240 volts as fed into the primary — because the turns ratio would be 1:1 On the other hand, if a 6.3 volt winding is required to operate a number of valves with 6.3 volt heaters, then this heater winding would need to have 1,200 times 6.3 / 240, or approximately 32 turns.

In the above illustration we suggested 1,200 turns for a 240-volt winding on the assumption that the transformer might be wound on the basis of five turns for every volt of input or output. This is a likely enough figure, but, in practical transformers, the turns-per-volt figure may vary considerably from one type to another, according to the size of the core, the grade of the iron used and the ideas of the designer.

The thickness of the wire used on each winding depends on the current which it has to handle or deliver. In the case of a heater winding, which may be required to deliver several amperes, relatively thick wire has to be used and it is commonplace to see heater windings using 16-gauge enamelled wire or thicker.

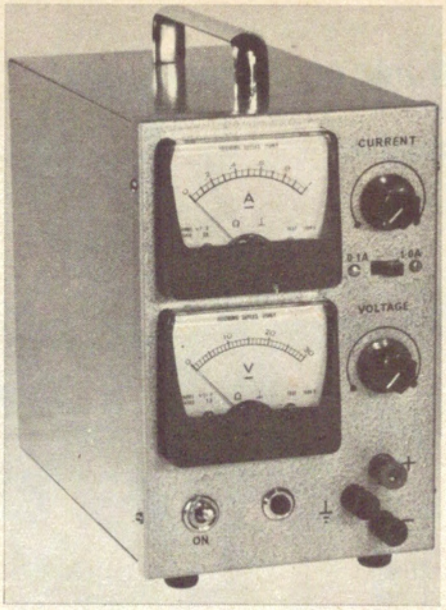
It is important to realise that the gauge of wire used in a transformer winding determines only the amount of load current it can handle, without over-heating, if required to do so. Thus a winding rated to deliver, say, three amperes, can deliver up to three amperes without tending to overheat, according to the number of valves which may be connected to it. If only one valve were connected to the particular winding, the current drawn from it would probably be less than one amp.

Typical low power transformers designed for use in the power supply of a radio set, television receiver or similar equipment may have one, two or even three heater windings, to give the voltages and currents likely to be required. If designed in recent years for valve equipment, most heater windings are likely to be designed to produce a voltage of 6.3 volts RMS, to suit most modern valves.

In the circuit of figure 1 we have shown two heater (or filament) windings, one to supply the rectifier and the other to supply the heaters of all other valves in the receiver. The latter is shown as having a centre-tap connection, earthed to the chassis.

Heater wiring is usually earthed for two reasons:

Firstly, the heater winding is very close, inside the transformer, to other windings producing high alternating voltages. Because there is some capacitance between them, some of the high voltage energy can be coupled capacitively to the heater winding and to the wiring connected to it.



A typical transistorised regulated power supply suitable for use with experimental circuits. It provides an adjustable output voltage from 0 to 30V at a maximum current of 1A. The meters are included to indicate the output current and voltage.

This doesn't interfere in any way with the basic operation of the heater circuit but the high ripple voltage present on the heater wiring throughout the chassis can couple into grid circuits and produce an objectionable hum or buzz in the output.

A second reason is that wiring running from one stage to another thoughout a high-gain receiver can transfer signals by stray coupling and produce troublesome regeneration.

Earthing the heater wiring largely obviates both effects. Although we have shown a centre-tap earth return, this is not strictly necessary except, perhaps, in equipment having very high audio gain. In many cases it is sufficient to earth one side only of the heater wiring.

For the plates and screens, AC from the power mains must be rectified and filtered till it becomes virtually pure DC. This involves, normally, a high tension secondary winding on the power transformer, a rectifier, a filter choke and two or more filter capacitors.

As might be expected, the high tension winding involves many turns of fairly fine wire, so that a considerable voltage is developed between its outer ends. Since the voltage across it is alternating, each end swings alternately positive and negative with respect to the other.

In valve rectifier circuits such as that shown, the high tension secondary winding has a centre-tap which is returned to chassis (shown as earth) so that half the total secondary voltage appears between earth and the respective ends. When one end of the winding swings positive with respect to earth the other end simultaneously swings negative by an equal amount.

