POWER Rectifier Circuits common and uncommon

By L. N. Nash

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

(Continued from page 308 of the August issue)

LAST month's article finished with an explanation of the advantage of the cascade voltage doubler circuit over the conventional voltage doubler circuit.

Fig. 21 gives an example of a combined H.T./EHT supply on these principles. A further advantage of this circuit is shown in Fig. 22, where the same circuit but of inverse polarity is added to the same transformer winding, in the same method of circuit development as the previous treatment of the other basic circuits. The result here is an output at *four times* the voltage output of a simple half-wave circuit, so that this circuit is called the "Cascade Quadrupler". These types of circuit are called "Cascades" on account of their cumulative method of working. Thus the first rectifier and condenser, MR1 and C1, function as a normal simple half-wave circuit, charging up C1 to the peak. On the half cycle of opposite polarity, where MR1 is now blocked, polarities are such that the charged C1 and the reversed transformer winding voltage act in series addition as voltage drive for the second rectifier and condenser MR2, C2 also operating in simple half-wave circuit, thus clearly leading to a doubled voltage output. The operation of C3/MR2 and MR4/C4 follows similar lines.

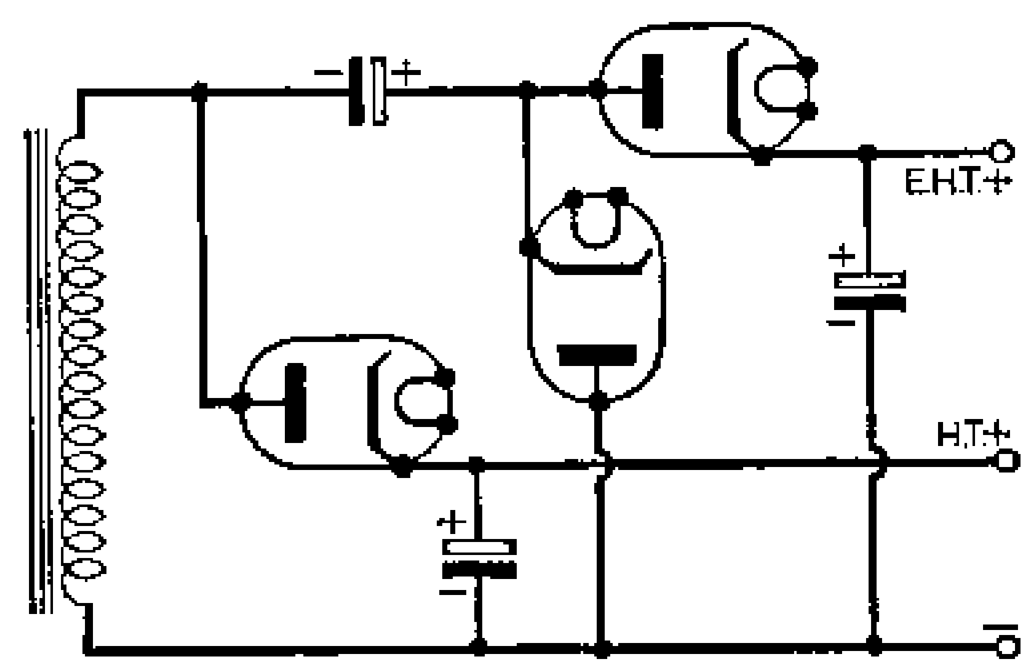

Fig. 21 (above)—Combined H.T./EHT circuit using the cascade voltage doubler principle.

Progressive Cascading

In principle, the charge voltage on C2 and the transformer voltage can be made to act in series across a further rectifier on the next half cycle, and so on up to any number of cascaded stages. Thus a D.C. output voltage of any desired multiple of the output of a simple half-wave circuit is possible with rectifier cascade-multipliers, without the need for any transformers. But such circuits are of little use to the constructor, because rectifiers and condensers of the large voltage ratings required are not commercially available.

