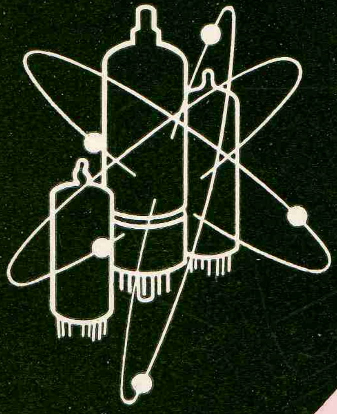

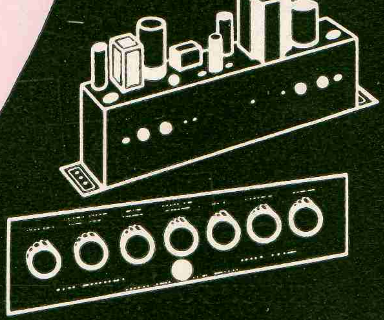

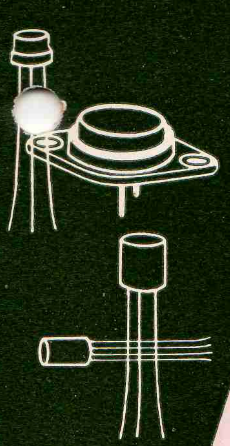

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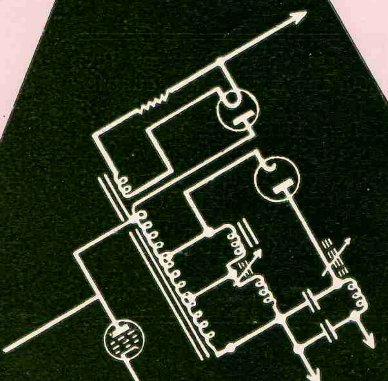

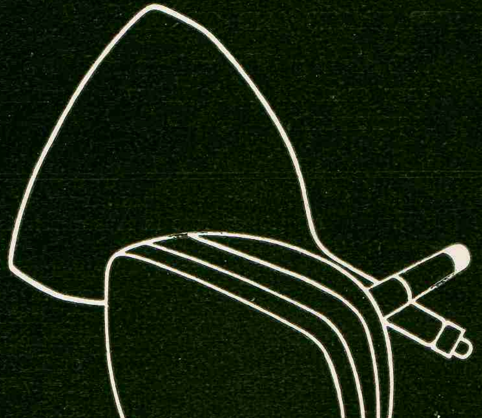

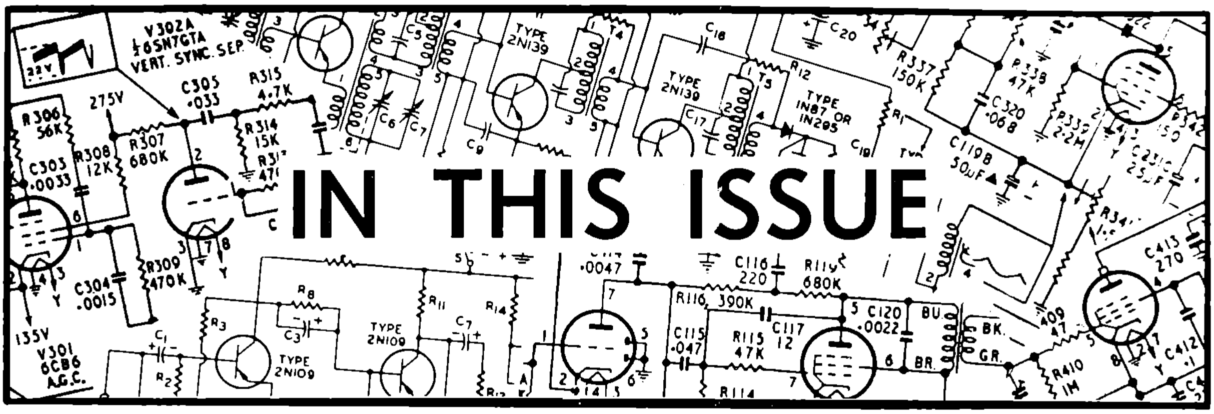

IN THIS ISSUE

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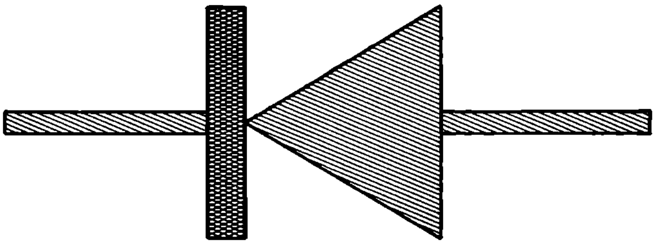
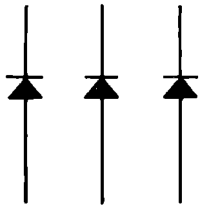


SILICON POWER RECTIFIERS



By B. J. Simpson

INTRODUCTION

With the flood of semiconductor devices which is being made available to the electronics industry today has come the silicon power rectifier, and the time has come for us to take a closer look at this device, to see what it can do for us. Basically the unit is quite simple. It is a silicon junction diode consisting of a slice of "n"-type silicon into which a layer of "p"-type silicon has been alloyed or diffused. The general arrangement is shown in Fig. 1.

Silicon rectifiers are available with ratings from a few watts up to high-power units handling quite large voltages and currents. They lend themselves to a wide range of applications, and will operate over a wide range of temperatures from extreme cold up to 150°C or more. Junction temperature of up to 200°C (depending on type) can be tolerated before breakdown of characteristics occurs.

The silicon used in these units is an almost perfect single crystal of pure metal, to which has been added a "doping" agent. Silicon is a group 4 material, having four valence electrons. The doping material may be a group 3 material, such as aluminium or gallium, having 3 valence electrons and producing p-type silicon, or it may be a group 5 material, such as arsenic or antimony, having five valence electrons and producing n-type silicon. *

Since it is impossible to control the introduction of all undesired elements in the manufacture of the crystal, elements of both groups will be present, the net result being dependent on the difference between the numbers of group 3 and group 5 atoms present in the material. For example, a preponderance of group 5 atoms will result in electrons being the majority carriers, and the material will be n-type. In the converse case, holes will be majority carriers, and the material p-type.

It is a well-known fact that if a positive potential is applied to the p-type side of a p-n junction and the return is connected to the n-type side, then current will flow very easily. If the polarity of the applied voltage is reversed, only a minute current will flow. These junction diodes, however, have other interesting and valuable properties which are perhaps less obvious to the casual onlooker.

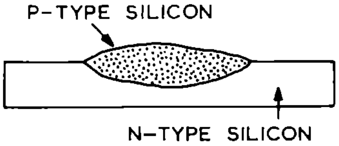


Fig. 1 — Cross-section of a p-n Junction.

CHARACTERISTICS

The forward resistance of the rectifier is very low, less than 1 ohm, whilst the reverse resistance is very high, usually of the order of 100 megohms. The low forward resistance means that the forward voltage drop will also be low, usually of the order of 0.5 to 1 volt. This small forward voltage drop represents for all practical purposes the power loss, as the inverse current losses are so small as to be negligible. In most cases rectification efficiencies better than 99% can be realised.

A typical diffused-junction type is shown in Fig. 2. To give some idea of the capabilities of these units, the 1N1763 shown has a maximum reverse current of 100 microamperes at the peak inverse voltage of 400 volts. The maximum dc forward current is 500 milliamperes at up to 75°C. Maximum instantaneous forward voltage at an instantaneous forward current of 15 amperes is 3 volts — this demonstrates the low forward resistance.

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* For further information on this point, see "Radiotronics", Vol. 24, No. 2, February, 1959.

When these figures are related to the size of the rectifier, they are surprising. They are even more startling when it is realised that the active portion of the unit is little more than 1% of the total size. The larger portion of the device is taken up by the terminals and the case. The case is required to protect the active element, and to seal it against moisture and atmospheric contaminants.

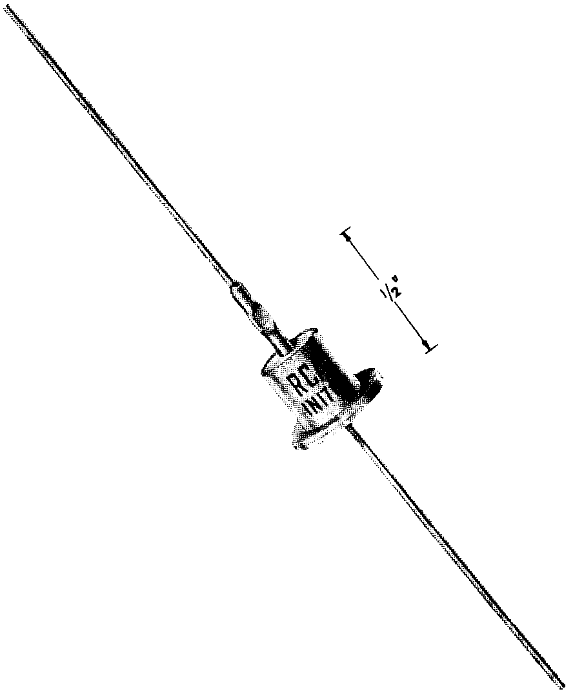


Fig. 2 — A typical Silicon Rectifier.

The extremely small size of the active element is made possible by the outstanding electrical characteristics of the barrier layer. The current density rating of a silicon junction is in the region of 600-900 amperes per square inch, whilst a barrier layer only one thousandth of a centimetre thick will withstand an applied voltage of 1000 volts. In terms of the 1N1763, therefore, we might expect to find a junction area of between 1/1200 to 1/1800 of a square inch, and approximately 0.0005 centimetre thick. (These are not the dimensions actually used in the 1N1763, as they make no allowance for tolerances and other matters involved in meeting the overall specification for these units.) The space charge across the barrier layer will be of the order of one million volts per centimetre.

The high efficiency of the silicon rectifier is due largely to the space charge already mentioned, which can be regarded as equivalent to a large, constant internal reverse bias, positive at the n-side and negative at the p-side. When the external supply voltage is positive at the n-side, the internal and external potentials are additive, tending to increase the reverse bias and prevent current flow. (The minute reverse current which does flow is due to diffusion of minority carriers).

When the supply voltage polarity is reversed, it overcomes the reverse bias and a large current will flow. The external voltage required to overcome the internal space charge is quite low, being typically of the order of 0.5 to 1 volt. This voltage is significant only in that it limits low-voltage operation. Once conduction starts, current increases exponentially at first, and then very sharply in linear fashion. See the typical forward voltage and current characteristics shown in Fig. 3. The curve shown is for the 1N1763.

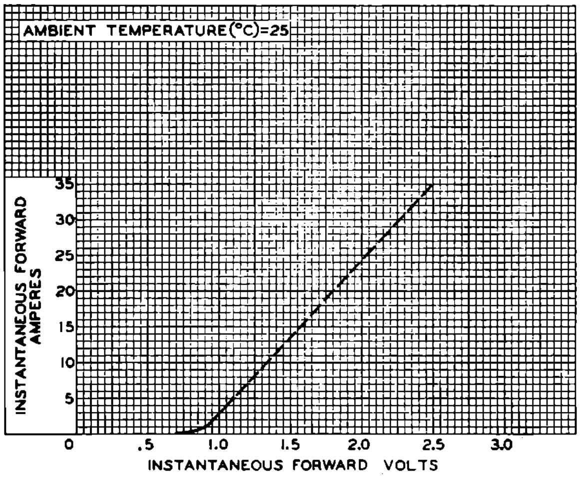


Fig. 3 — Typical Forward Voltage and Current Characteristic of a Silicon Rectifier.

The high reverse resistance of the silicon rectifier is maintained with applied voltages up to the "avalanche" voltage, at which point a sharp break occurs in the characteristics, and resistance decreases rapidly. Avalanche voltage is dependent on the junction temperature, becoming generally higher as the temperature is increased. At very low temperatures avalanche occurs very suddenly, and the reverse-current characteristic is without the "plateau" indicating fairly constant reverse resistance over a wide voltage range. See Fig. 4.

The avalanche voltage depends mainly on two factors. One is the resistivity of the slice of crystal from which the wafer or dice was cut. The second factor is external to the crystal, and is surface contamination. Contaminants ionize at relatively-low voltages, and thereby place a comparatively low-resistance path in shunt across the junction. In high voltage units free of contamination and with uniform impurity distribution in the crystal, avalanche is caused by ionization of atoms within the crystal, whereupon the characteristics of the junction become similar to those of a gas-filled diode.

