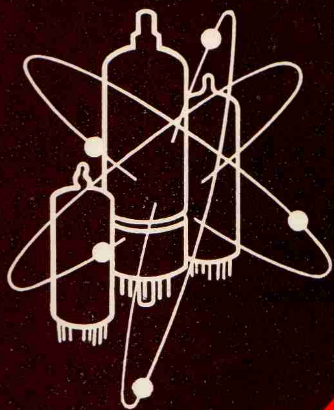

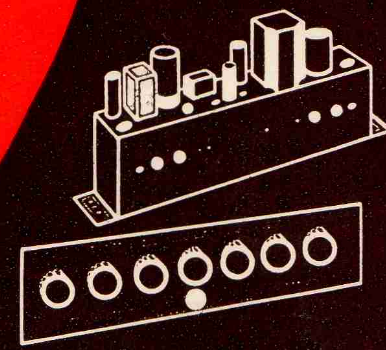

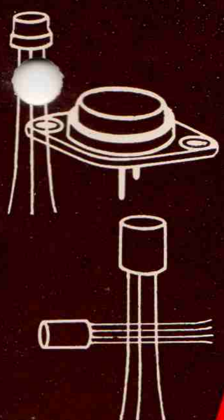

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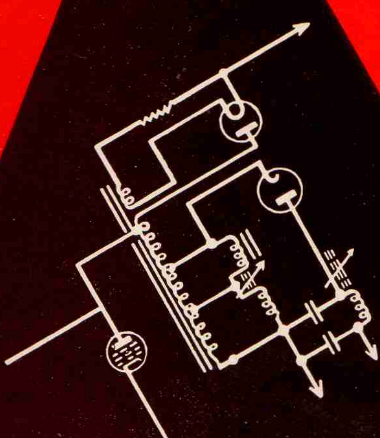

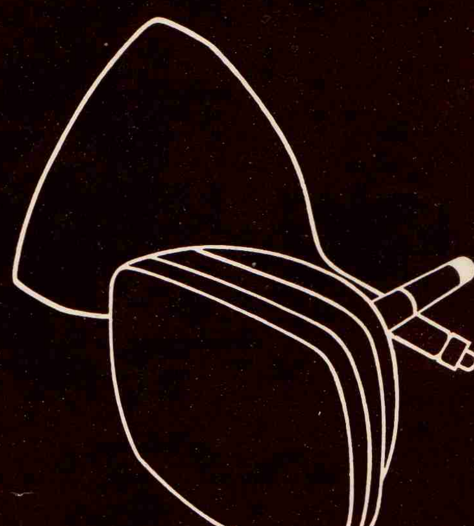

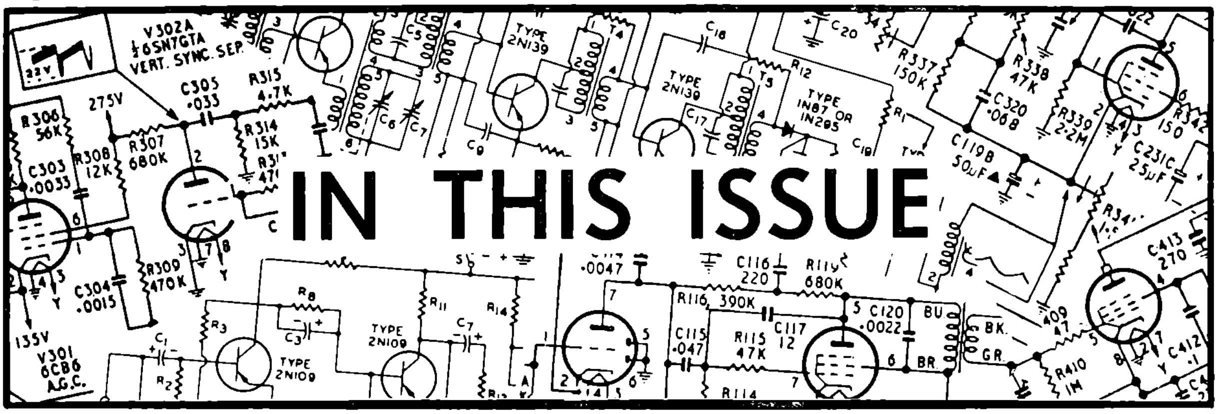

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ZENER DIODES

By B. J. Simpson

Among the semiconductors which are destined to make an increasing impact on electronics in the near future is the zener diode. This is therefore possibly a good time to examine the present state of the art as it applies to this device. This article is intended to do just that, and to serve as an introduction to the zener diode for those not yet familiar with its possibilities.

CHARACTERISTICS

The zener diode is a silicon junction diode, and may be described as basically similar to the silicon power rectifier (See "Radiotronics" Vol. 24 No. 9, Sept., 1959). The important difference is that the zener diode is designed to exploit one particular characteristic of the silicon junction diode, known as zener breakdown.

Silicon diodes possess a very high ratio of reverse to forward resistance. The high value of reverse resistance is maintained until the reverse voltage reaches a critical value, this critical value being determined by the design of the particular diode. When the reverse voltage reaches the critical or "zener voltage" value, a non-destructive breakdown occurs. Beyond this point current flow increases very rapidly, whilst the voltage drop across the diode remains substantially constant.

An analogy can be drawn between the zener diode and the long-familiar gas regulator tube, with the zener voltage corresponding to the striking voltage of the gas tube. Unlike the gas tube however, the zener diode does not possess different "striking" and "operating" voltages. It may be suspected from these remarks that the zener diode can be used in lieu of the gas regulator tube. This is true, but is only one of the many applications which will be described later.

Because in a zener diode we are interested in the conduction of reverse current, the reverse breakdown characteristic of the normal silicon diode is more conveniently termed the conduction characteristic when dealing with zener diodes. It is however essentially the same property which is being described, as will be seen from Fig. 1, which shows a typical conduction characteristic for a zener diode.

For values of applied voltage from zero to Va, (forward voltages) the steep slope of the characteristic indicates a low forward resistance, i.e., a small change of voltage produces a large change in current flow. With reverse voltages however, the almost horizontal line formed by the characteristic up to a reverse voltage of Vz indicates a very high reverse resistance. The forward-to-reverse resistance ratio of a silicon diode may reach a value of one million to one.

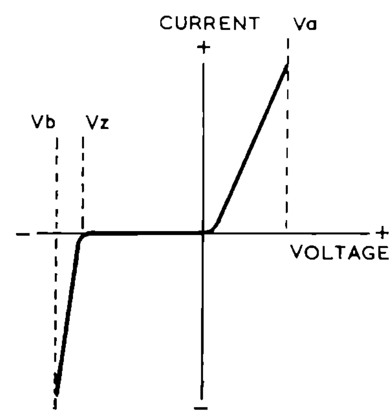


Fig. 1.—Conduction Characteristic of a Zener Diode.

