

POWER Rectifier Circuits

common and uncommon

A SURVEY OF PRINCIPLES OF
PRACTICAL IMPORTANCE, AND
USES OF SUCH CIRCUITS

By L. N. Nash

A NUMBER of very useful and thorough practical articles have appeared in recent months in *PRACTICAL WIRELESS* and *Practical Television* concerning rectifiers, rectifier circuits, metal rectifiers, crystal diodes, etc. It is now felt that a useful addition to this series would be a practical discussion of power-rectifier circuits in particular, and consequently the author has compiled the present article from his own practical experience in the workshop, in building the most varied of such circuits.

Varied Circuits

After a preliminary discussion of some important general principles, and a brief survey of conventional circuits as a brief recapitulation of more detailed material in past articles, the author will proceed to introduce a number of more unusual and unconventional power-rectifier circuits, pointing out their individual advantages and disadvantages. These circuits form the actual main subject of this article. All circuits given have actually been built and used by the author, principally in the form of the power-supply portion of a chassis of equipment. Where actual component values are quoted in the diagrams, these may be used directly by constructors if they wish to build any of the circuits concerned as power-supply portions of a chassis of equipment for any purpose they may desire. All circuits bearing specific component values have been built and proved by the author. Those circuits intended to illustrate only a principle, however, will bear a note to that effect since some component values specified will be approximate, and the circuits should then be treated merely as the basis for the constructor's own experiments.

Naturally, if the same circuit is desired, but a different output voltage or current or both, modifications may be necessary even to those component values specified. It is highly likely that the constructor will have gained sufficient knowledge from this article and other rectifier-articles in this magazine to be able to judge the extent and direction of such possibly necessary modifications.

Construction and Layout

It is assumed that almost all power-rectifier circuits connected with the normal experimenter's

work receive a 50c/s mains-frequency input, so that all questions of critical layout and short wiring as arising in high-frequency circuits do not apply here. The layout is thus not in any way critical in any of the circuits, and leads of even considerable length are perfectly tolerable if deemed necessary for any particular purpose, such as bringing a particular switch or fuse to the front panel, etc.

Far more important is the question of adequate and substantial insulation. Many modern wires with plastic insulation soften at relatively low temperatures, and it is inadvisable, for example, to run such wires unprotected hard against cores of transformers which heat up considerably in normal operation. A good quality oil-fabric sleeving should be used for such wires at all such danger points, and for voltages above about 500 it is the author's practice to use two such sleeveings pushed over each other, having different diameters to suit. All leads going through the chassis should be protected by substantial rubber grommets. Apart from the danger of mechanical damage by chafing, unprotected chassis holes for wires promote danger of flashover at higher voltages, due to the concentration of the electrostatic field at sharp corners. This is very important here, because it is for the various higher voltage rectifier circuits that the full advantages of the unusual circuits to be introduced in this article become apparent.

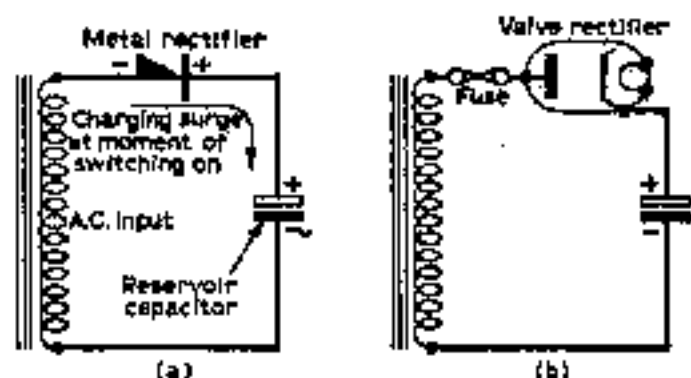


Fig. 1a—A fuse taken direct from the transformer to the rectifier would be likely to blow easily on switching on, due to the charging surge of the reservoir condenser; b—with a valve rectifier, the condenser charges more slowly as the valve heats up.

Fusing Considerations

It is necessary to use switches of adequate voltage rating, and to pay proper attention to any fuses that may be deemed necessary. A fuse in the lead direct from the transformer to the rectifier protects against rectifier and smoothing condenser faults as well as output overloads, but has the disadvantage of easily blowing upon switching on, due to the charging surge of the reservoir condenser (Fig. 1a). This trouble is present if a metal rectifier is used. With a valve rectifier, the reservoir condenser charges more slowly as the valve heats up, and thus this form of fuse is then more applicable (Fig. 1b).