A further advantage claimed for silicon power rectifiers is the fact that rectification takes place within the solid fused junction, in an area whose properties do not vary appreciably with age. This, together of course with small physical size, is making these units very popular in equipment where it is desirable for the B+ voltage to be substantially maintained at the nominal level. An example of this is the TV set, where a gradually-fading B+ voltage will give rise to many troubles.

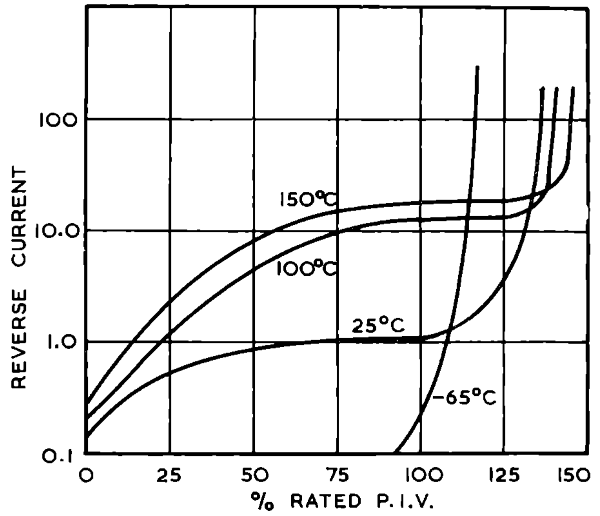


Fig. 4 — Typical Reverse Voltage Characteristic of a Silicon Rectifier.

MANUFACTURE

The usual method of producing pure single crystal of silicon is the crystal "pulling" technique. In this method a small portion of silicon is dipped into a crucible of molten silicon, and then withdrawn at a predetermined rate whilst being slowly rotated. Stringent precautions are taken during this process to exclude contaminants, as molten silicon is very active. The crucible holding the molten silicon is made of quartz, and the entire process is carried out in an inert atmosphere. The temperature in the crucible is most important. The process is carried out at approximately 1400°C, and the desired temperature must be maintained within about one degree.

After the "pulling" operation, checks are carried out to ensure that the crystal has the required characteristics, and it is then cut into small "dice" of the necessary size and thickness. Further checks are then imposed to ensure maintenance of thickness and other specified characteristics, before the alloying or diffusion stage is reached. The alloying process is carried out at high temperatures, and results in the formation of a p-n junction on one side of the wafer or "die", and an ohmic contact on the other.

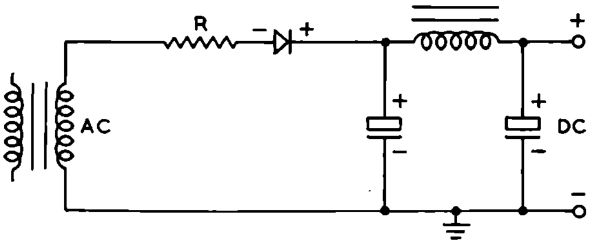


Fig. 5 — Silicon Rectifier as Half-wave Rectifier.

Low resistance in the ohmic contact is very important. Once the internal space charge is overcome by the application of a sufficiently-high voltage, the junction resistance decreases exponentially at first, and then according to a power law. In the final analysis current flow is limited mainly by lead resistance.

The alloyed dice are brazed to a base and a contact provided for the alloyed (p-material) side. The unit is then hermetically sealed inside the protective case. The mounting and assembly processes are carried out with stringent precautions against surface contamination, which could ionize and shunt the p-n junction. Ionization is possible because of the very high space charge across the barrier layer. The final stage is, of course, the careful inspection and testing of the unit to ensure stability and adherence to specification.

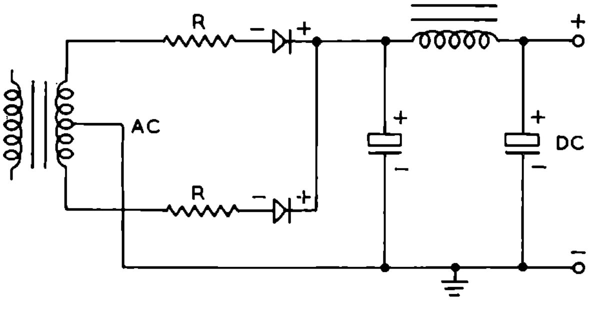


Fig. 6 — Silicon Rectifiers in Full-wave Centre-tapped Rectifier Circuit.

CIRCUIT ARRANGEMENTS

Silicon rectifiers are normally half-wave units, but they can, of course, be connected into a variety of single and polyphase circuit arrangements. The four more common circuit arrangements for single-phase input are mentioned here — polyphase arrangements are normally outside the scope of experimenters and servicemen, but the necessary circuit configurations are similar to those used with thermionic rectifiers.

The single-phase half-wave rectifier is shown in Fig. 5. This is the simplest arrangement, the only point to note being the resistor R. This is a surge-limiting resistor of a few ohms which must be used with a capacitor-input filter to prevent rectifier failure. The required value is usually stated by the manufacturer for various circuit arrangements. Also with a capacitive load, care must be taken not to exceed the peak voltage rating because the dc voltage contributes to the total voltage. In some cases special transformer design is required because of the high rms to dc ratios, and the core-saturation effect of the unidirectional current in the secondary.

Fig. 6 shows the conventional full-wave centre-tapped arrangement using two rectifiers. With this arrangement the transformer secondary insulation must withstand the total terminal voltage which is 2.7 times the dc voltage; the full terminal voltage appears as a back voltage.

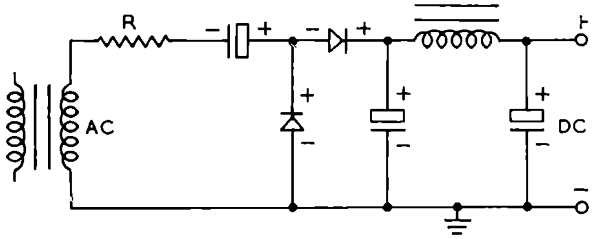


Fig. 7 — Silicon Rectifiers in Half-wave Voltage-doubler Circuit.

Voltage doubler arrangements are commonly met with. The half-wave voltage doubler arrangement is shown in Fig. 7 and the full wave arrangement in Fig. 8. It will be seen from these and the other circuits given that the circuit arrangements are the same as those used in the 1930's, when copper-oxide and selenium rectifiers were used in radio receivers. There is, however, the addition of the surge-limiting resistor R, and the design-problems of the power transformer are modified by the superior characteristics of the silicon rectifier.

APPLICATION

The equation for using silicon rectifiers in any circuit arrangement except a bridge configuration is:

$$E_{rms} = FE_{dc} + V$$

where

Erms = RMS ac input voltage
F = Form factor (See Table 1).
Edc = Required dc output voltage.
V = Voltage drop per rectifier.

For a bridge configuration the second right-hand expression becomes 2V. Where two or more rectifiers are used in series, the expression becomes VN (or 2VN), where N is the number of rectifiers in series per section. If rectifiers are used in parallel, load-balancing resistors are required (See "Series and Parallel Operation" below); the voltage drop across these resistors must then be taken into account also. The voltage drop per rectifier for the required output current is obtainable from the manufacturer's data.

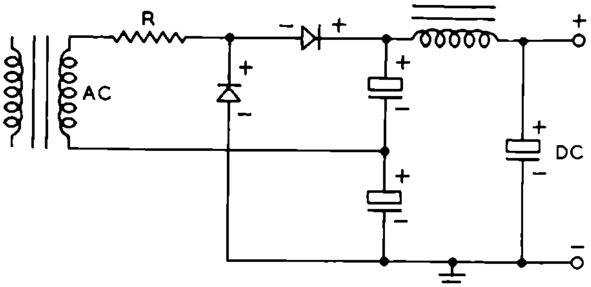


Fig. 8 — Silicon Rectifiers in Full-wave Voltage-doubler Circuit.

Silicon rectifiers will operate satisfactorily at quite high temperatures, but for very high temperatures they must be operated at reduced ratings. Information on the permissible operating temperatures and derating curves are included in the manufacturer's data. The higher-powered units are frequently made with a threaded stud mounting, which allows them to be fixed onto a chassis or a heat-radiating fin. The use of cooling fins is quite common in high-power work to keep the junction temperatures down.

The determination of cooling fin area for a specified application is quite simple. One square inch of cooling area, based both sides of $\frac{1}{8}$" aluminium plate or 1/16" copper plate, radiates approximately 8 milliwatts per degree Centigrade above ambient. The approximate cooling-fin area may therefore be determined from the expression:

$$\text{Area (sq. in.)} = \frac{2.\mathrm{Idc}}{0.08\mathrm{Tr}}$$

where

Idc = Calculated dc current.
Tr = Temperature rise above ambient.

By the way of example, let us assume a rectifier passing 5 amperes, with an ambient temperature of 95°C. The requirement is to limit the maximum temperature to 120°C, i.e., 25°C above ambient. The cooling-fin area is then given by:

$$\text{Area} = \frac{2 \times 5}{0.008 \times 25} = \frac{10}{0.2} = 50 \text{ sq. in.}$$

The cooling fin size will then be

$$\sqrt{\frac{50}{2}} = 5 \text{ square inches approximately.}$$

TABLE I

CIRCUIT	LOAD	FORM FACTOR
SINGLE PHASE HALF WAVE	BATTERY	1.0
	RESISTIVE	2.22
SINGLE PHASE CENTRE TAP	BATTERY	0.8
	RESISTIVE	1.11
SINGLE PHASE BRIDGE	BATTERY	0.8
	RESISTIVE	1.11
SINGLE PHASE VOLTAGE DOUBLER	BATTERY	0.4
	RESISTIVE	0.55
FULL WAVE VOLTAGE DOUBLER	BATTERY	0.4
	RESISTIVE	0.55

Heat can be a major problem in using these rectifiers because of the extremely small size of the junction. The current density is so high under normal conditions that precautions must be taken against any other condition which may tend to raise the junction temperature.

Heat generated at the junction is controlled by adherence to manufacturer's ratings and recommendations. It is heat radiated or conducted into the junction from outside which is solely within the control of the user, and must be attended to by him. Even in this category some help is given by the manufacturer, who usually specifies maximum soldering temperatures and times. In other matters, such as proximity to heated components, e.g., power resistors, the sole responsibility rests with the equipment designer.

REACTIVE CIRCUITS

An important consideration in the use of silicon rectifiers is protection from momentary overloads of reverse voltage or load current. This problem is not so acute with thermionic rectifiers, which have higher forward resistance and can handle larger reverse voltage overloads. These types of overloads are most likely to occur in reactive circuits.

When using silicon rectifiers in capacitive circuits it must be remembered that the forward resistance decreases very rapidly with increasing voltage. A surge-limiting resistor must therefore be used to keep the current at all times within the specified ratings. It may be that the source impedance of the ac input voltage is sufficient to limit forward current — this is a point for the circuit designer. Series connection of two or more rectifiers does not provide surge protection. Surge limiting is required with all circuit configurations.

The required value of surge resistor is usually quoted by the manufacturer for various circuit arrangements. It is determined by the surge-current rating of the rectifier and the peak applied voltage. For example, assuming an rms ac input voltage of 200 volts, and a maximum surge current rating of 10 amperes, the required value of surge-limiting resistance is given by

$$\frac{200 \times \sqrt{2}}{10} = \frac{283}{10} = 28.3 \text{ ohms.}$$

When inductive loads are under consideration, remember that a voltage is generated by the collapse of the magnetic field in the inductive components when the circuit is switched off. The magnitude of the voltage is dependent on the inductance value and the rate of change of circuit condition. The magnitude can be many times that of the supply voltage, values up to 15 times the supply voltage being quite possible, although values of up to three times supply voltage appear to be the usual thing.

The back emf so generated is reverse voltage at the rectifier. As silicon rectifiers are sensitive to reverse voltage overloads, even for a matter of microseconds, protection must be incorporated in circuits which are predominantly inductive. Where the type and arrangment of the circuit permits, suppression of the back emf can be achieved by shunting the inductor with a resistor or a capacitor. Where this is not possible, a selenium rectifier or varistor can be connected across the inductor without undue circuit disturbance. Transient suppression is best carried out whilst monitoring the circuit with an oscilloscope, which will show their position, magnitude and duration.