It is however the behaviour of the diode in the region beyond the zener voltage Vz which is now of interest. Beyond Vz the high reverse resistance disappears. With increasing reverse voltage the reverse current increases very rapidly, as shown by the slope of the characteristic in the Vz to Vb region. Within a fraction of a volt the reverse resistance may fall from several megohms down to a few ohms, and the current increase from a fraction of a microamp to several milliamps. The steep slope of the characteristic indicates breakdown of the diode (zener breakdown). This breakdown, unlike most encountered in electronics, is non-destructive provided the permissible dissipation in the diode is not exceeded.

The important characteristics of the zener region (Vz to Vb) are the high rate of change of current with change of applied voltage, together with low dc resistance and low dynamic impedance. Features of prime interest in the use of zener diodes are the sharp breakdown characteristic at Vz, a high ratio of resistance in the regions zero to Vz and Vz to Vb, in addition to the low dc resistance in the zener region already mentioned. The forward characteristic of the diode is usually of no interest, and is usually omitted when the (reverse) conduction characteristic is drawn.

MANUFACTURE

Zener diodes with breakdown voltages ranging from a few volts up to several hundred volts are available.

The required breakdown voltage is arranged by selection and processing of silicon with a suitable resistivity characteristic. The doping of the two sides of the diode is so arranged that the entire voltage drop appears across a relatively small depletion layer. This facilitates the breakdown and large current flow in the zener region.

The zener diode should not be confused with the punch-through diode developed by the Massachusetts Institute of Technology, although in many applications they would be interchangeable. In the punch-through diode breakdown is encouraged by placing one contact very close to the junction. Increasing the reverse voltage and thereby the size of the depletion layer can then more easily result in the latter touching the contact, producing a heavy current flow.

TEMPERATURE COEFFICIENT

As may be expected with a semiconductor, the breakdown voltage of a zener diode is to some extent dependent on temperature. The temperature coefficient of a zener diode is related to its operating voltage. Diodes with high zener voltages have positive temperature coefficients, the magnitude of which decreases with a decrease in operating voltage. There is a crossover point at approximately 5.5 volts where the coefficient becomes effectively zero, and below the crossover point the coefficient becomes increasingly more negative.

The crossover point where the coefficient becomes zero applies only for a stated breakdown voltage at a stated reverse current. An essentially zero temperature coefficient can be realised by providing a suitable value of reverse current in any diode with a zener voltage near the crossover, (approximately 4.5 to 6.5 volts) or alternatively, either a positive or negative coefficient can be produced at will. It must be stressed however that the required coefficient is obtained only at one value of reverse current. The temperature coefficient for low voltage zener diodes is constant for a given type, and is related to breakdown voltage as shown in Fig. 2.

It follows from the foregoing that when a very accurately-maintained reference voltage is required, the natural choice is a zener diode with an operating voltage around 5.5 volts, together with provision for a predetermined reverse current flow through the diode. Such an arrangement is claimed to produce a stability rating of ±0.003% /°C over a wide ambient temperature range, improving to ±0.001% /°C over the short temperature ranges likely to be encountered in fixed installations.

Where stabilised reference voltages are required of magnitudes other than near the crossover point, two alternatives are available. The zener diode reference element can be placed in a thermostatically-controlled oven, a costly and space-wasting measure. Alternatively some success has been obtained in using auxiliary diodes operating with forward current, and exhibiting a negative temperature coefficient, to nullify the positive coefficient of a zener diode. Extreme care is needed in matching the coefficients exactly, and the result is again more costly than the simple diode arrangement.

MULTIPLE-UNIT APPLICATION

Frequently, where precision is more important than economics, zener diodes are used in series to provide the required operating voltage. A single unit rated for the required voltage could of course be used if available, but suffers from

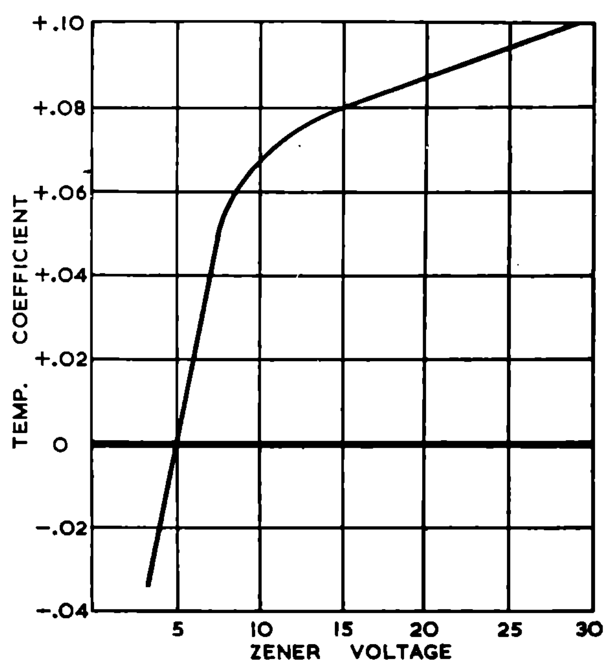


Fig. 2.—Temperature Coefficients of Low-Voltage Zener Diodes.

two disadvantages, a high positive temperature coefficient and high dynamic resistance. The use of smaller series-connected units improves the temperature coefficient, gives lower dynamic resistance, and lower thermally-induced resistance.

The power dissipation per diode in a series combination will be inversely proportional to the number of units used,* providing a significant decrease in junction temperatures and increased life expectancy. Furthermore, use of units in series offers the possibility of setting up a zero-temperature-coefficient system at almost any voltage by using series-connected units with zener voltages of the order of 5.5 volts.

The use of zener diodes in parallel is not possible. Such operation would require each paralleled unit to have an identical zener voltage, and this is impractical due to manufacturing tolerances. Assuming two diodes in parallel, the one with slightly smaller zener voltage will draw heavy current first and probably prevent the other unit ever becoming operative in the zener region.

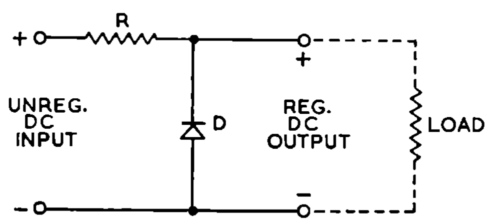


Fig. 3.—Simple DC Voltage Regulator.