As with the heater windings, the rating of the high tension secondary, in terms of voltage and current, varies with the size of transformer and the receiver which it is to supply. A small transformer, to supply a small mantel radio receiver, might typically have a HT secondary rating of 150 volts either side of the centre tapping, at a nominal current rating of 30 milliamps — this figure referring to the permissible DC load current.

A large transformer, intended to supply a television receiver, or amplifier, might have a voltage rating per side of up to 400 and a nominal DC load current of up to 250 or even 300 milliamps.

The two ends of the HT secondary winding are connected to the two plates of the rectifier valve, as depicted. This valve is virtually two diode elements in the one envelope, the plate and filament structure being expressly designed to carry a considerable amount of current.

A valve of this type, intended for use in a power supply and having two separate anodes or plates, was commonly referred to as a full-wave rectifier.

The filament of the rectifier is fed from a separate winding on the transformer, which is typically rated to deliver five volts at two or three amperes. It is quite usual for rectifier valves to consume considerable heater or filament power, the cathode or filament being designed to provide copious electron emission and thus allow the valve to pass heavy current without danger of early failure in service.

To follow the action of the rectifier, consider the instant when a positive voltage has appeared on the left-hand half of the HT secondary and therefore on the upper rectifier plate, as drawn.

Since the plate is positive, electrons will tend to flow to it from the heated filament. We can consider the result in a couple of ways, both of which lead to the same conclusion:

(1) In losing electrons, which are essentially negative charges, the filament of the rectifier must itself become positive.

(2) When conduction takes place through the rectifier, the impedance of the filament-to-plate path in the valve must decrease. The filament must, therefore, approach the plate potential, and, since this is temporarily positive, the filament must tend also to become positive.

Whichever way one cares to look at it, the result is the same — a positive potential on the plate and conduction through the valve produces a positive voltage at the filament.

When the same plate swings negative, during the next half-cycle, there is no conduction through the valve and, therefore, no tendency for the filament to develop a simultaneous negative potential.

On the contrary, as the first plate swings negative, the second plate simultaneously becomes positive and conduction takes place between the filament and this second plate. Once again, therefore, the filament tends to be carried positive.

In other words, during successive half cycles, when each plate in turn swings positive, current flow through on half of the rectifier or the other tends to carry the filament positive also. Since there are 100 half cycles per second with 50Hz power mains, 100 positive pulses are apparent at the rectifier filament per second.

The 50Hz alternating voltage at the rectifier plates is thus changed to pulsating DC at the rectifier filament, positive with respect to chassis and having a heavy ripple content of 100Hz.

This positive voltage is generated at the rectifier filament quite independently of the five-volts AC coming from the transformer winding to heat the filament. This latter voltage, applied across the rectifier filiament, raises it to operating temperature. When the positive voltage is generated, it carries the filament as well as the transformer winding feeding it, to a high positive potential in respect to chassis.

Obviously enough, since the rectifier filament winding is expected to be at a positive potential with respect to chassis, it must not be earthed.

Instead a wire connected to one wire of the filament or its supply winding becomes the source of the positive potential which must ultimately be fed to the plates and screens of the remaining valves in the equipment.

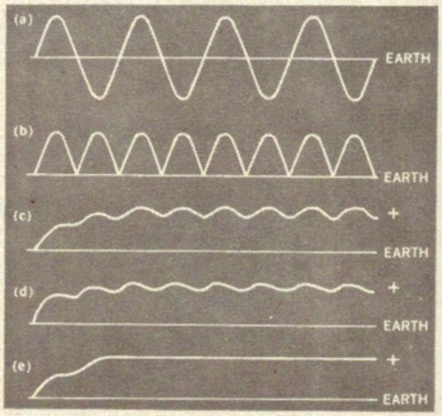


Figure 2: Voltage waveforms associated with rectification and filtering in a simple power supply. Filtering is necessary to produce smooth DC from the pulsating rectifier output. The waveforms shown are: (a) the transformer secondary voltage, (b) the rectifier output, (c) the effect of the choke, (d) the effect of the capacitor, and (e) the output DC.

However, the plates and screens must be fed with substantially pure DC, not a voltage which has a very high ripple content. To get rid of the ripple, it is necessary to use what is known as a filter system, which as shown in figure 1 may involve a filter choke or inductor and a number of filter capacitors.