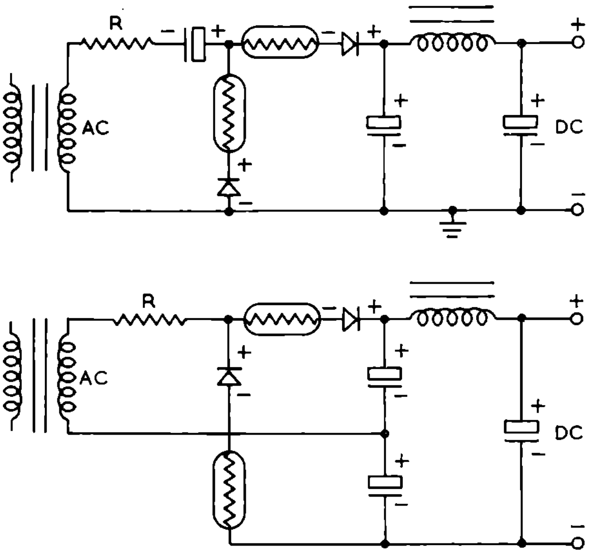


Fig. 9 — Addition of Voltage-dropping Resistors in Converted Circuit to Restore B+ Voltage to Nominal Value.

SERIES AND PARALLEL OPERATION

No precautions are necessary when using silicon rectifiers in series, except that the total voltage applied must be within the total ratings of the two units. The current rating is that of one unit. Parallel operation is possible, but here, due to the extremely non-linear characteristics, and the sharp break in the conductivity curve, load-balancing resistors must be used as a precaution against one unit taking the entire load.

The balancing resistors are of quite low value, usually about 1 ohm, and are connected in series with each rectifier unit. The permissible voltage rating for parallel connection is that of one unit, whilst the current rating is the total for the number of rectifiers used.

CONVERSIONS

Frequently the problem of converting existing equipment to use silicon rectifiers crops up, where it is felt that the advantages to be gained warrant it. Such conversions are quite feasible, provided a few elementary precautions are taken. The first precaution is the addition to the circuit of the surge limiting resistor.

The second item is the matter of higher rectification efficiency which will be obtained with the silicon rectifiers. In a typical thermionic rectifier arrangement, a forward resistance of 10 ohms is a typical figure. With a filter input capacitor of 32 microfarads, the time taken for the capacitor to charge to 63% of the applied voltage is 320 microseconds. If now a silicon rectifier is substituted, with a typical forward resistance of 0.5 ohms, the charging time is reduced to 16 microseconds.

This means that not only will the capacitor charge more quickly, but the maximum charging potential is higher, i.e., the B+ voltage is going to be higher. In typical cases the B+ voltage rises 15-30 volts as a result of the conversion. Whether this is a good thing or not depends on circumstances. If the increase in B+ voltage is undesirable, extra resistance must be placed in circuit to reduce the B+ voltage to the nominal value.

This is quite simply done in the case of the single-unit half-wave rectifier shown in Fig. 5, and the full-wave centre-tapped rectifier shown in Fig. 6, by increasing the value of the surge-limiting resistor R by an amount roughly equal to the forward resistance of the original thermionic rectifier. A typical additional value is 10 ohms, so that R becomes the recommended surge resistor value plus 10 ohms.

In the case of the half-wave and full-wave voltage doubler shown in Figs. 7 and 8, an additional resistor, of a value determined on the basis already mentioned, must be inserted in series with each of the rectifiers. The surge limiting resistor is still required. The modified arrangements are shown in Fig. 9. The additional resistors required to hold down the B+ voltage are shown ringed.

ACKNOWLEDGEMENT

Thanks are expressed to the engineers of the AWV Application Laboratory, who kindly read and criticized this article.

* * *

NEW RCA RELEASES

RADIOTRON 5R4-GYB

The 5R4-GYB is a new full-wave vacuum rectifier of the glass-octal type designed for use in compact power supplies of industrial and military equipment having high dc requirements. Rated for service at altitudes up to 40,000 feet, this valve is particularly useful in aircraft equipment where rigid requirements for dependability are an important factor.

The 5R4-GYB features a button-stem construction to provide sturdiness and to reduce electrolysis, a short T-12 bulb, a short micanol octal base having external barriers to retard arcing at high altitudes, and a permissable maximum bulb temperature of 230°C to increase reliability under temporary adverse operating conditions.

The 5R4-GYB has a maximum peak inverse plate voltage rating of 3100 volts and a maximum peak plate current rating per plate of 715 milliamperes. It is electrically identical with the 5R4-G, 5R4-GY, and 5R4-GYA. It is directly interchangeable with them in equipment where clamp designs do not restrict such interchangeability.

(Continued on page 240)

Off The Beaten Track

A SERIES DESCRIBING SOME OF THE MORE UNCOMMON VALVES AND VALVE DESIGNS

No. 2. — TV CAMERA TUBES

This month we introduce to readers not already familiar with them the tubes used in TV cameras to pick up the scene in the studio. The camera tube converts the light received from the scene into electrical intelligence which is then processed and transmitted to our homes, where the picture is reconstituted.

The basis of all camera tubes is a light-sensitive area onto which the scene is focused through a suitable optical lens system. The light-sensitive area is then scanned by an electron beam, the scanning pattern of which is identical with that used in scanning your TV picture tube— in fact, the two scans must of course be synchronised.

Several types of electronic pickup tubes have been developed over the years, but now all except two of them have been discarded for all practical purposes. It is proposed therefore to mention briefly some of the earlier types which formed the basis for modern tubes. This will show how development of the TV camera tube has progressed to the high-efficiency tubes used today.

THE ICONOSCOPE FAMILY

The iconoscope was in wide use some twenty years ago, and came in two forms, the single-sided mosaic and the double-sided mosaic types. The mosiac was the photo-sensitive element. In the single-sided version, it consisted of a mica plate onto which was laid a pattern of small dots of photosensitive material, backed up by a metal plate. The single-sided mosaic was scanned from the front, i.e., from the same side as the televised scene. A diagram of the single-sided type of iconoscope is shown in Fig. 1. In the double-sided type, the mosaic consisted of a fine insulated mesh, with the interstices filled with the photosensitive material.

The iconoscope was a "storage"-type tube. The image thrown onto the mosaic produced photo-emission in the individual elements of the mosaic depending on the light intensity, producing a charge at each point of the image. Once during each picture period or frame, this charge was released by the passage over the elements of the scanning electron beam. This produced a current through the "signal plate", as the metal mesh or backing plate of the mosaic was called. This current was modulated with the picture intelligence.

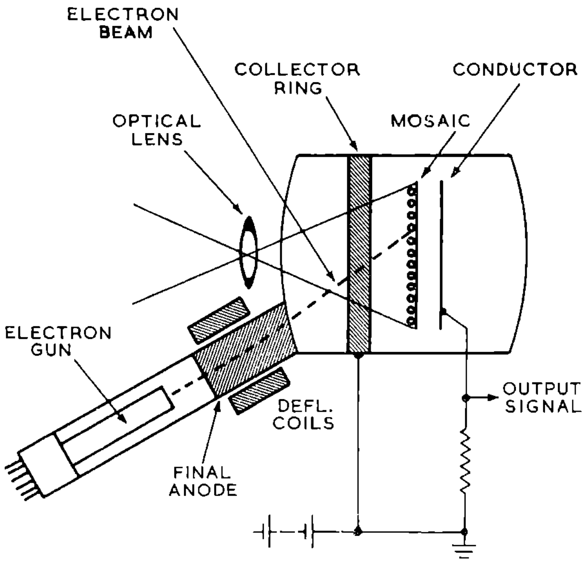


Fig. 1. — Arrangement of an Iconoscope.

DEVELOPMENTS OF THE ICONOSCOPE PRINCIPLE

The iconoscope had good sensitivity but low efficiency. Various steps were taken to improve the iconoscope. The image iconoscope was developed, in which increased sensitivity was achieved by the use of a continuous photocathode and secondary emission amplification at the mosaic, by placing an image-tube section ahead of the mosaic. In this system the optical image was thrown onto a semi-transparent photocathode. Electrons emitted from this photocathode were accelerated away and focused onto the mosaic.

A second development of the iconoscope was the orthicon, in which limitations imposed on photo-emission and secondary emission were removed by using low-velocity scanning, but at the expense of some loss of stability. The third, and at the moment final, development of the iconoscope is the image orthicon so widely used today. In this tube there is an image section, two-sided mosaic or target, low-velocity scanning, and an electron multiplier to amplify the signal current.

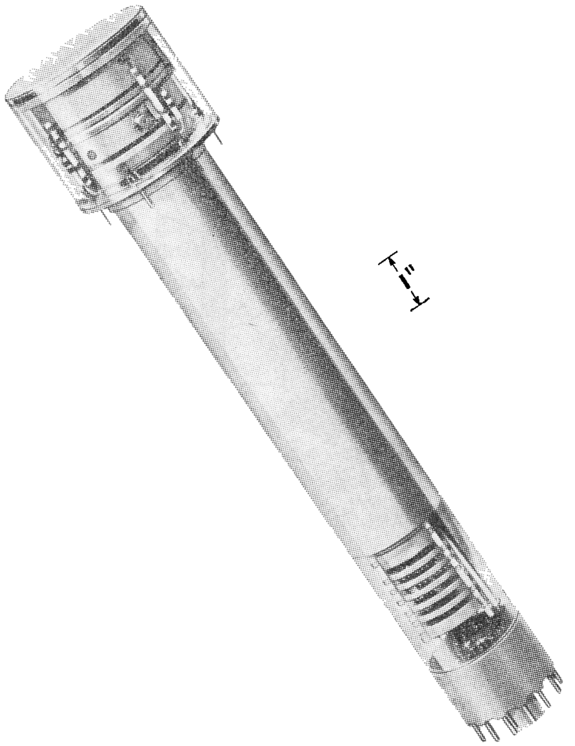


Fig. 2 — A Typical Image Orthicon.

THE IMAGE ORTHICON

The image orthicon is a highly-sensitive tube in which the photo-sensitive element is a photocathode. A photograph (Fig. 2) shows an image orthicon, with a three-inch diameter bulb. This type is a tube of high sensitivity, and may be used in a group of three for colour pickup as described later for the Vidicon.

Principle of Operation

The image orthicon has three sections — an image section, a scanning section, and a multiplier section, as shown in Fig. 3. The image section contains a semitransparent photocathode on the inside of the faceplate, a grid (grid No. 6) to provide an electrostatic accelerating field, and a target which consists of a thin glass disc with a fine mesh screen very closely spaced to it on the photocathode side. Focusing is accomplished by means of a magnetic field produced by an external coil, and by varying the photocathode voltage.

Light from the scene being televised is picked by an optical system and focused on the photocathode which emits electrons from each illuminated area in proportion to the intensity of the light striking the area. The streams of electrons are focused on the target by the magnetic and accelerating fields.

On striking the target, the electrons cause secondary electrons to be emitted by the glass. The secondaries thus emitted are collected by the adjacent mesh screen which is held at a definite potential of several volts with respect to target-voltage cutoff. Therefore, the potential of the glass disc is limited for all values of light and stable operation is achieved. Emission of the secondaries leaves on the photocathode side of the glass a pattern of positive charges which corresponds with the pattern of light from the scene being televised. Because of the thinness of the glass, the charges set up a similar potential pattern on the opposite or scanned side of the glass.

The opposite side of the glass is scanned by a low-velocity electron beam produced by the electron gun in the scanning section. This gun contains a thermionic cathode, a control grid (grid No. 1), and an accelerating grid (grid No. 2). The beam is focused at the target by the magnetic field of an external focusing coil and the electrostatic field of grid No. 4.

Grid No. 5 serves to adjust the shape of the decelerating field between grid No. 4 and the target in order to obtain uniform landing of electrons over the entire target area. The electrons stop their forward motion at the surface of the glass and are turned back and focused into a five-stage signal multiplier, except when they approach the positively charged portions of the pattern on the glass. When this condition occurs, they are deposited from the scanning beam in quantities sufficient to neutralize the potential pattern on the glass. Such deposition leaves the glass with a negative charge on the scanned side and a positive charge on the photocathode side. These charges neutralize each other by conductivity through the glass in less than the time of one frame.

Alignment of the beam from the gun is accomplished by a transverse magnetic field produced by an external coil located at the gun end of the focusing coil. Deflection of the beam is accomplished by transverse magnetic fields produced by external deflecting coils.