TYPICAL APPLICATIONS

Probably the largest single field of application of zener diodes is as voltage regulators and reference elements. They also find a number of other applications, such as gating, coupling, limiting, sensing and protective devices. It is impossible to enumerate every application, if only for the reason that there are probably many not yet thought of, but it is hoped to give some indication of what these units can do.

The Zener Diode and the Gas Regulator

The zener diode, as previously mentioned, can be used instead of a gas tube as a regulating or voltage reference device. Moreover, the zener diode offers certain important advantages. It is available with operating voltages from about 2 volts up to several hundred volts, whereas the lowest voltage gas tube operates around 75 volts, with a top limit, except for certain multi-unit tubes, of about 150 volts.

The zener diode does not require the provision of a starting or striking voltage some 20% or so higher than the operating voltage; the starting and working potentials are the same. The encapsulated diode is not subject to photoelectric effects on the operating voltage, and is of course totally immune to an inherent problem encountered in the use of gas regulators, that of plasma oscillation.

* Strictly true only for perfectly-matched diodes.

DC Voltage Regulator

The dynamic resistance in the zener region is a function of the dc reverse current, and is lower for higher current-ratings. Dynamic resistance expresses the change in voltage for a small change in dc current. It is determined by measuring the ac voltage developed across the diode when operating with a specified ac current and the design-centre dc current both flowing through the diode.

The dynamic resistance is a measure of the regulating ability of the diode. The usual value of dc (reverse bias) current chosen for regulator service is about 20% of the maximum rated reverse current, although any current in the zener region may be chosen provided other considerations are met, e.g., rated dissipation under all conditions from no load to full load.

A simple shunt voltage regulator using a zener diode is shown in Fig. 3; the similarity to a gas-valve regulator is immediately apparent. The precautions necessary in setting up such a circuit are also similar. Resistor R must function as a current-limiter, holding maximum diode current below the rated maximum, whilst at the same time the voltage across the diode must not fall below the zener breakdown point. Provided these conditions are met, increases and decreases in load current are compensated for by the diode, which will draw a smaller or a larger current respectively, and maintain the output voltage across the load substantially constant.

The greater the current through the diode the better the circuit regulation and reduction of ripple. One may thereby be induced to set a higher mean value of diode current to obtain these advantages, in spite of increased power consumption. A factor called thermally-induced resistance now enters into consideration.

A higher diode current causes an increased junction temperature. Eventually a point is reached where the dynamic resistance of the diode will increase due to thermally-induced junction resistance. The latter will tend to limit regulation at high diode currents, whilst the dynamic resistance is the dominant factor at low diode currents.

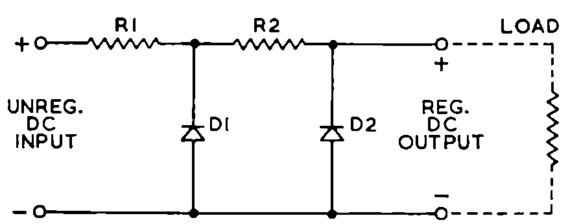


Fig. 4.—Two-stage DC Voltage Regulator.

Superior performance in dc voltage regulator service can of course be obtained by using cascaded arrangements. A simple two-stage regulator is shown in Fig. 4. The improved regulation is obtained at the expense of a higher dc input voltage, due to the voltage division which takes place in the successive stages.

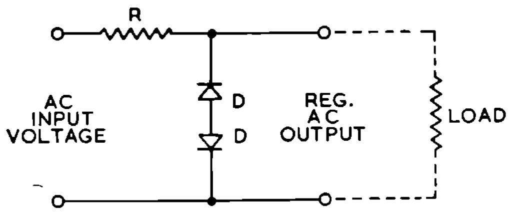


Fig. 5.—Simple AC Voltage Regulator.

AC Voltage Regulators

For ac voltage regulation zener diodes are used in pairs back to back, or sometimes "double-anode" units are used. These are merely two diodes connected cathode-to-cathode in series in the same capsule. As in the case of the dc regulator, units can be used in cascaded circuit arrangements if desired.

A typical single-stage regulator is shown in Fig. 5. The low-voltage units available allow this system to be used for the regulation of heater voltages and other low ac voltages, as well as for primary power voltages which can be handled by the high-voltage units. The ac regulation offered by the zener diode is achieved by clipping the ac peaks, and consideration must therefore be given to harmonic generation and the operation of the load with a non-sinusoidal input waveform.

Limiting and Clipping

It follows from the mention of dc and ac voltage regulation that zener diodes can be used as either negative or positive peak limiters, and when used in pairs, as bi-polar clippers. They may be used with pulsed or sinusoidal waveforms, and have the advantage over normal diodes that no bias voltage is necessary to determine the operating point. The operating point is fixed merely by selecting a zener diode with an appropriate breakdown voltage.

Voltage Reference

Zener diodes lend themselves readily to service as reference-voltage devices, either ac or dc. This application in its simplest form is basically nothing more than a voltage regulator, in which the load current is zero or very small. The constant voltage drop across the diode is the reference voltage. Diodes for this type of service can be obtained with voltages specified within 1%.

It was mentioned previously when discussing temperature coefficient that a diode with a zener voltage of the order of 5.5 volts can be set up with a certain value of bias current to provide a substantially zero temperature coefficient. It also follows therefore that whether or not a zero temperature coefficient is being aimed at, the reverse bias current through the reference diode should be maintained as close as possible to the nominal value.

The obvious way of ensuring this is to use further zener diodes to provide regulation for the applied voltage. The system then becomes similar to a two-or-more-stage voltage regulator, with diodes of decreasing zener voltages, the last stage being the reference diode. Where a zero-temperature coefficient is desired, this system is often improved by making the stage ahead of the reference element consist of two diodes of the same type in series, and so on. The idea is to set up a zero temperature coefficient not only in the reference element, but also in the bias voltage supply circuit.

Possibly most common use of reference voltages is in regulated power supplies. Here the voltage is used as a "key-point"—in voltage regulators using valves or transistors. Regulation in this instance is not provided directly by the zener diode or other reference voltage source, but by the other electronic components in the circuit.