It is of course necessary to use a sufficient number of fuses to ensure complete cut-off in the event of a failure. Thus, in the conventional full-wave valve rectifier circuit of Fig. 2, a single fuse placed at A will protect against output overloads, but a pair of fuses is necessary at B and C to protect adequately against internal faults of the circuit as well as output overloads. A single fuse at D is to be considered dangerous, as in the event of a short between anode and cathode of one diode, the transformer winding is then shorted through the other diode on one half-cycle, which renders the transfer of the fuse from A to D pointless.

Comprehensive Protection

In small power units of normal voltage output, an output fuse at A and a mains fuse in the transformer primary circuit (which takes care of internal faults) are sufficient. But for high-voltage or high power units, this simple protection is not sufficient. If other circuits (heaters, subsidiary H.T. voltages, etc.) are fed from the same large transformer, it may be impossible to make the rating of the mains primary fuse low enough for it to blow before excessive fault currents could flow in the faulty rectifier circuit in question. In such cases fuses at such positions as B and C in Fig. 2 are necessary. For conventional rectifier circuits, the matter need not be taken too critically, but for the more unusual circuits, where faults could have a whole chain of expensive consequences, proper fuse protection is well worth the extra expense and trouble. This does not mean that the unusual circuits here to be discussed are in any way unreliable or prone to breakdown due to improper operation of components other than under specified conditions. On the contrary, no components are operated under other than permissible conditions in the specified circuits, and the author has found a high degree of reliability of such circuits, under periods of continuous operation even as long as a week at a time.

Modulation Hum

A rectifier is the basis of normal detector circuits, as will be known to all experimenters. The question of "detection", i.e. removal of the audio or video signal from the modulated R.F. carrier, is in principle little different from the reverse process, that of "modulation" of the R.F. carrier with the audio signal at the transmitter, so that in principle the same rectifier circuit could function for both purposes.

If in any way the wiring connected to a power

rectifier picks up an R.F. signal, over the mains wiring in the house, or by any other available process, then the rectifier (be it a valve or a metal rectifier, that makes no difference) will invariably modulate this picked-up signal with the 50c/s mains hum, in addition to any modulation it may already have. If now the same circumstances which led the rectifier wiring to receive the R.F. signal enable it to be radiated again, then any receiver picking up this re-radiated signal cannot distinguish the original modulation from the distant transmitter from this local "modulation hum". Consequently a powerful hum is present on the radio concerned, but only when stations are tuned in. Normally only local stations are affected, as distant weak stations provide insufficient signal at the power rectifier. However, it is perfectly possible for even weak stations to be affected if the power rectifier circuit picks up and modulates an R.F. signal and re-radiates it to an I.F. stage in a poorly screened receiver. In such a case hum will be present as soon as any station whatsoever is tuned in.

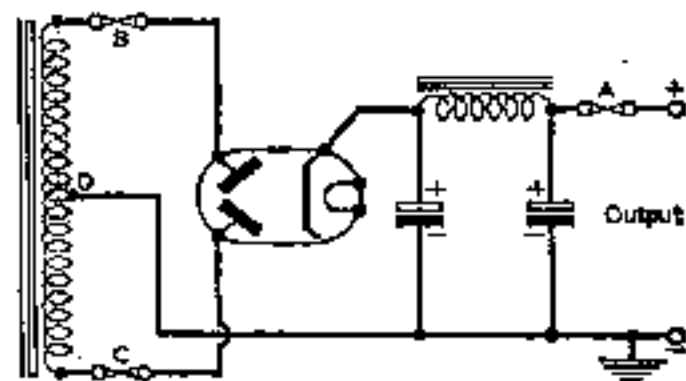
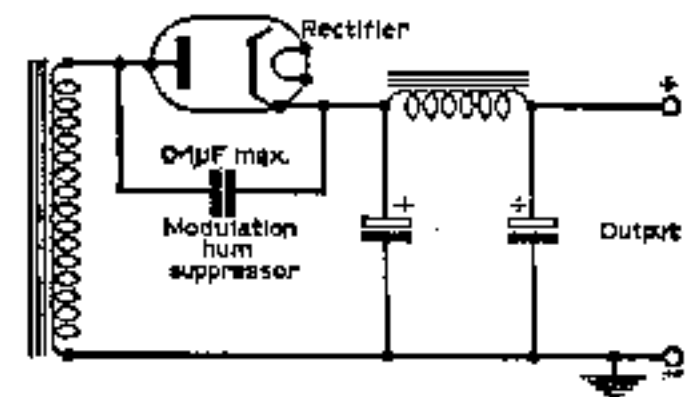


Fig. 2 (above)—Possible positions for fuses in a full-wave rectifier circuit.