The inductor consists normally of a large number of turns of wire wound within a laminated iron core, much like that used for small power or output transformers. It must be capable of carrying the amount of current involved in the particular supply and, with this current flowing, must have an inductance usually of several Henries.

In some older-type radio receivers a filter choke, as such, was not used. Instead the current from the pwer supply was passed through a winding around the pole piece of the dynamic speaker. This gave the requisite inductive effect for filtering, and the magnetic field created by the current served at the same time to energise the speaker's magnet system. The so-called "field" winding on the loud-speaker therefore served a double purpose.

It may be remembered that in an earlier chapter we learned that an inductor tends to resist any change in the amount of current flowing through it. If the current increases above average, part of the energy involved is diverted into creating a stronger magnetic field around the winding. If the current decreases, the magnetic field is reduced and returns some of its energy to the winding as current flow.

As a result of this action, current flowing through a filter choke loses a good deal of its ripple content and becomes more nearly pure DC. This is illustrated in figure 2, where (a) represents the transformer secondary AC voltage, (b) the basic rectifier output, and (c) the effect of the inductor.

As indicated earlier, capacitance is also involved in a filter system, its effect being more or less complementary to that of inductance. A capacitor tends to oppose any change in the potential or voltage across it. If the voltage rises above an average value, some of the energy involved is diverted into the capacitor as an extra charge. If the voltage then subsequently falls, the charge is released, tending to maintain the original potential.

When one or more capacitors is connected between the B-plus supply line and earth, as in figure 1, they naturally tend to oppose or absorb the change in potential due to ripple from the rectifier. They charge on "peaks" and release energy subsequently to fill the "troughs." Diagrammatically, the effect is as illustrated in figure 2d.

If properly designed, the combined effect of the choke and capacitors is to completely eliminate the ripple content for all practical purposes, and the output from the supply becomes virtually pure DC. (see figure 2e.)

The rectifier circuit of figure 1 is known as a condenser-input or capacitor-input filter, because the rectifier feeds directly into a capacitor. In the less common arrangement, where the rectifier feeds directly into an inductor, the filter is described as a choke input filter.

Filter capacitors normally need to have a large value of capacitance, certainly not less than eight microfarads each. To obtain this capacitance in small space and with adequate working voltage, not forgetting price either, they are invariably electrolytic types, as described in an earlier chapter.

The main point to remember about electrolytics is that they must be connected the right way round, with their positive terminal connected to the positive side of the circuit.

In recent years, much higher values of filter capacitance have become practical and, as a result, chokes having much lower inductances will suffice for the same degree of filtering. In point of fact, many small power supplies these days do not use a choke at all, relying only on large capacitors to give an adequate storage and filtering effect.

Readers may recall from the earlier chapter on semiconductors that a semiconductor diode behaves almost identically with a valve or thermionic diode. In view of this, it should not be very surprising to learn that semiconductor diodes can be used in rectifier circuits in place of diode valves.

In point of fact, they are somewhat better suited to this task than valves, as they require no heating power and also tend to conduct more easily during the part of the cycle when they are called upon to do so. They also have a longer life, and are more reliable in service. At present, their only disadvantage is that they tend to be vulnerable to damage from transient overvoltage "spikes" which are at times present on AC mains.

Two semiconductor diodes can be used in a full-wave rectifier circuit similar to that shown using a valve in figure 1, the only difference being that the diodes do not require a filament wiring on the transformer. They are simply wired with their cathode connections tied together as the output connection leading to the filter circuit and the load circuit, and each anode connecting to one end of the transformer HT secondary winding.

This type of rectifier circuit is not often used where semiconductor diodes are employed, however, because it requires the diodes to have a high peak inverse voltage rating. The peak inverse voltage is the reverse-bias voltage which appears across each diode when it is "off" and the other is conducting.

With the full-wave rectifer circuit, the reverse-bias impressed upon the diodes when they are non-conducting is actually 2.828 times the half-secondary RMS alternating voltage, and this can require the use of costly diodes having a very high peak inverse voltage rating.

Because of this, it is often more desirable to employ what is called the full-wave voltage doubler rectifier circuit whenever moderate to high voltages and currents must be rectified by semiconductor diodes. Figure 3 shows a circuit of this type.