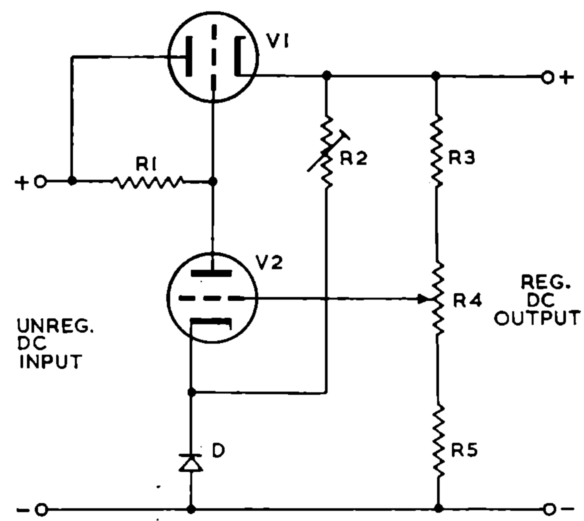


Fig. 6.—Zener Diode Voltage Reference in Regulated DC Power Supply.

A typical application of this kind is shown in the simplified dc voltage regulator circuit of Fig. 6. Here the diode is used in lieu of the neon lamp or gas tube. The constant voltage drop across the diode D provides a reference voltage for V2 cathode. Resistor R2 provides the desired bias current for the diode, and the output voltage of the circuit is determined by the setting of R4. It will thus be seen that apart from the use of the zener diode the circuit is standard.

Fig. 7 shows a simple transistorized voltage regulator circuit using a zener diode reference element. A circuit of this type is limited in regulating voltage by the rating of available transistors, but only a low-power zener diode is required, as will be seen later. In view of the wide present interest in semiconductor devices in general, it may be useful to examine the operation of the transistorized voltage regulator.

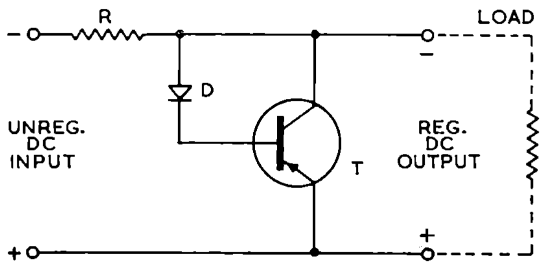


Fig. 7.—Simple Transistorized DC Voltage Regulator Using Zener Diode Reference Element.

The transistor functions as a shunt regulator, and is analogous to a triode in valve regulators. The base current of the transistor passes through the zener diode reference element, the anode of which, together with the collector of the transistor, is returned to the negative side of the regulated supply. Resistor R performs the usual function. With this arrangement, the transistor base current is a function of the output voltage, and collector current flows in parallel with the external load current.

In this application the zener diode current is adjusted to a value near the zener region, and the transistor base current is therefore normally very small. A rise in output voltage however, will cause the diode to enter the zener region, and pass a heavy current through the transistor base. This results in a heavy collector current which lowers the output voltage by producing a greater voltage drop across resistor R. Because of the current amplification of the transistor, the base current is small compared with the collector current, so that a low-power zener diode may be used.

Another transistorized voltage regulator is shown in Fig. 8. This is a series-type circuit suitable for heavier-duty applications than that of Fig. 7. The parallel-connected power transistors T1 and T2 function as voltage-sensitive series resistors to regulate the output voltage. Their operation is controlled by the low-power transistor T3, which senses the output voltage and alters the resistance of T1, T2 to maintain the output voltage at a predetermined level.

The reference voltage for the voltage-sensing stage is provided by the zener diode D. This diode requires a bias current, which is generally arranged by a special transformer or transformer winding, with a semiconductor diode rectifier and filter arrangement. A preset series resistor is used to adjust the current to the required value.

Miscellaneous Applications

No attempt can be made to cover all possible uses of this versatile device, but it may serve to trigger some ideas if a few are mentioned briefly. One proposal is the use of a zener diode of appropriate ratings in lieu of the cathode bias resistor in a valve amplifying stage. This application results in a very constant bias voltage, and no cathode by-pass capacitor is required because of the very low impedance of the diode. It is suggested that this application produces something very close to fixed-bias operation in power valves, because the voltage is constant and degeneration in the cathode lead is negligible, allowing full gain to be realised from the valve.

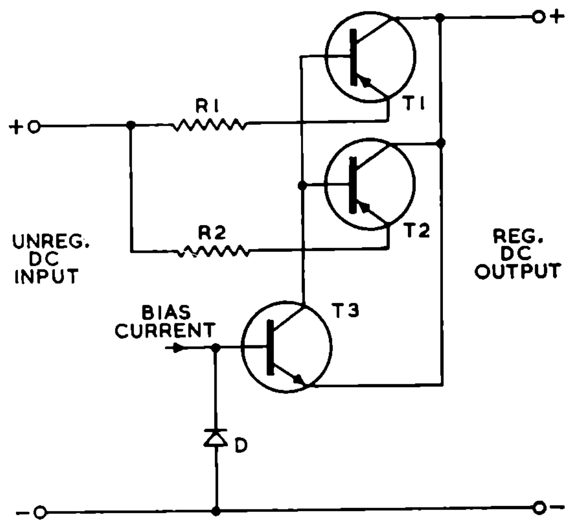


Fig. 8.—Transistorized Series-Type Voltage Regulator Using Zener Diode Reference Element.

Perhaps this application finds its greatest use however in providing bias in paraphase amplifiers, single-ended push-pull circuits, and other arrangements where the bias supply has to be isolated from other parts of the circuit. Amplifiers intended to operate relays when the input reaches a preset value are improved by using zener diodes for cathode bias instead of resistors. Operation is rendered more stable by the fact that the bias remains constant instead of varying under different signal-input conditions.

Marginal or selective relay operation from a common varying dc voltage source is facilitated by the use of zener diodes. Each relay is connected in series with a diode of appropriate zener voltage rating, and will therefore operate only when the breakdown voltage of the associated diode is reached. This method offers more reliable

(continued on page 280)

Installation and Cooling of Silicon Rectifiers

INSTALLATION

Silicon rectifiers can be damaged by mishandling and overheating. Precautions must be taken therefore during installation to ensure that the manufacturer's instructions regarding bending and twisting of leads, soldering temperatures, and other similar factors are observed. As a general rule for the more common wire-lead types, the leads should not be bent closer than about $\frac{3}{8}''$ from the seal, and should not be twisted after bending. There are other installation problems concerned with cooling, which are dealt with later in this article.

Soldering

In making soldered connections the soldering iron should be kept in contact with the leads for as short a time as possible consistent with making a good electrical connection. This precaution is necessary to avoid excessive heat transference and for the same reason the use of soldering "guns" of the "quick heat" type is not recommended. When soldering diodes or wiring-up equipment in which silicon diodes are connected do not use an electric soldering iron without an earth connection, as the leakage current from the element to the bit may be sufficient to damage the diode. Never attempt to make circuit changes or re-connections on "live" equipment, because accidental short circuits and earth return currents through a soldering iron may cause failure of the diode.