The electrons turned back at the target form the return beam which has been amplitude modulated by absorption of electrons at the target in

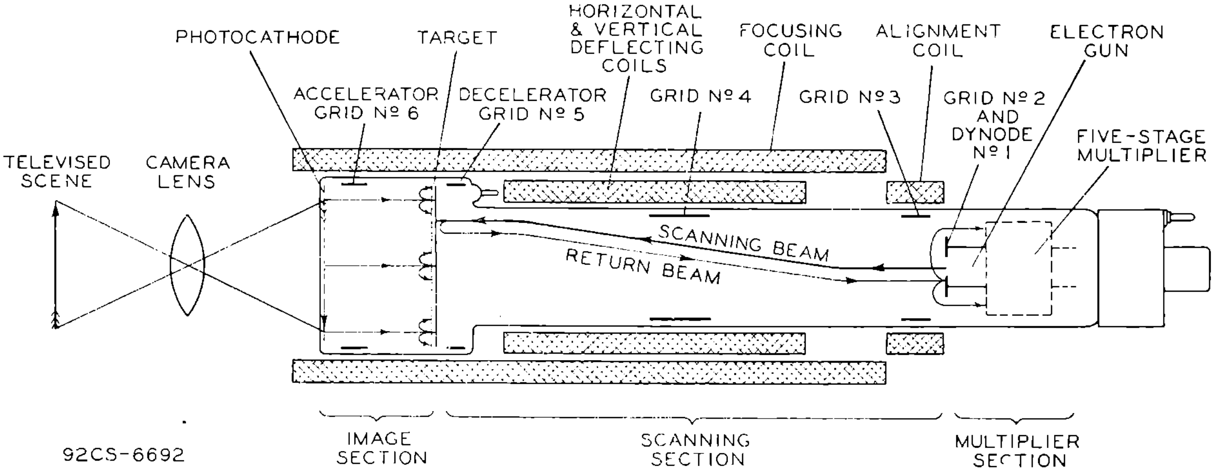


Fig. 3 — Schematic Arrangement of an Image Orthicon.

accord with the charge pattern whose more positive areas correspond to the highlights of the televised scene.

The return beam is directed to the first dynode of a five-stage electrostatically focused multiplier. This utilizes the phenomenon of secondary emission to amplify signals composed of electron beams. The electrons in the beam impinging on the first-dynode surface produce many other electrons, the number depending on the energy of the impinging electrons. These secondary electrons are then directed to the second dynode and knock out more new electrons. Grid No. 3 facilitates a more complete collection by dynode No. 2 of the secondaries from dynode No. 1. The multiplying process is repeated in each successive stage, with an ever-increasing stream of electrons until those emitted from dynode No. 5 are collected by the anode and constitute the current utilized in the output circuit. The multiplier section amplifies the modulated beam about 500 times. This multiplication permits the use of a video amplifier with fewer stages.

The signal-to-noise ratio of the output signal from the tube is high. The gain of the multiplier is such as to raise the output signal sufficiently above the noise level of the video amplifier stages so that they contribute no noise to the final video signal. The signal-to-noise ratio of the video signal, therefore, is determined only by the random variations of the modulated electron beam.

It can be seen that when the beam moves from a less-positive portion on the target to a more-positive portion, the signal-output voltage across the load resistor (R_{25} in Fig. 3) changes in the positive direction. Hence, for highlights in the scene, the grid of the first video amplifier stage swings in the positive direction.

An interesting fact relating to the fine mesh used in the image section is that special facilities had to be developed for ruling fine parallel lines on sheets of glass. The engraved sheets are then used as forms for the reproduction of the screens used in vidicons and image orthicons.

A specially-developed machine is used to produce the masters, and is capable of ruling 750 parallel lines to the inch. The width of the lines is no greater than the filament spun by spiders. When the need for the ruling machine was seen, it was found that no suitable machine was available. The subsequent development and construction of the machine is a unique achievement.

The room housing the ruling machine is temperature controlled. Temperature changes would cause imperfections in the ruled lines, so the room is maintained to within one-half degree of

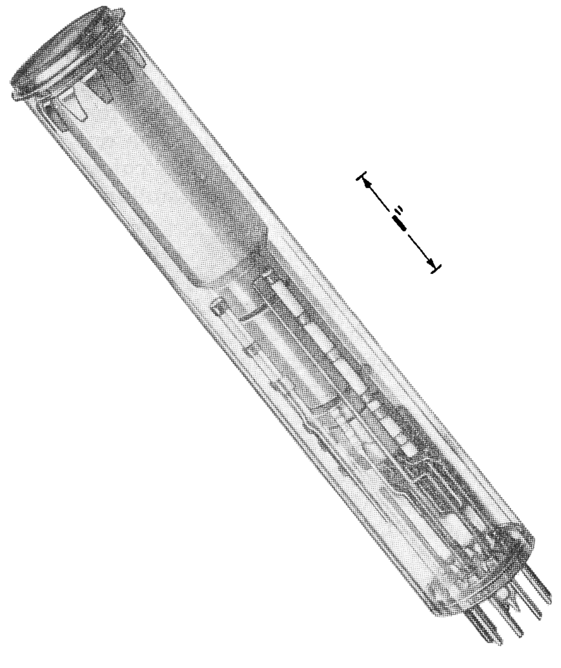


Fig. 4 — A Typical Vidicon.

the optimum operating temperature. Vibration is another critical factor, and the machine, therefore, is mounted on an eight ton, cast concrete inertia block, which is in turn spring-mounted on top of pilings which rest on bedrock 20 feet below ground level.

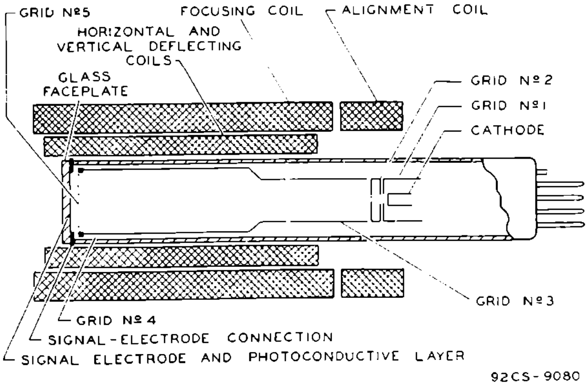


Fig. 5 — Schematic Arrangement of a Vidicon.

THE VIDICON

The vidicon uses a photoconductive layer as the light-sensitive element, instead of a photoemissive mosaic or target. It is a small device, as indicated in Fig. 4, where a photograph of a vidicon tube approximately one inch in diameter is shown. The vidicon is most commonly used in small portable TV cameras, industrial TV apparatus, and similar applications where its small size and simpler associated circuitry offer advantages.

Principles of Operation

For purposes of illustration, a one-inch vidicon has been chosen. This is intended for film and live-scene pickup, for either monochrome or colour cameras, and has a maximum resolution of about 600 lines. When the vidicon is used for colour pickup, three tubes are used, and each one views the scene through an appropriate colour filter. Each therefore produces the information relating to one colour only.

The structural arrangement of the tube, shown in Fig. 5, consists of the signal electrode, which is a transparent conducting film on the inner surface of the faceplate; a light-sensitive element consisting of a thin layer of photoconductive material deposited on the signal electrode; a fine mesh screen (grid No. 5) located adjacent to the photoconductive layer; a beam-focusing electrode (grid No. 4) connected to grid No. 5; a dynamic-focusing electrode (grid No. 3); and an electron gun for producing a beam of electrons.

Each element of the photoconductive layer is an insulator in the dark but becomes slightly conductive when it is illuminated, and acts like a leaky capacitor having one plate at the fixed positive potential of the signal electrode and the other floating. When light from the film or live subject being televised is focused on the photoconductive-layer surface next to the faceplate, each illuminated layer element conducts slightly, depending on the amount of illumination on the element, and thus causes the potential of its opposite surface (on the gun side) to rise in less than the time of one frame toward that of the signal-electrode potential. Hence, there appears on the gun side of the entire layer surface a positive potential pattern, composed of the various element potentials, corresponding to the pattern of light from the film projector, or live subject, imaged on the layer.

The gun side of the photoconductive layer is scanned by a low-velocity electron beam produced by the electron gun. This gun contains a thermionic cathode, a control grid (grid No. 1), and an accelerating grid (grid No. 2). The beam is focused at the surface of the photoconductive layer by the combined action of the uniform magnetic field of an external coil and the electrostatic fields of grids No. 3 and No. 4. If desired, grid No. 3 may be operated separately to permit the use of circuitry to provide for the feature of dynamic focusing. Grid No. 5 serves to provide a uniform decelerating field between itself and the photoconductive layer so that the electron beam will approach the layer in a direction perpendicular to it—a condition necessary for driving the surface to cathode potential. The beam electrons approach the layer at low velocity because of the lower operating potential of the signal electrode.

When the gun side of the photoconductive layer with its positive potential pattern is scanned by the electron beam, electrons are deposited from the beam until the surface potential is reduced to that of the cathode, and thereafter are turned back to form a return beam which is not utilized. Deposition of electrons on the scanned surface of any particular element of the layer causes a change in the difference of potential between the two surfaces of the element. When the two surfaces of the element, which in effect is a charged capacitor, are connected through the external signal-electrode circuit and the scanning beam, a capacitive current is produced and constitutes the video signal. The magnitude of the current is proportional to the surface potential of the element being scanned and to the rate of scan. The video-signal current is then used to develop a signal output voltage across a load resistor. The signal polarity is such that for highlight in the film or live subject, the grid of the first video-amplifier tube swings in a negative direction.

Alignment of the beam is accomplished by a transverse magnetic field produced by external coils located at the base end of the focusing coil. Deflection of the beam is accomplished by transverse magnetic fields produced by external deflecting coils.

NEW SILICON RECTIFIERS FOR INDUSTRIAL AND MILITARY APPLICATIONS

1N440B — 1N441B — 1N442B — 1N443B — 1N444B 1N445B — 1N536 — 1N537 — 1N538 — 1N539 1N540 — 1N1095 — 1N547

The 1N536, 1N537, 1N538, 1N539, 1N540, 1N1095 and 1N547 are hermetically sealed silicon rectifiers of the diffused-junction type. They are specifically designed for use in power supplies of industrial and military equipment capable of operating at dc forward currents up to 750 milliamperes and temperatures ranging from −65° to +165°C.

These silicon rectifiers have peak inverse voltage ratings of 50, 100, 200, 300, 400, 500 and 600 volts, respectively and a maximum reverse current of 5 microamperes at rated peak inverse voltage and ambient temperature of 25°C. In addition, the maximum forward voltage drop at a dc forward current of 500 milliamperes (at an ambient etmperature of 25°C.) is 1.1 volts for the 1N536, 1N537, 1N538, 1N539, 1N540 and 1.2 volts for the 1N1095 and 1N547.

These silicon rectifiers are designed to meet stringent environmental, mechanical, and life requirements of prime importance in military applications. Special attention has been given to the following features: (1) sturdy and compact mount structure, (2) axial leads for flexibility of circuit connections, (3) welded hermetic seals—every unit pressure tested to assure protection against moisture and contamination, (4) superior junction formation made possible by a diffusion process with very precise controls, (5) special temperature cycling tests to assure stable performance over the entire operating temperature range, and (6) special coating to provide against effects of severe environmental conditions.

GENERAL DATA

Mechanical:

Operating Position .... Any
Case .... Metal
Envelope Seals .... Hermetic
(See also Dimensional Outline)

RECTIFIER SERVICE

Maximum Ratings, Absolute-Maximum Values:

PEAK INVERSE VOLTAGE AND DC REVERSE VOLTAGE:

1N536	50 volts	1N540	400 volts
1N537	100 volts	1N1095	500 volts
1N538	200 volts	1N547	600 volts
1N539	300 volts		

RMS SUPPLY VOLTAGE:

1N536	35 volts	1N540	280 volts
1N537	70 volts	1N1095	350 volts
1N538	140 volts	1N547	420 volts
1N539	210 volts		

FORWARD DIRECT CURRENT:*

At Ta = 50°C. .... 750 ma
At Ta = 100°C. .... 500 ma
At Ta = 150°C. .... 250 ma

* See also Rating Chart, Fig. 1.

FORWARD SURGE CURRENT, ONE CYCLE 15 a
OPERATING FREQUENCY 100 kc
AMBIENT TEMPERATURE:
Operating −65 to +165°C.
Storage .... −65 to +175°C.