Fig. 3 (below)—Shunting a condenser across a power rectifier, to remove modulation hum.



Remedies

Now for the practical consequences of this discussion! Two measures are available to combat modulation hum. The first is to render the power rectifier inoperative as a rectifier for R.F. whilst being unaffected at mains frequency. This is achieved by shunting a condenser across it between anode and cathode. Naturally, this shunt condenser (see Fig. 3) forms an A.C. bleeder together with the reservoir condenser, and thus increases the A.C. ripple on the D.C. output. Thus there is an upper limit to the size of the shunt condenser usable. It is a good rule of thumb to use a shunt-

capacity of about 1% of the value of the reservoir condenser used, but not exceeding 0.1 μ F.

The second measure is to assign the rectifier a proper place on the chassis in relation to other circuits. The power rectifier should always be as far away from all R.F. and I.F. circuits as possible, and the latter should be adequately screened, for this and other reasons. A mains transformer with a shield between primary and secondary is very helpful. In high-voltage circuits, where shunt-condensers across the rectifiers may be impossible, because maximum values tolerable on account of the low values used for the reservoir condenser are useless to shunt R.F., it may be necessary to use a good transformer with a screen and build the whole rectifier circuit into a screening can. But such severe cases should be extremely rare.

Neighbouring Receivers

It must be added on this topic that the author has several times been called upon to repair a receiver suffering from "severe hum", and finally cured the fault by shunting the rectifiers in a radio belonging to a completely different family, in some cases several floors removed in the same house. Careful work with a portable direction-finding receiver was necessary to locate the offender, and such work is really the job of GPO interference-tracing vans. It is here mentioned merely as an example of the surprising range of re-radiated signals with modulation hum, under "favourable" conditions. One can cause considerable annoyance

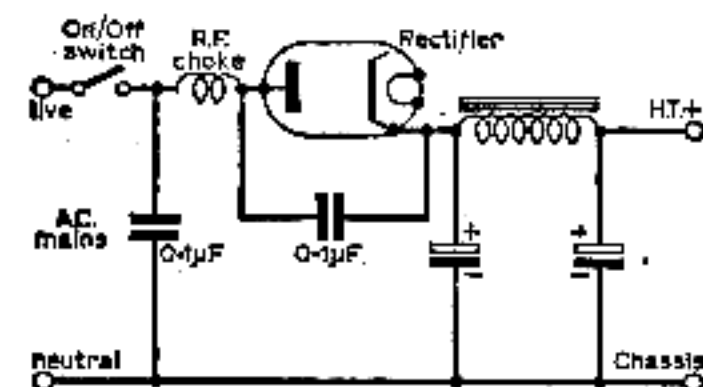


Fig. 4 (above)—Curing modulation hum in older mains installations sometimes requires more than just a shunt-condenser.

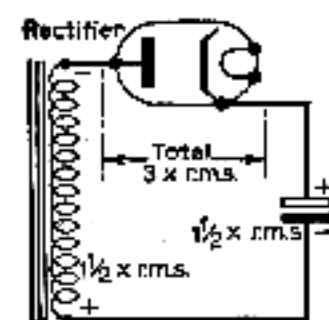


Fig. 5 (left)—The relation between r.m.s. input and peak inverse voltage (PIV) ratings.

to one's neighbours with an unsuitable rectifier circuit, as well as impair the performance of one's own equipment. Notorious offenders are A.C./D.C. sets drawing H.T. through a rectifier connected direct to the mains, as this arrangement offers easy entry and exit of R.F. signals over the mains. Sets using a transformer are far better, and in many cases the R.F. losses of the mains transformer are high enough to remove all trace of modulation hum even without rectifier-shunt condensers.