It may be mentioned, however, that the rectifiers may be replaced by spark-gaps of graded separation, trimmed so that breakdown just occurs at the half-cycles corresponding to the maximum voltage, exactly where a normal rectifier would be required to conduct in such a circuit. This is an interesting example of the use of spark gaps in substitution for rectifiers, which has actually been used in historical equipment for high-voltage supply for atomic research. Generators with spark-gap cascades have been built with an output of well over a million volts, using a transformer winding input of some thousands of volts.

This completes the survey of those rectifier circuits considered to be of practical use to the experimenter. Many other interesting types, such

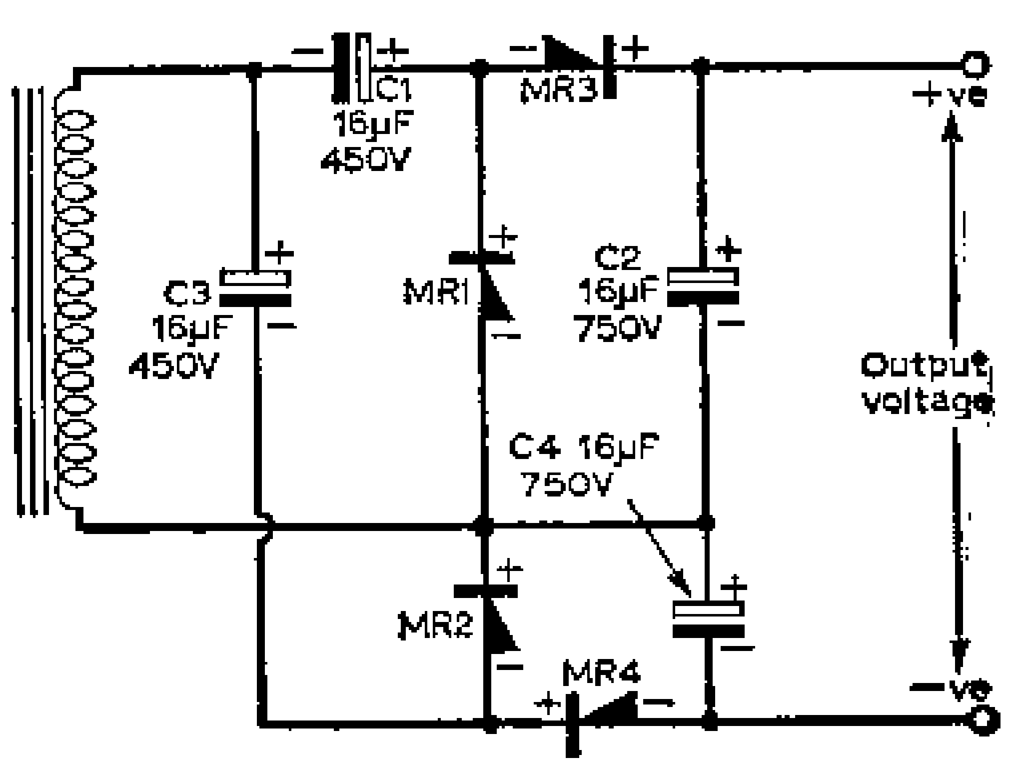

Fig. 22 (right)—The cascade voltage quadrupler circuit. Transformer secondary 250V r.m.s.; rectifiers E250C50 selenium. Do not mount on the same metal chassis, as otherwise flashover inside the casing is likely. Use separate cooling plates of aluminium insulated from each other. (The values given are approximate.)

as three-phase and polyphase equipment, grid-controlled rectifiers, etc., are not considered to be of practical importance for the general experimenter.