Characteristics, at Ta = 25°C.:

Maximum Forward DC Voltage Drop at DC Forward Current of 500 ma:
1N536 to 1N540 .... 1.1 volts
1N1095 and 1N547 .... 1.2 volts
Maximum Reverse Direct Current at Maximum Peak Inverse Voltage .... 5 μa

Characteristics, at Ta = 150°C.:

Maximum Reverse Current Averaged over one Complete Cycle at Maximum Peak Inverse Voltage:
1N536, 1N537 .... 0.4 ma
1N538, 1N539, 1N540, 1N1095 0.3 ma
1N547 0.35 ma

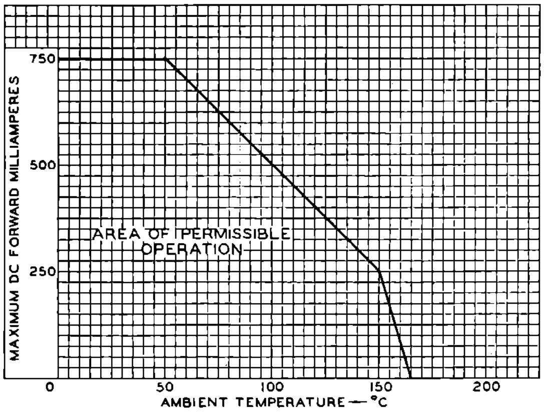


Fig. 1 — Rating Chart for 1N536 to 1N540, 1N1095, 1N547.

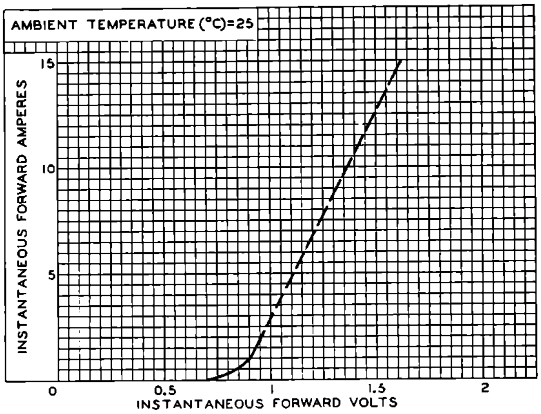


Fig. 2 — Typical Forward Characteristic for 1N536 to 1N540, 1N1095, 1N547.

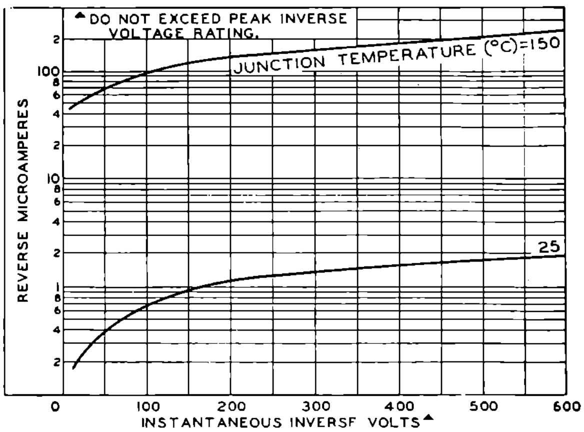


Fig. 3 — Typical Reverse Characteristics for 1N536 to 1N540, 1N1095, 1N547.

The 1N440B, 1N441B, 1N442B, 1N443B, 1N444B, 1N445B are hermetically sealed silicon rectifiers of the diffused-junction type specifically designed to meet very low-reverse (leakage) current requirements in magnetic amplifiers, dc blocking circuits, power supplies, and other industrial applications.

These units have a maximum dc forward current rating of 750 milliamperes at an ambient temperature of 25°C., and peak inverse voltage ratings of 100, 200, 300, 400, 500, and 600 volts, respectively. These silicon rectifiers feature (1) sturdy compact mount structure, (2) axial leads for flexibility of circuit connections, (3) welded hermetic seals — every unit is pressure-tested to assure protection against moisture and contamination, (4) superior junction formation made possible by a diffusion process with very precise controls, (5) special temperature-cycling tests to a sure stable performance over the entire operating temperature range, and (6) special coating to provide protection against the effects of severe environmental conditions.

GENERAL DATA

Operating Position .... Any
Case .... Metal
Envelope Seals .... Hermetic
(see also Dimensional Outline)

RECTIFIER SERVICE

Maximum Ratings, Absolute Maximum Values:

PEAK INVERSE VOLTAGE AND DC REVERSE VOLTAGE:

1N440B	100 volts	1N443B	400 volts
1N441B	200 volts	1N444B	500 volts
1N442B	300 volts	1N445B	600 volts

RMS SUPPLY VOLTAGE:

1N440B	70 volts	1N443B	280 volts
1N441B	140 volts	1N444B	350 volts
1N442B	210 volts	1N445B	420 volts

FORWARD DIRECT CURRENT:*

At Ta = 50°C.:	
1N440B to 1N443B	750 ma
1N444B, 1N445B	650 ma
At Ta = 100°C.:	
1N440B to 1N443B	500 ma
1N444B	425 ma
1N445B	400 ma
At Ta = 150°C.:	
1N440B to 1N443B	250 ma
1N444B, 1N445B	0 ma

* See also Rating Chart, Fig. 4.

PEAK RECURRENT FORWARD CURRENT ... 3.5 a
FORWARD SURGE CURRENT, ONE CYCLE 15 a
AMBIENT TEMPERATURE:
Operating −65 to +165°C.
Storage —65 to +175°C.

Characteristics, at Ta = 25°C.:

Maximum Forward DC Voltage Drop at Full-load DC Forward Current ... 1.5 volts
Maximum Reverse Direct Current at Maximum Peak Inverse Voltage:

1N440B	0.3 μa	1N443B	1.5 μa
1N441B	0.75 μa	1N444B	1.75 μa
1N442B	1.0 μa	1N445B	2.0 μa

Characteristics, at Ta = 150°C.:

Maximum Reverse Current Averaged over one Complete Cycle at Maximum Peak Inverse Voltage:
1N440B, 1N441B .... 100 μa
1N442B to 1N445B .... 200 μa

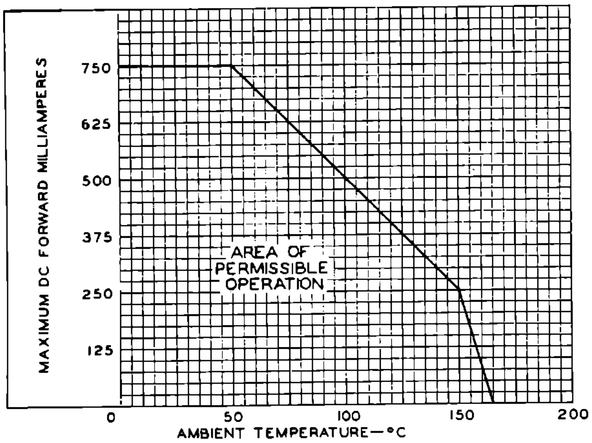


Fig. 4 — Rating Chart for 1N440B to 1N443B.

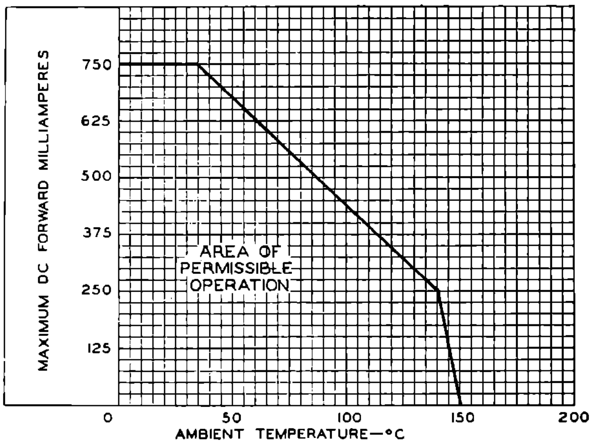


Fig. 5 — Rating Chart for 1N444B.

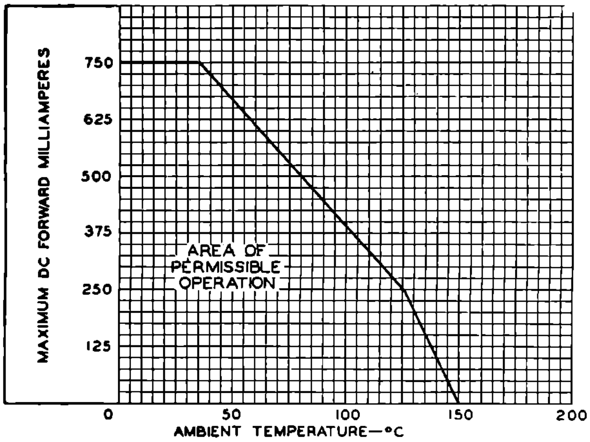


Fig. 6 — Rating Chart for 1N445B.

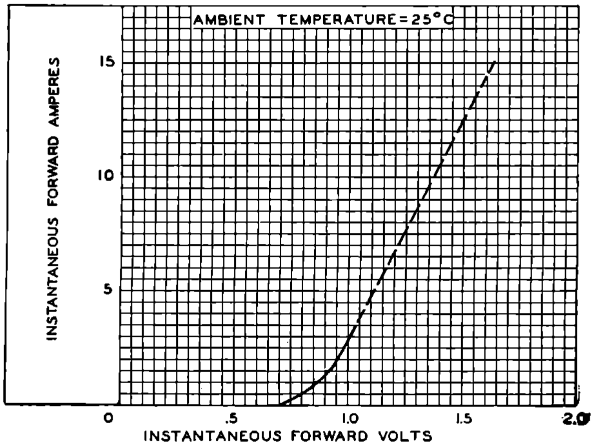


Fig. 7 — Typical Forward Characteristic for 1N440B to 1N445B.

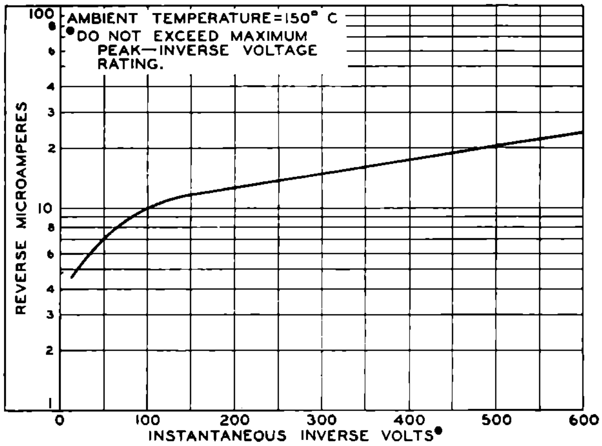


Fig. 8 — Typical Reverse Characteristic for 1N440B to 1N445B.

OPERATING CONSIDERATIONS FOR SILICON RECTIFIERS

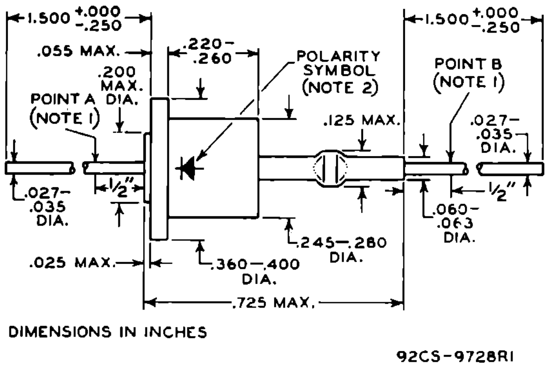
The maximum ratings in the tabulated data are established in accordance with the following definition of the Absolute-Maximum Rating System for rating electron devices. Absolute-Maximum ratings are limiting values of operating and environmental conditions applicable to any electron device of a specified type as defined by its published data, and should not be exceeded under the worst probable conditions.

The flexible leads of these rectifiers are usually soldered to the circuit elements. It is desirable in all soldering operations to provide some slack or an expansion elbow in the leads to prevent excessive tension on the leads. It is important during the soldering operation to avoid excessive

DIMENSIONAL OUTLINE FOR TYPES

1N440B to 1N445B, 1N536 to 1N540,

1N1095, 1N547



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.

heat in order to prevent possible damage to the rectifiers. To absorb some of the heat, grip the flexible lead of the rectifier between the case and the soldering point with a pair of pliers.

When dip soldering is employed in the assembly of printed circuitry using these rectifiers, the temperature of the solder should not exceed 255°C. for a maximum immersion period of 10 seconds. Furthermore, the leads should not be dip soldered beyond points A and B indicated on the Dimensional Outline Drawing.

Because the metal cases of these rectifiers may operate at voltages which are dangerous, care should be taken in the design of equipment to prevent the operator from coming in contact with the rectifier. It is recommended that these rectifiers be mounted on the underside of the chassis.