Manufacturers usually specify a minimum distance from the seals of the diode for soldering purposes. Where no distance is specified, a half-inch clearance should provide the necessary protection for the junction. However at all times a heat sink should be provided between the body and the soldering point by holding the lead in a pair of pliers. Keep the pliers in position until the joint has cooled sufficiently to allow touching it. When dip soldering is employed, a maximum solder temperature of about 250°C should be used, and the immersion time limited to ten seconds or less. Never make a soldered connection directly to the anode stud or body of a diode.

When a heat sink is used with a stud-mounted diode, any soldered connections to the heat sink must be made before the diode is mounted in position. If the diode is insulated from the heat sink, the anode connection should be made using a suitable solder tag, the lead being soldered to the tag before assembly. It is most important that the washer portion of the tag in contact with the mounting nut is free of solder or flux which could interfere with a good thermal and/or electrical contact.

General Precautions

If it is necessary to make high voltage flash tests on any completed equipment it is essential to connect a short circuit link with low-resistance contacts across each diode or series/parallel group of diodes.

If the mounting position is such that the air flow may be impeded, it is desirable to check the temperature of the diode case under working conditions by means of a calibrated thermo-couple junction attached to the case or stud.

Never drill holes in the anode stud or body of diodes for the purpose of fitting a thermo-couple junction. It should preferably be affixed by means of adhesive tape, putty or some similar means which will ensure good thermal contact without modifying the heat transfer to the heat sink.

COOLING

The rating of silicon power rectifiers is closely related to the junction temperature. The problems involved are most-commonly overcome by using cooling fins and arranging for a supply of cooling air by natural convection. The use of fins effectively increases the surface area of the diode and accelerates this cooling action.

Where cooling fins are not practical as for example in some types of sealed equipment, cooling of the diode can be assisted by mounting the diode on a substantial body of metal. This "heat sink" will have a comparatively high thermal capacity, and may in turn be mounted in such a way as to dissipate heat into the equipment case and thence to the atmosphere.

Standard fin units are available from most manufacturers, but frequently considerations of size, shape and conditions peculiar to the design of a certain unit of equipment preclude the use of standard units. In such cases the problem of designing suitable cooling fins arises.

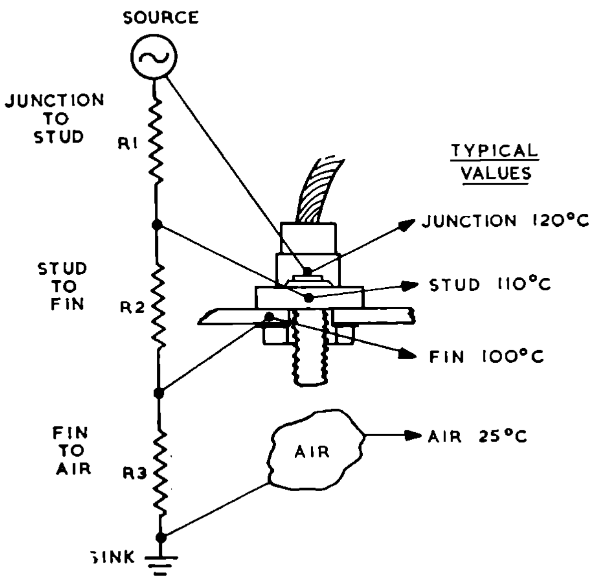


FIG. 1

Cooling Fin Design

Materials with high thermal conductivity such as copper or aluminium are the most suitable materials for cooling fins. It is undesirable to use materials which have a contact potential significantly different from copper as there is a possibility of corrosion developing between the stud and cooling fin. Fig. 1 shows how the Rectifier/Fin/Air System may be presented using a thermal "Ohm's Law" analogy. The flow of heat (watts) through the various thermal resistances (R1, R2, R3) between the source (silicon junction) and ground (atmosphere) produces a temperature drop across each proportional to the value of the resistance.

An estimation of the maximum thermal resistance permissible for satisfactory operation of a diode may be determined from the equation:—

$$R3 = \left\{ \frac{T2 - T1}{W} \right\} - R2.$$

where R3 = Thermal resistance of the cooling fin (°C per watt).
R2 = Thermal resistance between stud mounting and fin surface.
T2 = Maximum permissible stud temperature (°C).
T1 = Ambient air temperature (°C).
W = The rated dissipation of the diode in watts.

The value for R2, the thermal resistance between mounting stud and cooling fin, will depend on the size of the mounting flange on the diode, and should be obtained from the manufacturer's data. The value will in general be of the order of 1°C per watt for the smaller units with a mounting-flange diameter of about three-eighths of an inch, ranging to 0.3°C per watt for larger units with mounting flange diameters of about five-eighths of an inch.

Having estimated the cooling fin thermal resistance from the equation given above, reference to Fig. 2 will provide an assessment of the necessary surface area/air flow relationship. As typical examples it will be seen that for a fin resistance of 5°C per watt a cooling surface area of approximately 20 sq. ins. is required for convection cooling; or alternatively if forced air cooling is employed with an air flow of 10ft./sec. an area of approximately 8 sq. ins. is sufficient. The values of Fig. 2 refer to square copper or aluminium fins with a side/thickness ratio of approximately 30.

Since the enclosure of fin structures inside cabinets and stacking-fins side by side and any other operating environment which departs from the condition of unrestricted convection in free space will increase the thermal resistance of the fin, the values derived from Fig. 2 are necessarily only approximate and are intended to give a guide for trial purposes. It is therefore important to ensure that the case temperature does not exceed the maximum rating under the worst combination of operating conditions, and in critical applications the actual rectifier case temperature should be checked with a thermocouple. Both sides of the fin can be included in calculation of the surface area provided both are exposed to free air circulation.

Miscellaneous Considerations

Whenever practical the diode should be mounted centrally in the fin surface. Off-centre mounting reduces the cooling effect of a given area. Folded construction may be employed provided that the adjacent fin surfaces are separated by at least $\frac{1}{4}''$. Smaller spacing will tend to nullify the effect of the extra surface area obtained.

Fins made of metal other than copper or aluminium will generally require to have greater thickness to maintain the same thermal resistance, and may present corrosion problems.

The fin surface should be a dull black, to increase heat radiation, and may be roughened except in the region where the diode is fitted. The dull finish may be obtained by painting, anodising or etching. To ensure good thermal contact it is essential that the fin is clean, flat and free from burrs in the area where the diode is in contact. Some notes on insulated mounting washers are available in "Radiotronics", Vol. 24 No. 2, February, 1959.