Peaking and Smoothing

All rectifier circuits work into an output load through which the D.C. output current flows. In basic principle, this output load consists of a resis-

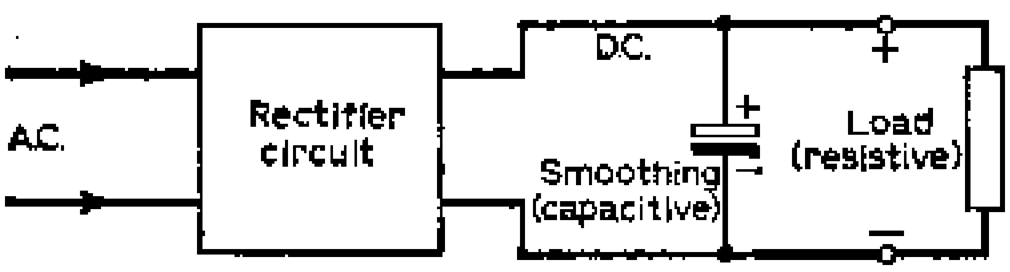

Fig. 23—Resistive and capacitive elements in parallel representing the output load.

tive element (the actual useful load) and a capacitive element (the "smoothing") in parallel, as shown in Fig. 23. Fig. 24 shows the more conventional smoothing, where the capacitive element is split at the "hot" end into two, and a choke or resistor inserted. This enhances the characteristic that the A.C. component of the output (hum ripple) goes preferably through the capacitive element to earth, whilst the true D.C. component goes through the resistive element (real load) to earth, which is the familiar purpose of smoothing —namely to remove as much as possible of the remaining A.C. component of the output.

Now, the capacitive element of the circuit of Fig. 23, as long as it is not charged to the final voltage, represents a short-circuit as soon as the

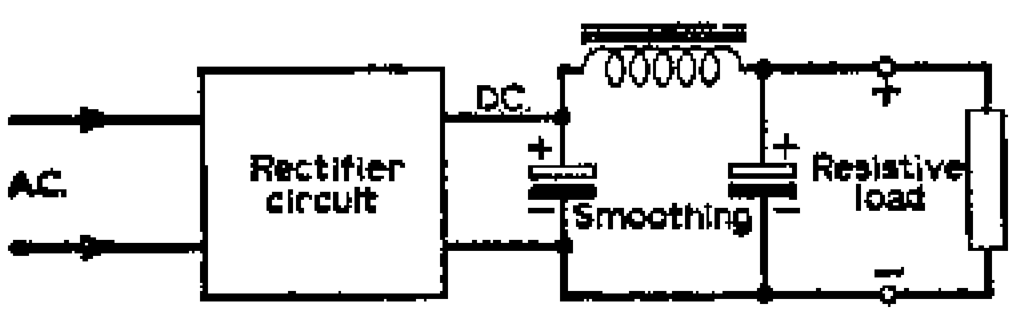

Fig. 24—Conventional smoothing.

transformer winding voltage has reached a part of the half cycle of the conduction-polarity where the voltage has risen above that to which the condenser is at the moment charged and charge current will then flow into the condenser to increase its voltage. It is thus perfectly obvious that this process goes on until the condenser has charged up to the peak voltage of the A.C. wave, which is about 1·5 times the r.m.s value for the mains sine wave. This property of rectifier circuits is known as (capacitive) peaking, and raises the peak inverse voltage rating required for the rectifier, as explained earlier in this article. Even if no physical condenser is present, the circuit stray capacities, even if very small, are inevitably fully sufficient to give full peaking on open-circuit output, so that no reduction in inverse voltage rating of the rectifiers is permissible even if no physical smoothing condensers are used, as in common accumulator charging circuits.

Load Characteristics

The remarks regarding full peaking made in the previous section apply to open-circuit output, i.e., the case when the resistive component of the output load is of infinitely large resistance. As soon as a finite resistive component is connected, i.e. an actual pure D.C. output current is drawn, this will draw charge away from the smoothing condensers.

Thus, in actual practice, the final operating output voltage will be somewhat less than the full peak voltage, according to the balance struck between the load current passing out of the condensers and the rectifier current passing into them on the appropriate portions of the A.C. cycle. Zero output D.C. load results in full peaking, as explained above, and as the output D.C. load current increases the voltage will fall below the peak, the decrease being normally linear with rise of current in most circuits, which means that Ohm's Law is obeyed to the extent that a definite corresponding internal impedance may be ascribed to the circuit. This *internal impedance* lies in the region of about 1k to 2k for normal conventional full-wave H.T. rectifier circuits, so that a decrease of 1V to 2V may be expected in the output voltage for each rise of about 1mA of output current drawn. The actual exact figures in a particular case will depend greatly on the smoothing capacity values, rectifiers, resistances of transformer windings, etc. A good power supply should have as small a change of voltage with load current as possible, i.e. as low an internal impedance as possible.