A surge-limiting impedance should always be used in series with the rectifier. The impedance value must be sufficient to limit the surge current to the value specified under the maximum ratings. This impedance may be provided by the power transformer winding, or by an external resistor or choke.

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NEW RCA RELEASES

(Continued from page 232)

RADIOTRON 6FV6

The Radiotron 6FV6 is a new sharp-cutoff tetrode of the 7-pin miniature type designed for use as an rf amplifier in vhf tuners of TV receivers.

Features contributing to the excellent performance of this valve in TV receivers are high transconductance (8000 micromhos) and a high ratio of plate current to grid-No. 2 current (7 to 1). The high transconductance provides for high gain per stage with corresponding reduction in equivalent noise resistance. The high ratio of plate current to grid-No. 2 current provides good signal-to-noise ratio.

The design of the 6FV6 includes a separate base-pin connection for the cathode and the internal shield. This basing arrangement permits the use of an unbypassed cathode resistor thus mini- and input conductance with agc bias.

RADIOTRON 8HP4

The 8HP4 is a new rectangular glass monitor picture tube which permits the design of small compact TV-monitor equipment. The 8HP4 has an aluminized screen to give increased brightness and contrast. The electron gun employs electrostatic focus and does not require an ion-trap magnet, features which simplify set-up and assure more stable performance in portable and mobile operation. The 8HP4 has a spherical Filterglass faceplate, an aluminized screen 7-3/16″ x 5-/38″ with slightly curved sides and rounded corners and a minimum projected screen area of 35.5 square inches. Employing 90° deflection, the 8HP4 has an overall length of only $10\frac{1}{4}''$ and weighs approximately $2\frac{1}{2}$ pounds. An external conductive coating may be utilized to provide a supplementary filter capacitor.

RADIOTRON 7412

The 7412 is a small, head-on type of cadmium-sulfide photoconductive cell for use in a variety of industrial light-operated relay applications. It is especially designed to meet the need for a

(Continued on page 245)
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Transistor Parameters

by H. R. Wilshire, A.S.T.C., S.M.I.R.E.,
A.M.I.E. (Aust.)

The characteristics of transistors may be specified using one or more of a number of systems of parameters. A suitable choice of the constants making up each of the systems will allow the devising of a circuit which behaves in the same way as the transistor. This "equivalent" circuit is necessary to allow the user of the transistor to predict its performance in equipment. The various parameter systems can be split into two fundamental classes — (1) the "device" parameters which represent the transistor's characteristics in terms of the physical constants of the device and (2) the "circuit" parameters which describe the relationships between the input and output voltages and currents and therefore are related to the circuit in which the transistor is used.

DEVICE PARAMETERS

There are two main forms of device parameters in common use—(a) those used for the low frequency "T" equivalent circuit and (b) those for the high frequency "hybrid-π" circuit.

T Equivalent Circuit

The four quantities specifying the transistors in this circuit are the emitter resistance r_e, base resistance r_b, collector resistance r_c and the forward current gain α. Another term, the transfer or mutual resistance r_m given by $r_m = \alpha r_c$ is also used. Two forms of the T equivalent circuit using these parameters in the common base configuration are shown in Fig. 1. For the common emitter connection a third form of the T circuit is shown in Fig. 2.

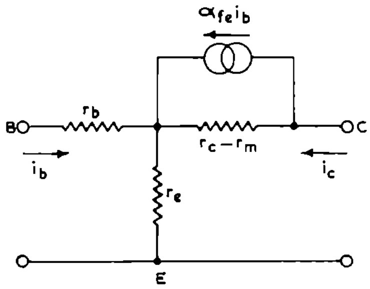

Fig. 2 — T Equivalent Circuit, Common Emitter Connection.

Hybrid π Equivalent Circuit

Additional terms are needed here to provide an accurate representation of the transistor's high frequency characteristics. The equivalent circuit is shown in Fig. 3.

The terms in the above circuit are defined as follows:—

$r_{bb'}$ is the resistance between the base lead and the artificial internal point b'.

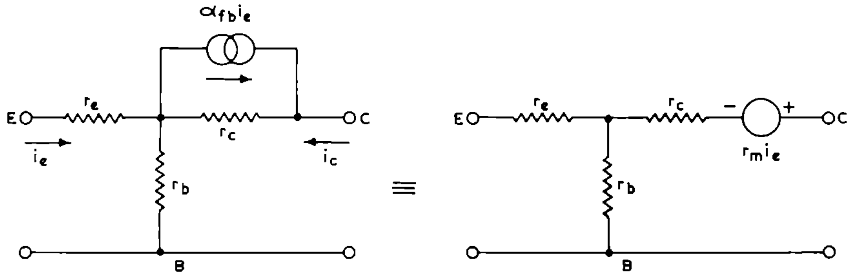

Fig. 1 — T Equivalent Circuit, Common Base Connection.

'h' SYSTEM	**Common Emitter**	h_{re}	h_{re} (3.13×10^{-4})	$\frac{h_{ib}h_{ob}}{1 + h_{fb}} - h_{rb}$	$1 - h_{rc}$	$\frac{r_e}{r_c - r_m}$ or $\frac{r_e(1 + \alpha_{fe})}{r_c}$ or $\frac{r_e}{(1 - \alpha_{fb})r_c}$	$\frac{r_{b'e}}{r_{b'c}}$
		h_{fe}	h_{fe} (48)	$\frac{-h_{fb}}{1 + h_{fb}}$	$-(1 + h_{fc})$	$\frac{r_m}{r_c - r_m}$ or $\frac{\alpha_{fb}}{1 - \alpha_{fb}}$ or α_{fe}	$g_m r_{b'e}$
		h_{oe}	h_{oe} $(21 \times 10^{-6}\ a/v)$	$\frac{h_{ob}}{1 + h_{fb}}$	h_{oc}	$\frac{1}{r_c - r_m}$ or $\frac{1 + \alpha_{fe}}{r_c}$ or $\frac{1}{r_c(1 - \alpha_{fb})}$	$\frac{1 + g_m r_{b'e}}{r_{b'c}} + \frac{1}{r_{ce}}$
	Common Base	h_{ib}	$\frac{h_{ie}}{1 + h_{fe}}$	h_{ib} (26.9Ω)	$\frac{h_{ic}}{-h_{fc}}$	$r_e + \frac{r_b}{1 + \alpha_{fe}}$ or $r_e + (1 - \alpha_{fb})r_b$	$\frac{r_{bb'} + r_{b'e}}{1 + g_m r_{b'e}}$
		h_{rb}	$\frac{-h_{re}(1 + h_{fe}) + h_{ie}h_{oe}}{1 + h_{fe}}$	h_{rb} (2.5×10^{-4})	$h_{rc} + \frac{h_{ic}h_{oc}}{-h_{fc}} - 1$	$\frac{r_b}{r_c}$	$\frac{r_{bb}}{r_{b'c}} + \frac{r_{rb'} + r_{b'e}}{(1 + g_m r_{b'e})r_{ce}}$
		h_{fb}	$\frac{-h_{fe}}{1 + h_{fe}}$	h_{fb} (-0.98)	$\frac{1 + h_{fc}}{-h_{fc}}$	$-\frac{\alpha_{fe}}{1 + \alpha_{fe}}$ or $-\alpha_{fb}$	$-\frac{g_m r_{b'e}}{1 + g_m r_{b'e}}$
		h_{ob}	$\frac{h_{oe}}{1 + h_{fe}}$	h_{ob} $(0.43 \times 10^{-6}\ a/v)$	$\frac{h_{oc}}{-h_{fc}}$	$\frac{1}{r_c}$	$\frac{1}{r_{b'c}} + \frac{1}{r_{ce}(1 + g_m r_{b'e})}$

Table 1 (Continued)

'h' SYSTEM	Common Collector	h_{ic}	h_{ie}	$\frac{h_{ib}}{1 + h_{fb}}$	h_{ic} (1325Ω)	$r_b + \frac{r_e r_c}{r_c - r_m}$ or $r_b + \frac{r_e}{1 - \alpha_{fb}}$ or $r_b + (1 + \alpha_{fe})r_e$	$r_{bb'} + r_{b'e}$
		h_{rc}	$1 - h_{re}$	$\frac{1}{1 - h_{rb}}$ ($\cong 1$)	h_{rc} ($\cong 1$)	$1 - \frac{r_e(1 + \alpha_{fe})}{r_c}$ or $1 - \frac{r_e}{(1 - \alpha_{fb})r_c}$ $\doteq 1$	$1 - \frac{r_{b'e}}{r_{b'c}}$ $\doteq 1$
		h_{fc}	$-(1 + h_{fe})$	$\frac{-1}{1 + h_{fb}}$	h_{fc} (−49)	$-\frac{r_c}{r_c - r_m}$ or $-\frac{1}{1 - \alpha_{fb}}$ or $-(1 + \alpha_{fe})$	$-(1 + g_m r_{b'e})$
		h_{oc}	h_{oe}	$\frac{h_{ob}}{1 + h_{fb}}$	h_{oc} (21×10^{-6} a/v)	$\frac{1}{r_c - r_m}$ or $\frac{1}{(1 - \alpha_{fb})r_c}$ or $\frac{1 + \alpha_{fe}}{r_c}$	$\frac{1}{r_{b'c}}\left(1 + g_m r_{b'e}\right) + \frac{1}{r_{ce}}$

$g_{b'e}$ is the conductance between point b′ and the emitter lead.

$g_{b'c}$ is the conductance between point b′ and the collector lead.

g_{ce} is the conductance between the collector and emitter.

$C_{b'e}$ is the capacitance between point b′ and the emitter.

$C_{b'c}$ is the capacitance between point b′ and the collector.

g_m is the intrinsic transconductance.

In a low frequency version of this circuit the capacitative terms are omitted since they have a negligible effect at low frequencies. The resistive forms of the conductive terms $g_{b'e}$, $g_{b'c}$ etc. i.e. $r_{b'e} = 1/g_{b'e}$ may be quoted as an alternative. The conversion formulae of Tables 1 and 2 apply to this low frequency resistive form of the hybrid π circuit.

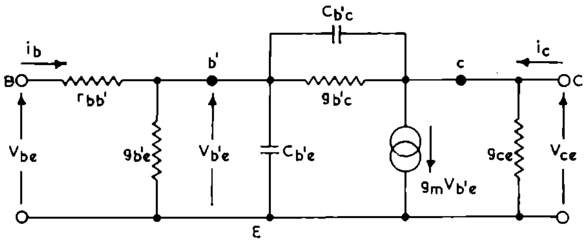

Fig. 3 — Hybrid-π Equivalent Circuit.

CIRCUIT PARAMETERS

For this system the transistor is considered as a network or "black box" with two input and two output terminals. The circuit parameters describe the properties of the transistor network in terms of the currents and voltages at its terminals.

Of the six possible ways in which the four variables i.e. input current and voltage and output current and voltage can be combined, only one—the "hybrid" system — has found general acceptance.

The hybrid system consists of four "h" terms which are defined in terms of the 4 pole network of Fig. 4.

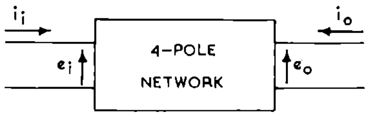

Fig. 4 — Four-pole Network.

$h_i = \left(\frac{e_i}{i_i}\right) e_o = 0$ = Input impedance with output terminals **short** circuited to ac.