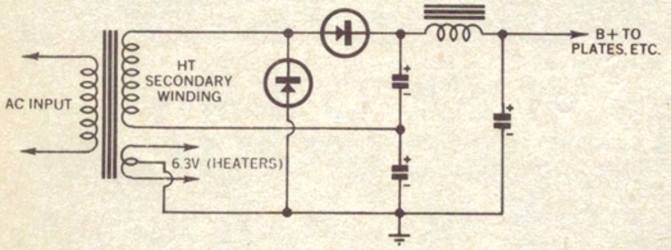


Figure 3: Most power supplies using semiconductor rectifiers use the full-wave voltage-doubling circuit as shown here. It suits the rectifiers better, and is more compact and economical.

A single untapped secondary HT winding is used on the power transformer, and the winding is arranged to produce an alternating voltage of only half (approx) the required DC output voltage. It should be noted, in passing, that this makes the power transformer somewhat simpler than in the full-wave circuit, and consequently somewhat less bulky and costly to produce.

Two semiconductor diodes are used as before, but this time they are connected in a different fashion. The first filter capacitor also undergoes a change, becoming two separate units which fill a more complex role than did the single unit of figure 1.

Neither end of the transformer HT secondary winding is earthed. Instead, one end goes to the junction of the two series-connected filter capacitors, while the other end goes to the two diodes. One diode has its cathode connecting to the winding and its anode earthed, while the other has its anode connecting to the winding and its cathode connecting to the top of the uppermost filter capacitor and the DC output circuit.

The operation is as follows: For the half-cycles when the top of the transformer winding is negative and the bottom positive, the "series" (upper) diode is reverse-biased and non-conductive. The "shunt" (lower) diode is forward-biased, however, being connected to the winding via the lower filter capacitor.

It therefore conducts, and in doing so it charges the lower capacitor to the peak value of the alternating voltage appearing across the winding. The capacitor voltage is as shown, with its earthed end negative with respect to the top end.

During the other half-cycle of the AC wave, when the top of the transformer winding is positive with respect to the bottom, the "shunt" diode is reverse-biased and non-conductive, while the "series" diode conducts. This time the upper capacitor is charged to the peak value of the AC secondary voltage, as it completes the circuit back to the lower end of the winding. The voltage across it has a polarity as shown.

As may be seen, the two capacitor voltages add together, and the total pulsating DC voltage available for filtering is twice the peak value of the transformer winding RMS voltage. Under load this voltage drops toward twice the RMS voltage.

The most important thing to realise about the voltage doubler circuit is that for a given and required DC output voltage, each diode has to deal with only half the voltage it would meet in a conventional full-wave circuit. Thus the doubler circuit allows the use of relatively inexpensive semiconductor diodes having but a moderate peak inverse voltage rating.

The voltage doubler circuit found almost universal acceptance in valve television receiver power supplies and in many other places where high current is required at a fairly high voltage. Silicon diodes are used almost universally in this circuit, as they are most easily arranged to have the required peak inverse voltage and forward conduction current ratings.

In power supplies where the voltage and current demands are very slight, it is possible to use a single diode valve or a single semiconductor diode in what is called a half-wave rectifier circuit. Such a circuit using a semi conductor diode is illustrated in figure 4.

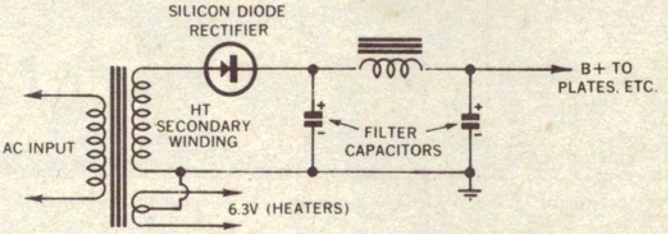


Figure 4: When only very low current drain is involved, a half-wave rectifier system may be employed. A valve rectifier could be substituted for the semiconductor in this circuit.

A single untapped transformer secondary winding is used as with the doubler, but this time it needs to provide an RMS voltage approximately equal to the required DC output voltage. One end of the winding is earthed and the other connects to the first filter capacitor via the diode.

The circuit is in effect half the full-wave circuit, and the diode only conducts on every alternate half-cycle when the top of the HT secondary is positive. The half-cycles when the winding voltage is reversed are not used.