In the design of prototype units due allowance should be made so as to accommodate top limit (forward volt drop) diodes in future production units. The sample diodes which are used for design purposes should be checked (readily performed with an accumulator and suitable series resistance). A check of prototype units should be made by means of a thermocouple. The case or stud temperature should not exceed the rated maximum under any likely combination of operating conditions. Thermocouple junctions should not have wires of larger diameter than 0.010 inches and should be fixed to the case or stud by a small amount of adhesive tape or putty, or other means which does not modify the normal heat transfer from the diode.

Thermocouples should be used wherever possible. However, in exceptional circumstances a check may be made by using temperature sensitive paints or crayons. Before using any temperature indicating material the instructions should be studied carefully, and the surface should be clean and free from grease and moisture. In general the materials which melt at specified temperatures are more suitable than those which depend upon change of colour, as the latter are usually dependent upon heating time. Where the rectifier assembly consists of several fin units in a stack, it is usually sufficient to measure the temperature of one of the inner fin units.

Mounting Finned Units

Convection cooled units should be mounted with the fin surfaces in a vertical plane. Horizontal mounting will necessitate approximately 33% greater area for equal cooling efficiency. Wherever possible the fins should be mounted in a position which allows cool air from outside the equipment to flow immediately below the fins with unrestricted circulation. Care should be taken that the air flow is not unnecessarily impeded by equipment mounted above and/or below the rectifier unit.

It is desirable to avoid mounting other components which dissipate considerable heat in close proximity to the rectifier assembly. Where this is unavoidable the transfer of heat to the rectifier may be minimised by suitable shielding.

To ensure good thermal contact (lowest thermal resistance) the diode should be tightened to the torque limit in the heat sink or cooling fin. Silicone grease applied to the contact areas before mounting will reduce the thermal resistance of any air pockets between the diode and heat sink, and will also help to prevent corrosion in the area of the joint.

If a metal chassis or panel of the equipment is used as a heat sink the rectifier should be located in that part of the chassis where the air is coolest and air movement least restricted. When a horizontal chassis is used as a heat sink only that side which is exposed to free air circulation should be regarded as an effective cooling area. Chassis or panels which are mounted with their surfaces in a vertical plane are generally more effective as heat sinks.

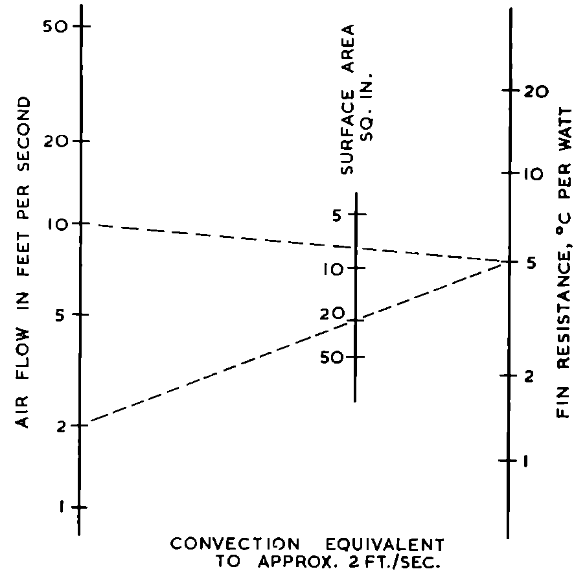


FIG. 2

Heat Sinks

Operation of silicon rectifiers in sealed equipment produces problems in cooling. Normal fin structures are seldom adequate because of the restriction of air flow, and it becomes necessary to extract the heat by conduction to the metal panel or framework. Circuit conditions which require electrical isolation do not permit direct mounting on the panel, but it is possible to obtain good heat transfer with the rectifier mounted on a block of copper, which is clamped against the panel with a thin sheet of mica inserted for insulation.

The block should be as large as possible and should have a sufficient number of fixing screws to ensure uniform pressure over the area in contact with the panel. If the equipment unit contains components which operate at high surface temperature (valves, wire wound resistor, etc.), it is beneficial to have a bright finish on the inside of the panel and to have all other internal surfaces finished in matt black. External surfaces should be finished in matt black or other dark colour. The best location for fixing the block-type heat sink is generally at the bottom of the panel.

When a block-type heat sink is used it is important that the tapped hole should be normal to the surface and the surface flat, otherwise only imperfect thermal contact will be made between the base of the diode and the block, and the stud may be strained. To ensure that the diode seats satisfactorily the hole should in some cases be counter-bored; this will depend on the design and tolerances of the diode case.

Forced-Air Cooling

For operation in restricted spaces or at higher ambient temperatures, forced-air cooling can be used. Forced air cooling at quite low velocities makes it possible to use fin units with smaller surface area and to maintain efficient cooling at high ambient temperatures. To estimate the fin surface area necessary, reference should be made to Fig. 2 which will serve as a guide to the approximate surface area required at various air flow velocities.

(With acknowledgements to G.E.C.)

Off The Beaten Track

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

No. 3 — UHF VALVES

The evolution of valves for operation at higher and higher frequencies has provided an interesting field of observation over the years. The main problems in designing and operating valves at ultra-high frequencies are generally well known, but it may be interesting to take a look at some of the developments in this field, not only to see how the problems are overcome, but also to see what has happened to the valve. What has happened to the valve is that it has become unrecognisable, at least to those familiar only with domestic radio valves.

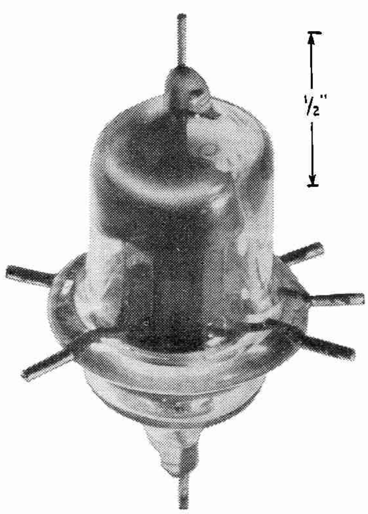


Fig. 1 — An Acorn Valve.

The problem of operating a valve at increasingly-high frequencies is mainly posed by the inductance of the connecting leads inside the valve and the interelectrode capacitances. The inductive reactance of the leads becomes increasingly high in relation to other circuit impedances as the frequency is raised, and is in series with the electrode connections. At the same time the impedance between the electrodes themselves becomes increasingly low as the capacitive reactance falls. Eventually of course these considerations make it impossible to operate the valve as the frequency is increased.