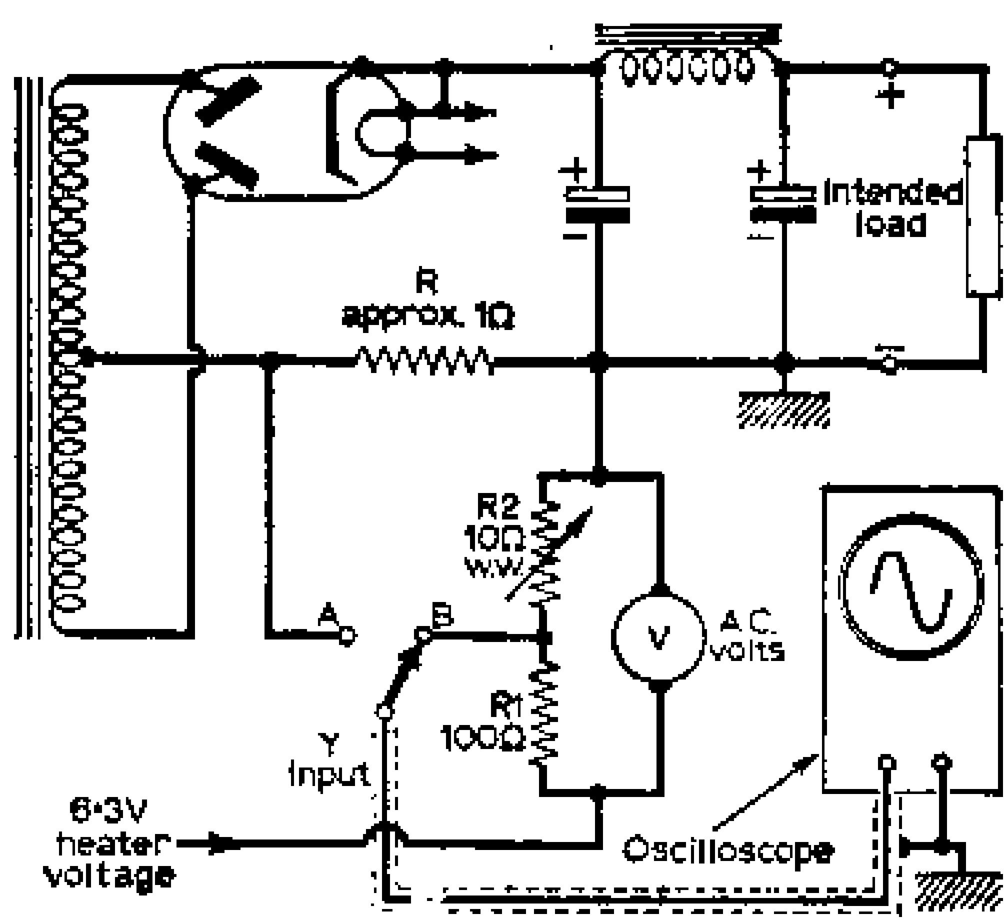

Fig. 25—Measuring peak surge rectifier current.

Condenser Values

Large values of smoothing capacities reduce the internal impedance, in that they keep the output voltage high at greater load currents, but this is at the expense of large surges of current through the rectifier at the A.C. cycle peaks, which exceed the surge-current rating of the rectifier for smoothing capacities larger than a critical value for a given circuit. Thus the use of too large a smoothing capacity can cause overheating and flashover in the rectifier.