It is virtually impossible ever to make an A.C./D.C. set run free of modulation hum without a shunt-condenser, which then takes a familiar simple form of a 0.1 μ F condenser straight across the mains input to the set. Whilst this measure virtually cures modulation hum in the set concerned, it is sometimes less effective in older domestic mains installations using long runs of wire without conduit, which function as efficient aerials. In such cases, the addition of the items in Fig. 4 may help.

Peak Inverse Voltage and A.C. Input Rating

The *peak inverse voltage* of a rectifier is the maximum voltage it can withstand in the non-conducting direction (i.e., with anode negative and cathode positive) without breakdown. The *A.C. input rating* is the maximum permissible r.m.s. voltage output of the transformer winding feeding the rectifier and smoothing circuits. Sometimes the one and sometimes the other is quoted in the characteristics for a rectifier, and there exists a definite relation between the two.

Considering the simple conventional half-wave rectifier circuit of Fig. 5, it is clear that the reservoir condenser charges up until it reaches a D.C. voltage equal to the *peak* of the applied A.C. voltage. Now this peak is roughly one-and-a-half times the r.m.s. value for the mains sine wave (exactly, $\text{peak} = 1.414 \text{ r.m.s.}$).

Inverse Voltage Stress

On the subsequent half-cycle, in which the rectifier is blocked because the transformer voltage has reversed, the peak condenser voltage and the negative peak transformer voltage (another one-and-a-half r.m.s.) act additively in series across the rectifier in the non-conducting ("inverse") direction. Thus, the total inverse voltage stress on the rectifier is *three times* the A.C. r.m.s. voltage output of the transformer.

Thus for a 350V r.m.s. A.C. transformer winding, the rectifiers must be rated for "350V A.C. input", or for "1000V peak inverse voltage"; both statements amounting to the same thing. It is this factor which limits the use of metal rectifiers at the higher voltages. In principle, sufficient elements of metal rectifiers may be connected in series to withstand the inverse voltage, but this becomes prohibitively expensive if high-current operation is desired. In such cases one finds valves more economical.

Valves

At normal H.T. current ratings of 50mA to 100mA it is at present relatively uneconomical to

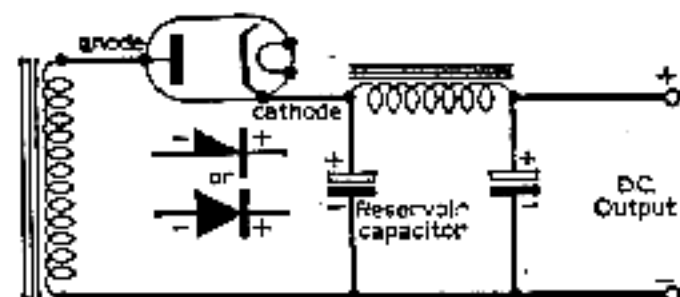


Fig. 6a—Basic half-wave rectifier circuit.

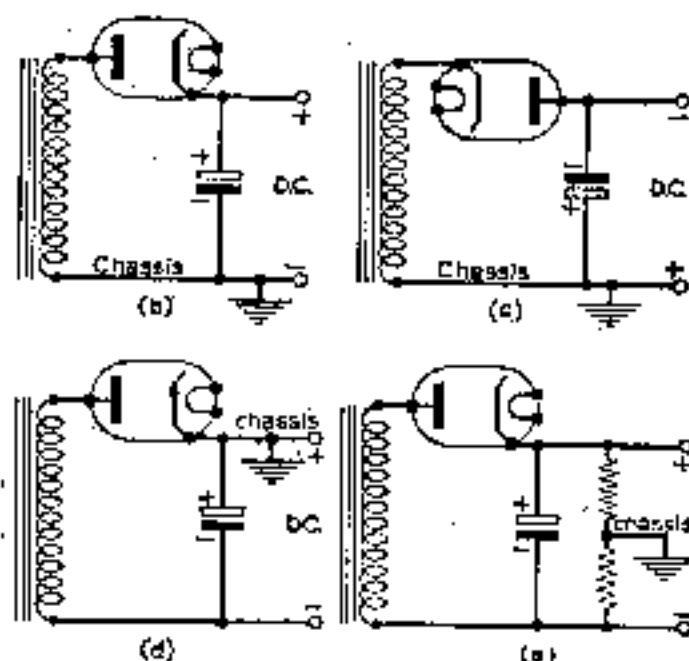


Fig. 6b—Positive-output half-wave rectifier circuit; c and d—negative-output half-wave rectifier circuits, e—obtaining positive and negative outputs simultaneously in a half-wave circuit.