T Circuit	r_e	$\frac{h_{re}}{h_{oe}}$	$h_{ib} - (1 + h_{fb})\frac{h_{rb}}{h_{ob}}$	$\frac{1 - h_{rc}}{h_{oc}}$	r_e (15Ω)	$\frac{r_{b'e}}{(1 + g_m r_{b'e}) + \frac{r_{b'c}}{r_{ce}}}$
	r_b	$h_{ie} - \frac{h_{re}(1 + h_{fe})}{h_{oe}}$	$\frac{h_{rb}}{h_{ob}}$	$h_{ic} + \frac{h_{fc}(1 - h_{rc})}{h_{oc}}$	r_b (590Ω)	$r_{bb'} + \frac{r_{b'e}}{1 + \frac{r_{ce}(1 + g_m r_{b'e})}{r_{b'c}}}$
	r_c	$\frac{h_{fe} + 1}{h_{oe}}$	$\frac{1}{h_{ob}}$	$\frac{-h_{fc}}{h_{oc}}$	r_c (2.35 MΩ)	$\frac{r_{b'c}}{1 + \frac{r_{b'c}}{r_{ce}(1 + g_m r_{b'e})}}$
	r_m	$\frac{h_{fe}}{h_{oe}}$	$\frac{-h_{fb}}{h_{ob}}$	$\frac{-(1 + h_{fc})}{h_{oc}}$	r_m or $\alpha_{fb} r_c$ or $\frac{\alpha_{fe}}{1 + \alpha_{fe}} r_c$ (2.31 MΩ)	$\frac{g_m r_{b'e} r_{ce}}{1 + \frac{r_{ce}(1 + g_m r_{b'e})}{r_{b'c}}}$
Hybrid-π (Low freq.)	$r_{b'e}$	$h_{ie} - r_{bb'}$	$\frac{h_{ib}}{1 + h_{fb}} - r_{bb'}$	$h_{ic} - r_{bb'}$	$r_b + (1 + \alpha_{fe})r_e - r_{bb'}$	$r_{b'e}$ (1250Ω)
	$r_{b'c}$	$\frac{h_{ie} - r_{bb'}}{h_{re}}$	$\frac{h_{ib} - r_{bb'}(1 + h_{fb})}{h_{ib}h_{ob} - h_{rb}(1 + h_{fb})}$	$\frac{h_{ic} - r_{bb'}}{1 - h_{rc}}$	$\frac{\{r_b + (1 + \alpha_{fe})r_e - r_{bb'}\}r_c}{r_e(1 + \alpha_{fe})}$	$r_{b'c}$ (4 MΩ)
	g_m	$\frac{h_{fe}}{h_{ie} - r_{bb'}}$	$\frac{-h_{fb}}{h_{ib} - r_{bb'}(1 + h_{fb})}$	$\frac{-(1 + h_{fc})}{h_{ic} - r_{bb'}}$	$\frac{\alpha_{fe}}{r_b + (1 + \alpha_{fe})r_e - r_{bb'}}$	g_m (38.6 ma/v)
	r_{ce}	$h_{oe} - \frac{(1 + h_{fe})h_{re}}{h_{ie} - r_{bb'}}$	$\frac{h_{ib} - r_{bb'}(1 + h_{fb})}{h_{rb} - h_{ob} r_{bb'}}$	$\frac{1}{h_{oc} + \frac{h_{fc}(1 - h_{rc})}{h_{ic} - r_{bb'}}}$	$\frac{r_{ce}}{1 + \alpha_{fe}} \frac{r_b + (1 + \alpha_{fe})r_e - r_{bb'}}{r_b - r_{bb'}}$	r_{ce} (116KΩ)

$h_r = \left(\frac{e_i}{e_o}\right) \; i_i = 0$ = Reverse voltage amplification factor with input terminals **open** circuit to ac.

$h_f = \left(\frac{i_o}{i_i}\right) \; e_o = 0$ = Forward current amplification factor with output terminals **short** circuited to ac.

$h_o = \left(\frac{i_o}{e_o}\right) \; i_i = 0$ = Output admittance with input terminals **open** circuit to ac.

Each of the "h" terms in this system has a different value depending on whether the transistor is used in the common base, common emitter or common collector configuration. The term for a particular configuration is specified by adding a second subscript e.g. h_{fe} is the forward current gain in the common emitter circuit and h_{oc} is the output admittance in the common collector circuit.

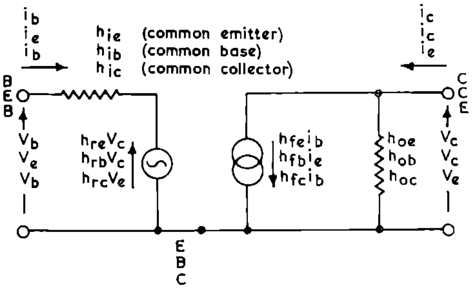

Fig. 5 — h System for Three Circuit Configurations.

The equivalent circuit most commonly used to represent the transistor in the network of Fig. 4 is shown in Fig. 5 for the three configurations.

In Fig. 5 the currents, voltages and "h" parameters appropriate to each circuit connection are shown from top to bottom in the following order:

Top: Common Emitter.
Centre: Common base.
Bottom: Common collector.

Conversion formulae relating the "h" parameters for the common base, emitter and collector configurations, and T and the hybrid-π circuit parameters are listed in Tables 1 and 2. The numerical values in parentheses are typical and apply to a particular junction transistor.

NOTE

When using these tables to determine the values of parameters such as h_{re}, h_{rb} and h_{rc} from those of another circuit configuration it will be found that the required parameter is given as a difference between two small and similar quantities. In these cases care must be taken to use the exact value for each term in the formula. For example to find the value of h_{rb} from the common collector parameters of the transistor whose characteristics are shown in parentheses it will be necessary to know the exact value for h_{rc}.

The table shows h_{rc} as approximately equal to 1 but in fact for this transistor $h_{rc} = 1 - 3.13 \times 10^{-4}$. In a similar way the table shows $h_{fb} \cong 0.98$. A more accurate figure would be required to provide perfect cross checking between all the formulae.

NEW RCA RELEASES

(Continued from page 240)

head-on type photoconductive cell having relatively small diameter and yet providing high sensitivity.

The 7412 utilizes a glass envelope and is hermetically sealed to permit operation under conditions of high humidity. It has a photosensitive area of 0.20" x 0.02"; a maximum diameter of 0.30"; and a maximum length (excluding flexible leads) of 1.35". Spectral response of the 7412 covers the approximate range from 3300 to 7400 angstroms. Maximum response occurs at about 5800 angstroms.

RADIOTRON 7448

The 7448 is a direct-view, 5 inch display storage tube having fast writing speed. The 7448 is especially suited for a variety of applications including fire-control radar; airplane-cockpit radar display; airport surveillance; transient studies; data transmission including half-tones; and visual communications requiring steady, non-flickering, narrow bandwidth transmission over telephone lines.

Performance of the 7448 when operated with 10,000 volts on the screen is characterized by a display having brightness of about 2750 foot-lamberts; good resolution capability in half-tone displays; and a writing speed of about 300,000 inches per second — a speed sufficiently fast to "freeze" transients of 1 microsecond duration for minutes.

RECTIFIER VALVES AND CIRCUITS

QUICK SELECTION CHART

This article presents a chart designed to facilitate selection of a combination of a rectifier circuit and a mercury-vapour rectifier valve type for any plication requiring dc voltage up to 21 kilovolts and direct current up to 60 amperes. It also contains a table of the electrical quantities involved in the design of rectifier-type dc power supplies, and gives the values of these quantities for the rectifier circuits shown in the chart.

The chart, Fig. 3, and Table 1 are based on five types of rectifier circuits. The chart is divided into voltage-current areas, each of which is labelled with the figure number of the rectifier circuit and the type designation of the rectifier valve which will usually provide, most economically, the combinations of voltages and currents within the limits of the area.

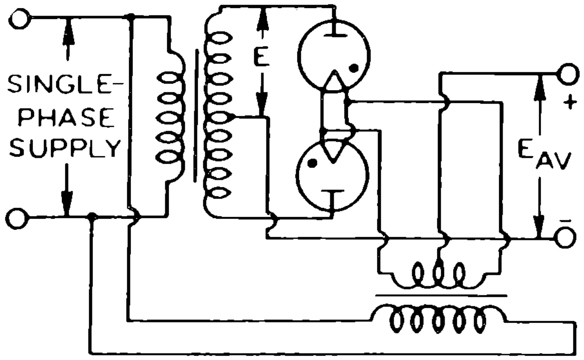

Fig. 1 — Full-Wave Single-Phase.

Use of Chart

To use the chart, simply determine the maximum dc output voltage and current required, locate the area in which the co-ordinates of these values intersect, and note the indicated rectifier circuit and valve type. For example, if the dc requirements before filtering are 3000 volts and 2 amperes, the indicated source is a full-wave, single-phase rectifier circuit (Fig. 1) using a pair of type 8008 or 872-A rectifier valves. If the required voltage is between 10,500 and 14,000 volts, and the required current between 15 and 30 amperes, the indicated source is the series three-phase rectifier circuit shown in Fig. 5, using six type 857-B rectifier valves. For applications requiring between 9600 and 14,000 volts, at currents between 7.5 and 15 amperes, the indicated source is the series-parallel, three-phase circuit (Fig. 6), using twelve type 6894 or 6895 rectifier valves.

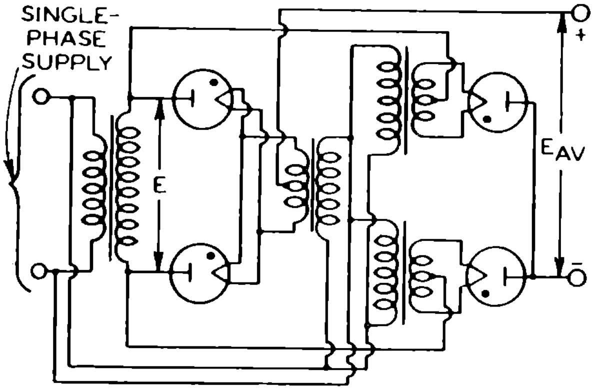

Fig. 2 — Series Single-Phase.

Use of the Table of Electrical Quantities

As an example of the use of the Table of Electrical Quantities, assume that the required dc output voltage before filtering is 2560 volts, and the required dc output current is 0.4 ampere. The recommended source for these requirements is a full-wave, single-phase circuit (Fig. 1) using two Type 866-A's. The rms voltage E which must be delivered by each half of the plate-transformer secondary winding is

$$\begin{aligned} E &= 1.11 \times E_{av} \\ &= 1.11 \times 2560 \\ &= 2842 \text{ volts rms} \end{aligned}$$

The peak inverse voltage E_{bmi} at the anodes of the 866-A's is

$$\begin{aligned} E_{bmi} &= 2.83 \times E \\ &= 2.83 \times 2842, \\ & \quad \text{or } 3.14 \times E_{av} \\ &= 3.14 \times 2560 \\ &= 8040 \text{ volts approx.} \end{aligned}$$

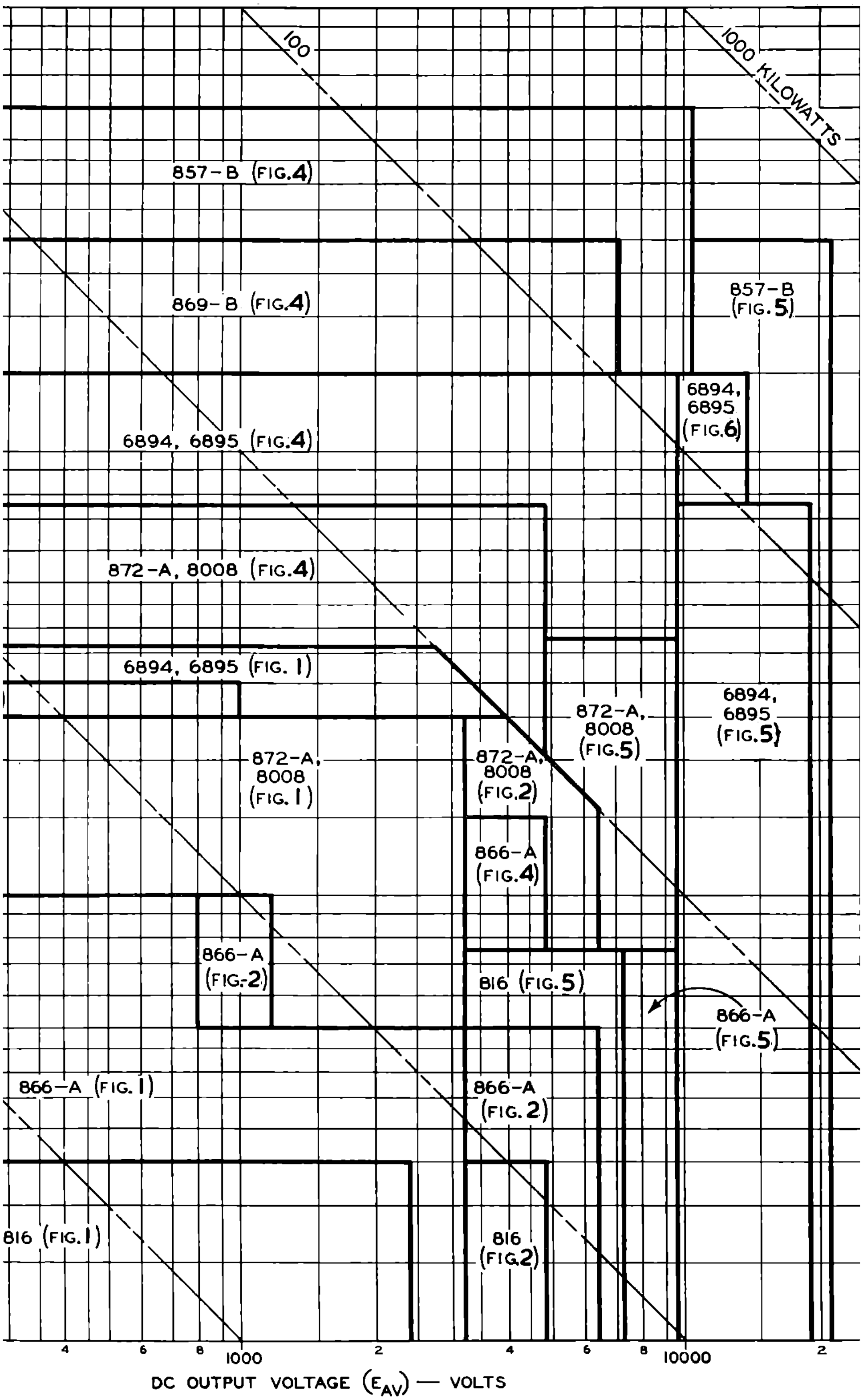

Fig. 3 — Rectifier Valve and Circuit Selection Chart.