Metal rectifiers, and especially the new silicon rectifiers, can tolerate higher peak currents than normal valve rectifiers. This is a great advantage of these devices, and allows the use of much larger smoothing capacities, which is very useful in half-wave circuits requiring the extra smoothing effect. It is extremely difficult to determine the maximum tolerable smoothing capacity on theoretical lines if one is about to try out a new rectifier circuit of one's own design, but fortunately it is a simple matter to measure the peak rectifier current in an experimental circuit if one posesses an oscilloscope and an A.C. voltmeter. Fig. 25 shows the arrangement for such a measurement, as typically applied to a conventional full-wave H.T. rectifier circuit. The normal load which the circuit is intended to feed is connected, and the small measuring resistor of about 1Ω (the resistance (R) of which must be known accurately) is connected as shown. It does not disturb the function of the circuit appreciably, serving merely to monitor the rectifier current.

The oscilloscope input is now connected to A, and the trace adjusted to suitable height and the timebase to display a convenient number of cycles. The waveform will not be a sine wave, but will display the regular current surges through the rectifiers. Without altering any settings of the oscilloscope controls, the oscilloscope input is now switched to B, and R2 adjusted until the mains sine wave display has exactly the same peak to peak amplitude as the peak to peak amplitude of the rectifier current display. If V is the reading of the A.C. voltmeter, then the peak rectifier current is given by

$$\text{I peak} = \frac{V}{R} \times \frac{3R2}{R1 + R2} \text{ Amps}$$

$$\left(\begin{matrix}\text{Resistances in Ohms} \\ \text{V in Volts r.m.s}\end{matrix}\right)$$

The data list should then be consulted to check whether the measured peak current is within the *surge-current* rating of the rectifier in use. If not, then the smoothing capacity must be reduced, the load current reduced, a different rectifier type used, or a surge limiting resistor or choke inserted (Fig. 26), or any suitable combination of such measures. If one were very careful in the design of circuits, the initial surge currents through the rectifiers as the condensers charge up from zero upon initially switching on would also be studied.

Surge Limiters

If the initial surges are found to exceed the rating of the rectifiers, then the same measures as indicated above can be used, though the best measure in this case would be the use of surge-limiter resistors or chokes. There is in principle a choice of three positions for such components, as illustrated in Figs. 26 a, b. c. Fig. 26a is normally used if resistors are used, whereas Fig. 26b is common if a choke is used, whereas Fig. 26c is seldom found.

There is not a great deal to choose between the three arrangements, the particular preferences being largely a matter of convention. Fig. 26b represents the familiar choke-input smoothing circuit, which has the characteristics of a very rapid initial fall of output voltage away from the full peak at low output currents, but thereafter far slower fall of output voltage with output current in the region of the operating value of output current (assuming proper choice of component values). The result is that such a smoothing circuit gives a smaller output voltage at a given load than the conventional smoothing circuit of Fig. 24, but the effective internal impedance is lower, i.e the regulation is better.