construct metal rectifier elements for A.C. input voltages exceeding at the very most 500V (peak inverse voltage 1,500), though series piles of elements for low-current EHT rectifiers are relatively cheap and common, even up to A.C. inputs of many thousands of volts. The modern developments in silicon power-diodes capable of carrying currents up to some amps in the larger types have a present peak inverse voltage limit of about 1000, so that maximum A.C. inputs of about 350V are permissible. There is nothing except the price, to prevent the use of two or more such diodes in series (to increase the voltage rating in direct proportion), but a valve would almost always be more economical in such cases. The silicon diodes need a heat sink in the form of a metal plate to which they are bolted, and if several such diodes are connected in series, the heat sinks will be at different potentials, and must be adequately insulated. This can introduce problems outweighing the disadvantages of a valve rectifier in the particular application envisaged.

Combination of Rectifier Types

The author is of the opinion that the "valve rectifier versus metal rectifier" controversy is largely futile. The truth is that the scope open to the constructor has been enriched by the availability of both types of rectifier. There are a number of applications where the ideal solution of a problem involves the use of a mixed circuit using both valve and metal rectifiers, as will become apparent in the course of this article. However, as a general principle, valves score on their high inverse voltage rating, but are clumsy and require heater voltage, and generate appreciably more heat. Metal rectifiers of copper oxide, selenium or silicon types score on high current ratings, but have limited inverse voltage rating. As a result, modern circuit practice has justifiably relegated valves to the higher voltage circuits.

When connecting metal rectifiers in series to increase the voltage rating, only identical types may be used in each series connection, as the series-connection of different types with different inverse resistances cannot enable the desired equal sharing of voltage to be realised. To allow for tolerances, it is not advisable to run a pair of series-connected rectifiers to a voltage higher than $1\frac{1}{2}$ times the rating of a single rectifier of the same type.

Conventional Half-wave Rectifier Circuits

The rectifier diodes in all the following circuits of conventional type have been drawn in the form of valves. They are of course equally applicable to the use of metal rectifiers or silicon diodes, bearing in mind the remarks in the previous paragraph.

Fig. 6a gives details of the simplest conventional rectifier circuit, the "half-wave" circuit, together with the most common equivalent symbols for valves and other types of rectifier. It is very important that the constructor familiarise himself with the accepted circuit symbols and representation of polarity of rectifiers because connection of a rectifier with wrong polarity in a circuit can lead to serious consequences. It is conventional to make the thin line of a metal rectifier symbol correspond to the valve-cathode, and this corresponds to the terminal marked "+" or "red" or "cathode" in a metal rectifier. The "triangle" or "arrow" of the metal rectifier symbol corresponds to the valve anode.

Chassis Connections

According to which side of the D.C. output of the half-wave circuit of Fig. 6a is connected to chassis (earthed), we can get a negative or a positive output voltage with respect to chassis, as shown in Figs. 6b and 6c. The "positive" form of Fig. 6b is used for H.T. supplies in A.C./D.C. sets, where the transformer winding of the diagram is actually replaced directly by the mains. Fig. 6b is used as it stands, with input from a mains transformer secondary winding of the desired voltage, in H.T. supplies for the simpler forms of A.C. mains radios, amplifiers, etc, where the current drain is not high enough to warrant the expense of the more efficient full-wave circuit. The "negative" version of Fig. 6c is often used to provide the input D.C. voltage to a negative grid-bias voltage bleeder chain in such circumstances which require higher grid bias voltages than are easily obtainable by the use of cathode resistors for the valves, or other conventional methods. An independent grid-bias supply of this type also has the advantage of greater stability and of fundamental independence from the anode currents flowing in the valve circuits being biased.

The half-wave rectifier circuit of Figs. 6a to e derives its name from its simple function. When the transformer winding voltage is of the same polarity as the ultimate output D.C. voltage, i.e. on alternate half cycles of the A.C. waveform, the rectifier conducts to charge the smoothing condensers. On the other half cycles, the rectifier is blocked, and the inverse voltage, discussed in the previous paragraph, is operative across the rectifier.

(To be continued)