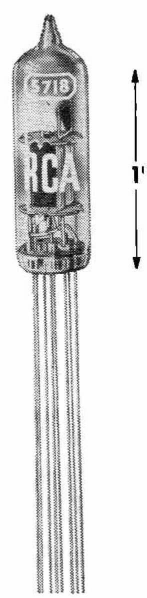


Fig. 2 — Subminiature Valve with Flying Leads.

Miniaturization, wide lead separation, and the use of insulators of low power factor at uhf frequencies have all helped in the past, but the tendency today is to a complete change in design and method of construction of valves for these frequencies. Often the valve is so designed as to form, when installed, an integral part of the tuned circuit, thus dispensing with other external connections. This necessitates the provision of special sockets and other hardware to use these types. A further step is the incorporation of the tuned circuit right inside the valve itself, as is done in the case of klystrons and magnetrons, for operation at microwave frequencies.

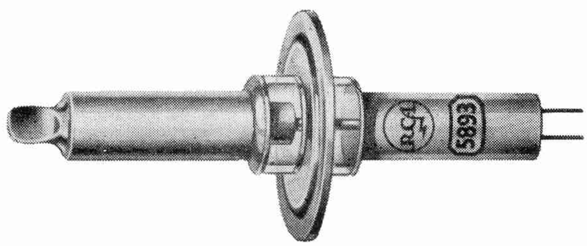


Fig. 3 — A Typical Pencil Triode.

Another problem in operating valves at the higher frequencies is transit time, the time taken by an electron to travel from cathode to plate. If the transit time is large in relation to operating frequency, satisfactory operation is not possible. Reduction of transit time calls for closer electrode spacing with attendant mechanical difficulties.

Acorns and Subminiatures

"Acorn" valves, so called from the shape and size of the glass bulb, were an early attempt to adopt valve design to higher frequencies. The assembly was made much smaller than was usual at the time, and the connections to the electrodes were brought to stiff wire pins disposed radially

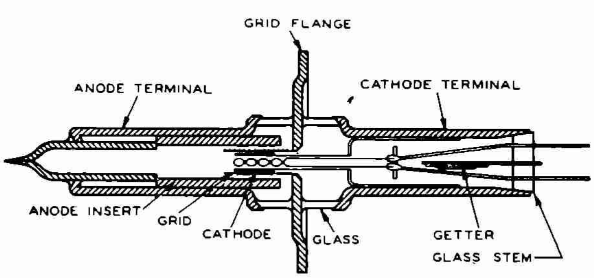


Fig. 4 — Structure of a Pencil Triode.

around the structure. This substantially reduced interelectrode capacitances. At the same time, in some types such as the 6F4 and 6L4, two connect-

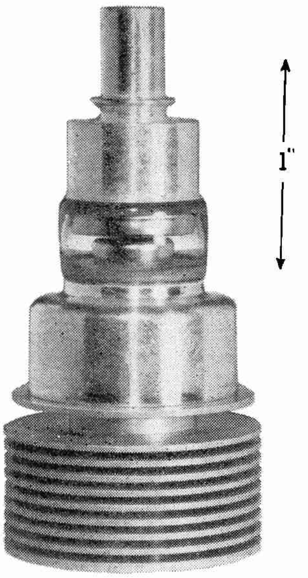


Fig. 5 — A Lighthouse Valve.

ing pins were provided for the grid and two for the plate; the effective lead inductances were thereby approximately halved by having two parallel paths in each case.

A typical acorn valve is shown in Fig. 1. Similar results can be obtained from sub-miniature valves with flying leads, such as the 5718 shown in Fig. 2. In this design the elimination of the conventional base and the small overall size greatly reduce losses. An average top operating frequency for both acorn and subminiature types would probably be 500 Mc, although some can be operated at full input up to 1,000 Mc.

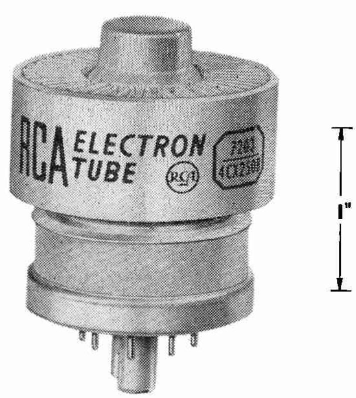


Fig. 6 — A Modern Coaxial Valve with Base.

Pencil-type Valves

"Pencil" valves are very slim, a typical type being about the size of a fountain-pen cap. They represent a complete break from conventional design, and are the forerunners of a long series of valves employing coaxial types of construction. A photograph of a typical pencil triode is shown in Fig. 3, and a diagram of its structural features is shown in Fig. 4. The pencil triode has typical operating frequencies, up to 3,000 Mc or more, depending on type. The design not only meets requirements of low transit time, low lead inductance and low interelectrode capacitances, but gives also extreme sturdiness with small size and weight.

It will be seen from Fig. 4 that the coaxial-electrode structure is of the double-ended metal-glass type in which the plate cylinder and cathode cylinder extend outward from each side of the grid flange. The latter is particularly effective in permitting isolation of the plate circuit from the cathode circuit in grounded-grid service. In addition, the disk-seal type of electrode termination, inherent in the design of "pencil-type" tubes, permits the utilization of closed-cavity resonators which minimize power loss through radiation, besides giving much lower inductance values and higher resonant frequencies than are obtainable with wire leads.

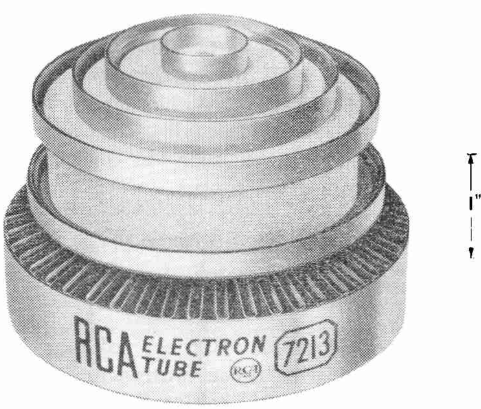


Fig. 7 — Modern Coaxial Valve with Ring Connectors.

Lighthouse Valves

Unlike the pencil types, lighthouse valves are single-ended, though still employing a coaxial method of construction. A lighthouse valve is shown in Fig 5, from which the derivation of the name will be apparent. This type of valve is specially-designed to be used in concentric-line circuits, which are so arranged mechanically that the valve can be pushed into the end of the assembly, with the plate post, grid ring and cathode shell contacting the line elements. A socket on a flexible lead is used to carry connections to the octal base.