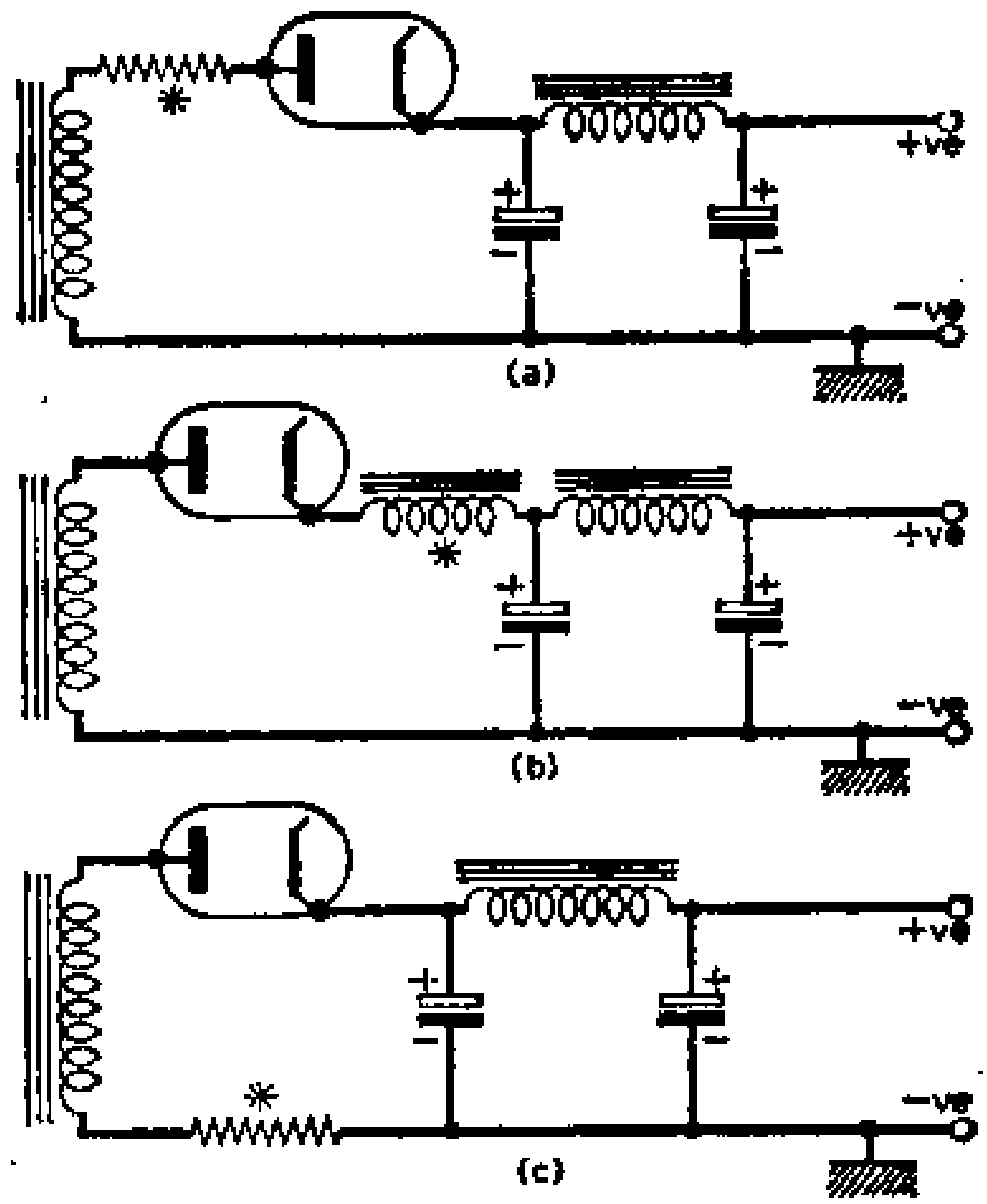

Fig. 26—The three positions for surge limiters.