TABLE I

rans. Sec. Voltage (RMS)
verage DC Output Voltage
eak Inverse Anode Voltage
eak DC Output Voltage
ajor Ripple Voltage (RMS)

f = Supply Frequency
f_r = Major Ripple Frequency
I_{av} = Average DC Output Current
I_b = Average Anode Current
I_p = Anode Current (RMS)

I_{pm} = Peak Anode Current
P_{al} = Line Volt-Amperes
P_{ap} = Trans. Pri. Volt-Amperes
P_{as} = Trans. Sec. Volt-Amperes
P_{dc} = DC Power (E_{av} x I_{av})

Note: The ratios given below assume the use of sine-wave ac supply voltage; zero voltage drop in tubes; no losses in transformer and circuit; no back emf in the load circuit; and no phase-back.

RATIOS	Fig. 1	Fig. 2	Fig. 4	Fig. 5	Fig. 6[•]
Voltage Ratios					
E/E_{av}	1.11	1.11	0.854	0.427	0.427
E_{bmi}/E	2.83	1.41	2.45	2.45	2.45
E_{bmi}/E_{av}	3.14	1.57	2.09	1.05	1.05
E_m/E_{av}	1.57	1.57	1.05	1.05	1.05
E_r/E_{av}	0.472	0.472	0.04	0.04	0.04
Frequency Ratio					
f_r/f	2	2	6	6	6
Current Ratios					
I_b/I_{av}	0.5	0.5	0.167	0.33	0.167
Resistive Load					
I_p/I_{av}	0.785	0.785	0.293	0.578	0.294
I_{pm}/I_{av}	1.57	1.57	0.605	1.05	0.525
I_{pm}/I_b	3.14	3.14	3.63	3.14	3.14
Inductive Load[□]					
I_p/I_{av}	0.707	0.707	0.289	0.577	0.289
I_{pm}/I_{av}	1	1	0.5	1	0.5
Power Ratios					
Resistive Load					
P_{as}/P_{dc}	1.74	1.23	1.05	1.05	1.05
P_{ap}/P_{dc}	1.23	1.23	1.06	1.05	4
P_{al}/P_{dc}	1.23	1.23	1.05	1.05	11
Inductive Load[□]					
P_{as}/P_{dc}	1.57	1.11	1.48	1.05	1.05
P_{ap}/P_{dc}	1.11	1.11	1.05	1.05	1.05
P_{al}/P_{dc}	1.11	1.11	1.05	1.05	1.05

A bleeder current equal to 2 per cent of the full-load current will provide sufficient excitation current for the balance coil or coils to assure good regulation under light-load conditions.

The use of a large filter-input choke is assumed.

The peak dc output voltage E_m of the rectifier is

$$\begin{aligned} E_m &= 1.57 \times E_{av} \\ &= 1.57 \times 2560 \\ &= 4019 \text{ volts approx.} \end{aligned}$$

The amount of ripple voltage E_r in the output of the rectifier is

$$\begin{aligned} E_r &= 0.472 \times E_{av} \\ &= 0.472 \times 2560 \\ &= 1208 \text{ volts approx.} \end{aligned}$$

The rms anode current I_p of each rectifier valve is

$$\begin{aligned} I_p &= 0.785 \times I_{av} \\ &= 0.785 \times 0.4 \\ &= 0.314 \text{ amperes rms} \end{aligned}$$

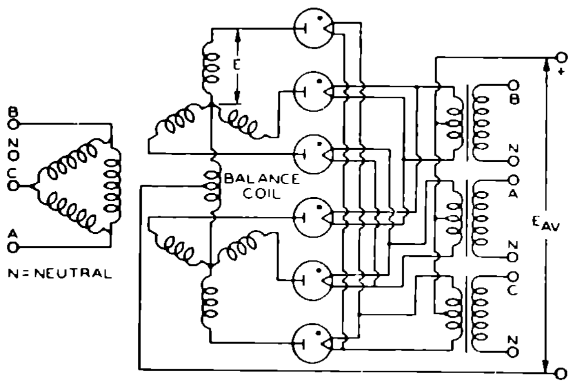

Fig. 4 — Parallel Three-Phase (Quadrature Operation).

The average anode current handled by each rectifier (I_b) is, of course, one-half the average output current of the rectifier, or 0.2 ampere. The peak anode current in each rectifier (I_{pm}), and the volt-amperes in the transformer secondary (P_{as}), transformer primary (P_{ap}), and line (P_{al}), depend upon the character of the rectifier load circuit. For a resistive load — that is, where no filter capacitor or filter choke is used —

$$\begin{aligned} I_{pm} &= 3.14 \times I_b \\ &= 3.14 \times 0.2 \\ &= 0.628 \text{ ampere,} \end{aligned}$$

$$\begin{aligned} P_{as} &= 1.74 \times (E_{av} \times I_{av}) \\ &= 1.74 \times 1024 \\ &= 1782 \text{ volt-amperes,} \end{aligned}$$

$$\begin{aligned} P_{ap} &= 1.23 \times (E_{av} \times I_{av}) \\ &= 1.23 \times 1024 \\ &= 1259 \text{ volt-amperes, \&} \end{aligned}$$

$$\begin{aligned} P_{al} &= 1.23 \times (E_{av} \times I_{av}) \\ &= 1259 \text{ volt-amperes} \end{aligned}$$

For an inductive load — that is, where a large input filter choke is used —

$$\begin{aligned} I_{pm} &= I_{av} \\ &= 0.4 \text{ ampere,} \end{aligned}$$

$$\begin{aligned} P_{as} &= 1.57 \times (E_{av} \times I_{av}) \\ &= 1.57 \times 1024 \\ &= 1608 \text{ volt-amperes,} \end{aligned}$$

$$\begin{aligned} P_{ap} &= 1.11 \times (E_{av} \times I_{av}) \\ &= 1.11 \times 1024 \\ &= 1137 \text{ volt-amperes, \&} \end{aligned}$$

$$\begin{aligned} P_{al} &= 1.11 \times (E_{av} \times I_{av}) \\ &= 1137 \text{ volt-amperes} \end{aligned}$$

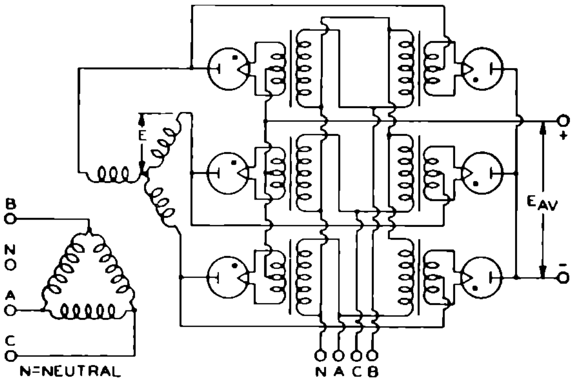

Fig. 5 — Series Three-Phase (Quadrature Operation).

The preceding calculations do not take into account the voltage drops in the rectifier valves and in the secondary windings of the plate-supply transformer. For most accurate results, both of these voltage drops should be added to E_{av} wherever this term is used.

The thyratron type 5563-A has the same electrical ratings as mercury-vapour rectifier types 6894 and 6895, and may be used in place of these types in applications requiring the use of grid-controlled rectifier valves.

Systems Analysis

The chart is also useful in systems analysis where the desired output power is known and the most economical voltage and current values are to be determined. In such cases the choice is immediately narrowed to those areas intersected by the diagonal line corresponding to the desired output-power level. In general, the valve-and-circuit combination for the area where this intersection occurs closest to the upper-right hand corner will be most economical. However, all

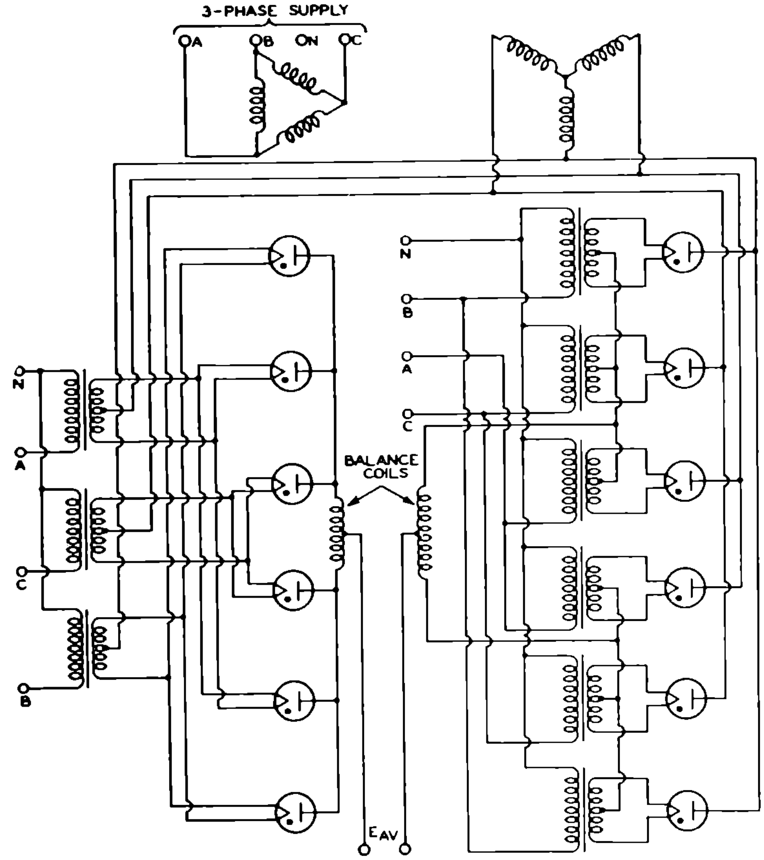

Fig. 6 — Series-Parallel Three - Phase (Quadrature Operation).

nearly equal choices made on this basis should be investigated more closely. For example, if the desired power output is 100 kilowatts, a parallel three-phase circuit (Fig. 4) using type 6894 or 6895 rectifier valves and delivering 14 to 19 kilovolts, or a series three-phase circuit (Fig. 5) also using type 6894 or 6895 rectifier valves and delivering 7 to 9.5 kilovolts, are about equally advantageous. Operation in the ranges below 7 kilovolts, between 9.5 and 14 kilovolts, and above 19 kilovolts is relatively expensive.

With acknowledgements to RCA.

* * *

"COMPLEMENTARY SYMMETRY"

CORRECTION

We regret that two errors intruded into the article "Complementary Symmetry" published on page 213 last month. Please note the following corrections.

1. Second paragraph, last line. The remark in parentheses should of course read "(base positive with respect to emitter)".
2. The diagrams were inadvertently transposed. The diagram now called Fig. 2 should be applied to the caption of Fig. 1 and vice versa.

RADIOTRONICS SUBSCRIPTIONS

A new method of advising readers that their subscription is expiring will be brought into use this year. This will replace the method used previously, when a tear-out order form was included in the November copy each year.

Starting this year we will be mailing a separate renewal card to all subscribers. All you have to do to renew is to mark the card with the number of years for which you wish to subscribe and RETURN THE CARD with your remittance. Because it is necessary to print the January 1960 issue early in December to avoid printers' holidays, these cards should be in our hands by December 1st this year to ensure continuity of supply.

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AWV