The half-wave circuit is thus rather inefficient, as it only uses half the energy available from the transformer. It is as a result only suitable for low current rectification and, as the diode has to have a peak inverse voltage rating of approximately 2.828 times the DC output (which is approx. equal to the RMS voltage of the HT secondary) it is really only practical for low voltages as well.

The half-wave rectifier circuit delivers only one pulse of DC for each AC input cycle, so that its DC output ripple frequency is 50Hz. This makes filtering somewhat more difficult compared to the 100 Hz ripple produced by the full-wave and doubler circuits.

So far in this chapter, we have thought mainly in terms of power supplies required for the operation of valve receivers and equipment from the mains. Let us now look at the type of power supply required to operate transistor equipment from the mains.

As we saw in an earlier chapter, transistors are relatively low-voltage devices compared with valves. They typically operate with supply voltages of from 3 to about 80 volts, whereas valves normally use somewhat higher voltages.

Where transistor circuits are required to deliver appreciable amounts of power — for example, in the case of transistorised audio amplifiers — they must accordingly be supplied with higher currents than valve circuits of equivalent performance. This is simply because to deliver power, they must be supplied with power, and power is effectively the voltage multiplied by the current.

Figure 5 shows a fairly typical type of transistor power supply. The power transformer has only one secondary winding, an untapped low voltage winding. This is connected to a so-called bridge rectifier circuit, using four silicon diodes or a selenium "stack" (as used in battery charger rectifiers), and thence to a very high value filter capacitor C1 and a further regulator and filter circuit using a transistor.

The bridge rectifier is full-wave, in that it operates on both half-cycles of the AC wave. It differs from the full-wave circuit of figure 1 in that it does not require a tapped supply winding, and it differs from the doubler in that it does not supply a DC output voltage twice that of the RMS input voltage.

In the bridge circuit, two diodes conduct during each half-cycle. When the top end of the transformer winding is positive, diodes D1 and D3 conduct, and when the lower end of the winding is positive diodes D2 and D4 conduct.

The peak reverse voltage across the diodes when they are non-conductive is 1.414 times the RMS supply voltage and (approx) the DC output voltage, so that the bridge circuit is midway between the full-wave and doubler circuits in its demands upon the diodes regarding their peak inverse voltage rating.

The low-voltage, high current requirement of transistor power supplies makes filtering the AC ripple from the DC output a difficult task. A very large first filter capacitor is required (some supplies use 10,000 uF or higher), and as we have shown a transistor filter circuit must often be used for additional filtering. To maintain the output voltage constant under load it may also be necessary to add further circuitry for regulating the output.

The transistor is used to give what we might think of as "amplified" smoothing of the power supply output. Its operation relies upon the fact that the bipolar transistor is a current amplifier. It is capable of controlling large currents when supplied with small input or "bias" currents, as we saw in chapter seven.

The general principle of transistor filtering and regulation is that the transistor is made to control the relatively large current drawn by the load circuit by supplying its control electrode — the base — with a smoothed and / or regulated source of bias current. As this reference source is required to supply only the small control current of the transistor, it is a relatively easy matter to provide it with filtering and regulation.

As may be seen from figure 5, the transistor (here an NPN type) has its collector connected to the pulsating DC output of the rectifier. Its base is supplied with smoothed bias current by means of the filter circuit formed by resistor R and capacitor C2, while the emitter becomes the output electrode and connects to the load transistors which must be supplied with power.

The simple resistor-capacitor filter circuit used to supply the base bias for the transistor is sufficient to provide adequate smoothing, because the base current required is relatively small. However the fact that the transistor is fed with well-smoothed base current means that its collector-emitter current — which is an amplified version of the base current — also tends to be well smoothed. Hence the relatively high current fed to the load transistors is smoothed, and the effective output voltage produced at the emitter of the filter transistor is also smoothed.

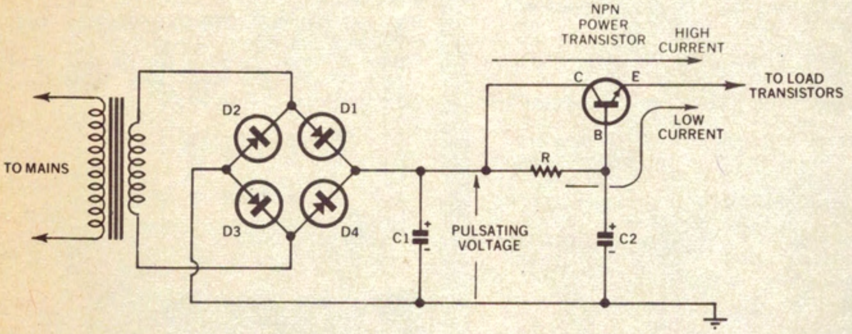


Figure 5: Fully transistorised equipment normally needs a much lower supply voltage than valves but at a much higher current. This typical transistor supply shows a bridge rectifier system, a high value filter capacitor, and a transistor dynamic filter circuit.