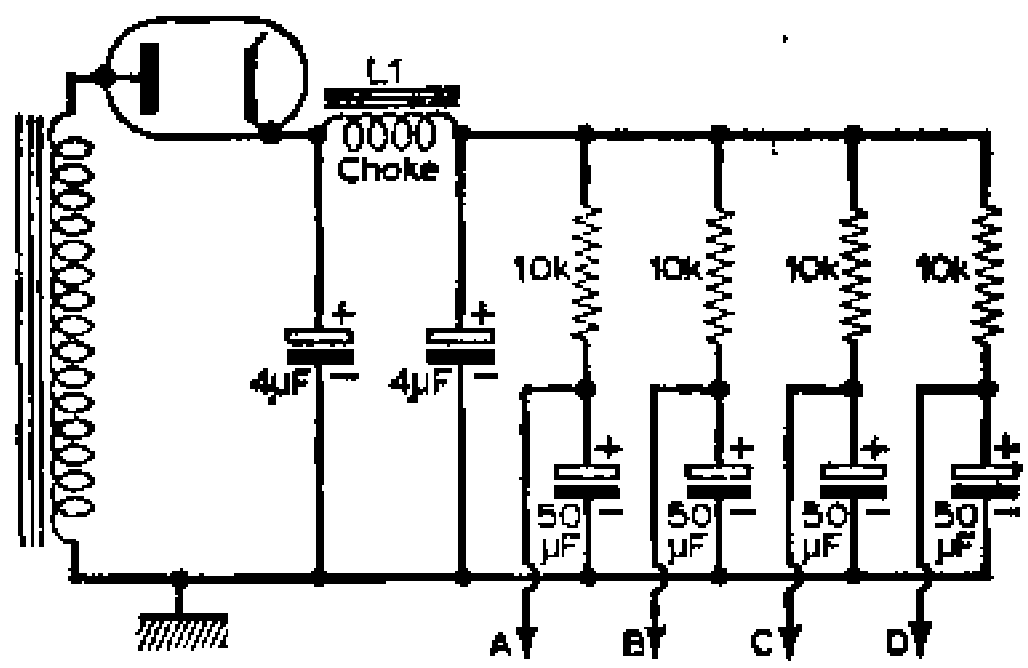

Fig. 27—This circuit provides decoupling and smoothing in one, and avoids unnecessarily large rectifier surge currents.

High Ratings

It should be mentioned that the use of television booster diodes as power rectifiers, in addition to advantages already discussed, has the further advantage of high surge-current rating. This is because these diodes are specially designed for pulse-operation in television line-output circuits, and therefore are fitted with excellent high-emission cathodes. Thus the PY81 is rated at a peak surge current of half an amp, so that with a 400V r.m.s. transformer winding giving a peak voltage of 600V forward, the surge-limiting resistance would only need to be at the very most about 1000Ω. The

(Continued on page 438)

Power Rectifier Circuits

(Continued from page 397)

resistance of the tranformer winding is often an appreciable fraction of this value, and added to this there is already the internal resistance of the rectifier present. Thus surge limiters of at the most a few hundred ohms will be needed with a PY81, however large the smoothing capacitors may be made. Under the conditions of Fig. 19 where the smoothing capacitors are only 5µF each, no limiting resistor was deemed necessary. It is in fact good practice not to make the smoothing condensers too large in the power supply itself, providing the additional smoothing internally in each consumer circuit connected, in the form of a large series resistor and electrolytic condenser, as shown in Fig. 27. This provides decoupling and smoothing in one, and avoids unnecessarily large rectifier surge currents.

Values

Good power supply designs use surprisingly small values for the smoothing capacitors, often only a few microfarads, especially for the first capacitor (the "reservoir" condenser) connected directly to the rectifier. If insufficient smoothing is thereby achieved, then electronic stabilisation is resorted to, which gives far lower internal impedances and far greater smoothing than is achieved by haphazard increases of smoothing capacities, and far lower strain is imposed on the rectifiers. Several such circuit designs have been published in this magazine.

All circuits using large values of smoothing capacitors connected directly to a rectifier are to be considered basically as compromises in compact or cheap-to-construct apparatus, where it is not deemed desirable to waste too much space or attention on the power supply. Such circuits give very reasonable performance life if capacities not exceeding about 32µF are connected direct to the output of normal valve rectifiers, and not exceeding about 64µF for metal rectifiers, and not exceeding about 100µF for silicon power-rectifiers. However, these figures must be treated as mere, very rough guides. The higher the reservoir capacity, the greater the strain on the rectifier, and the more is its useful life likely to be shortened.

Domestic Equipment

In domestic radio sets and other equipment subject only to intermittent service with long periods of rest, the matter is far less critical than for laboratory apparatus intended for long-period non-stop experiments. Thus the author is at present conducting experiments with Geiger-counter monitors for atomic radiation, for which a large quantity of electronic equipment is in non-stop operation day and night for weeks on end. If insufficient attention would have been given to proper design of power supplies for example, frequent breakdowns would have been inevitable, which would have caused the loss of valuable measurements, as well as the trouble and expense of such breakdowns. Even for television circuits a higher measure of care is required for power-supplies than for simple radio receivers, because higher voltages and currents are involved, more expensive equipment is in danger in case of breakdown, and the operating hours of television sets in most families are longer than those of radio sets! ■