This type of transistor filter circuit is often called a "dynamic" filter, because the filtering is achieved by the transistor effectively varying its instantaneous resistance to compensate for the pulsations at the rectifier output. Because the load voltage tends to duplicate the reference voltage at the base of the transistor, a transistor connected in this way is also said to be connected as an "emitter follower".

The feature of the emitter follower mode of connection which is of particular importance from the viewpoint of dynamic filtering and regulation, is that the load voltage is more or less independent of the transistor collector voltage. As long as there is sufficient collector supply voltage to supply the requirements of the transistor and load, any pulsations or variations present in the collector supply voltage tend to have little if any effect upon the load current and voltage.

Often the action of a dynamic filter is pictured by considering the transistor to have "amplified" the filter capacitor C2 to a value given by the product of C2 and the transistor current gain. Thus, it is said to act as a "filter capacitance multiplier."

For example, if C2 has a value of 500uF and the transistor has a gain of 100, the effective filtering is considered to be equivalent to a capacitor of 50,000uF shunted directly across the load.

While this comparison is fairly accurate as far as the filtering is concerned, it is not accurate as far as the source impedance seen by the load is concerned. This point is a little too involved for our purposes at present, but it should be remembered that the concept of "capacitance multiplication" is rather limited in its application.

As mentioned earlier, a transistor connected like that in figure 5 (as an emitter follower, in other words) can also be used to "regulate" the output of a power supply. This means that it can be arranged to keep the supply voltage substantially constant at the correct value, despite changes in the current drawn.

As you might have already guessed, this is done by holding the voltage supplied to the base of the transistor constant, so that the transistor has no choice but to maintain substantially the same voltage at its emitter. Usually the base voltage of the transistor is held constant by using a circuit with a so-called "Zener diode", which is a special sort of semiconductor diode made to be operated in the reverse breakdown condition. The operation of the circuit depends upon the fact that the voltage drop of such a zener diode remains effectively constant for a wide range in currents.

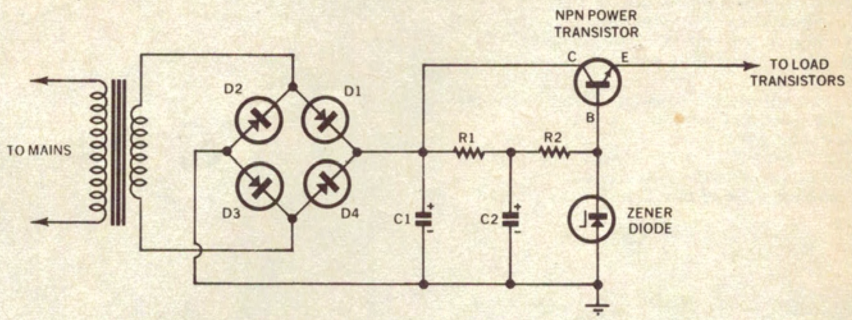


Figure 6: This transistor supply is similar to that of figure 5, but the transistor circuit performs voltage regulation as well as dynamic filtering.

Figure 6 shows the circuit of a very simple regulated power supply using a zener diode. Basically the supply is identical to that of figure 5, but the resistor in the base circuit is now divided into two, with capacitor C2 now connected between their junction and the negative line (which is earthed). The zener diode is connected between the transistor base and negative, holding the base above ground by the diode breakdown voltage.

In closing the discussion of power supplies, filtering and voltage regulation, it should be mentioned that, although the principles of dynamic filtering and regulation have been explained by reference to transistors, the same principles apply to valves. Dynamic filtering is not often employed in valve circuits — principally because it is fairly easy to achieve adequate filtering using normal inductor-capacitor filters — but valve-type voltage regulators are quite often used in test equipment and other equipment requiring well-regulated supply voltages.