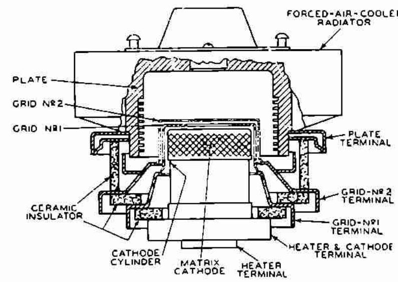


Fig. 8 — Cutaway View of Type 7213.

Nowadays these lighthouse valves are not met very often, as they have been superseded largely by a whole range of coaxially-constructed valves, in the latest of which ceramic has taken the place of glass, and in which spectacular reductions in size and increases in performances have been achieved.

Modern Coaxial Valves

A modern coaxial valve is shown in Fig. 6. In this case the concentric construction includes an external plate and cooling radiator for forced-air cooling. The plate is insulated with a ceramic ring from the base, which has a special 8-pin socket with locating peg. This particular type of valve is capable of 400 watts input up to 175 Mc and 250 watts input up to 500 Mc.

In Fig. 7 on the other hand is shown a modern completely coaxial valve, with all the connections brought to gold-plated concentric rings. Here again ceramic is used for insulation, and spite of the small size, this type is capable of 2,500 watts input up to 1215 Mc. In this type each electrode, its support, and the contact ring are completely

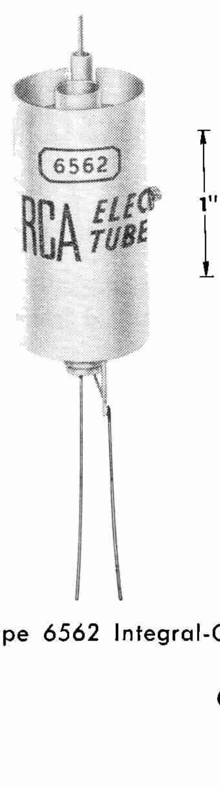


Fig. 9 — Type 6562 Integral-Cavity Oscillator.

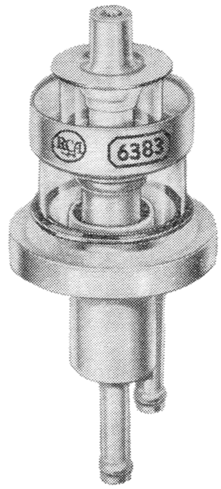


Fig. 10 — Type 6383 Liquid and Air Cooled Triode.

assembled before final assembly of the valve itself is undertaken. Other features of modern construction are shown in Fig. 8, which shows a cut-away view of the 7213. This illustrates very well the progress of uhf valves away from earlier designs.

Miscellaneous Types

Two other uhf valves will be mentioned as they have particular points of interest. The first is the 6562, which has two resonant cavities built into the valve. It is a fixed-tuned triode oscillator, intended for operation at 1680 Mc. One of the two cavities is fixed-tuned, and connected between grid and cathode. The other cavity is connected between grid and plate, and can be tuned between close limits by means of an externally-accessible screw. See the photograph, Fig. 9, where the tuning screw is visible at the right. The output of the oscillator is picked up on an integral loop coupled to the grid/plate cavity, and is brought out through a short coaxial line to an output probe, seen at the top of the photograph. In other respects the valve is of pencil-type construction.

The second type included here for interest is the 6383, shown in Fig. 10. Apart from the fact that this valve requires both liquid and air cooling, it is a concentric triode with ring connectors for grid and plate, and an end cap connector for cathode and heater. It is capable of full input up to 2,000 Mc, with a plate dissipation of 600 watts CCS class C Telegraphy. Air cooling is employed for the grid and cathode terminals and the outside of the envelope. Liquid cooling is used for the plate, introduced through two pipes which form an integral part of the plate. These pipes can be seen at the bottom of the photograph (Fig. 10), and feed the cooling jacket immediately below the plate ring.

Summary

This quick look at uhf valves has perhaps served to show some interesting developments which are outside the day-to-day experience of the average radio enthusiast. No doubt the story will evolve still further as time goes on, with perhaps new techniques such as the Nuvistor* construction playing their part.

* "Radiotronics", Vol. 24, No. 8, August, 1959

"Basic Radio and Radio-Receiver Servicing", 2nd Edition, Paul B. Zbar and Sid Schildkraut, McGraw-Hill, 130pp.

This laboratory manual for radio and TV technicians is written along the now-familiar lines adopted so successfully by these two members of the Electronic Industries Association, and mentioned so favourably in previous reviews in these pages. (See "Radiotronics", Vol. 23 No. 10 and Vol. 24 No. 4). This particular volume, as the name implies, deals with the introduction of the student to the radio receiver, it being assumed that a basic knowledge of electricity and electronics has already been acquired. (Other volumes in the same series deal with these matters). The text is heavily slanted towards problems of servicing the radio receiver. The direct approach is very pleasing, and represents an economy of time for the student. Although the pace is fast, even the closest scrutiny shows the coverage to be thorough. In addition to the conventional domestic radio, the problems of servicing series-string, portable, short-wave and communication receivers, car radios and FM sets, and transistorized radios, are all brought forward. An excellent foundation for the beginner serviceman.

"Transistor Fundamentals and Applications", Amalgamated Wireless Valve Co. Pty. Ltd., 40pp., 5/- post free.

This publication is a reprint in book form of a very useful and popular series of articles printed during the first half of 1959 in "Radiotronics",

(continued on page 270)

TRANSMITTING VALVES

FREQUENCY AND POWER-OUTPUT CHART

This chart is designed to simplify selection of a transmitting valve type for use in any type of service at a given frequency and power output. The chart covers power-output requirements up to 500 kilowatts, and operating frequencies up to 2000 megacycles per second. It is divided into power-frequency areas, each of which is labelled with the type designation of the transmitting valve which can be expected to deliver optimum performance over that area. In some cases, two or more valve types are shown in an area. The valve type shown in large letters is the most popular or economical type for operation in that area; the types shown in small letters have essentially the same power-output and frequency characteristics as the one shown in large letters, but may differ in other respects. If the area is subdivided by dashed lines, the valve type shown in large letters outside the dashed lines is recommended for use over the entire area.

Conversion Table

The power-output values shown in the chart are for CCS class C Telegraphy service. To permit quick conversion of power-output requirements for other types of service to class C Telegraphy values, a conversion table is given in Table 1. This table gives the approximate factor by which the required power output for each such type of service should be multiplied to obtain a corresponding class C Telegraphy output which can be read on the chart.

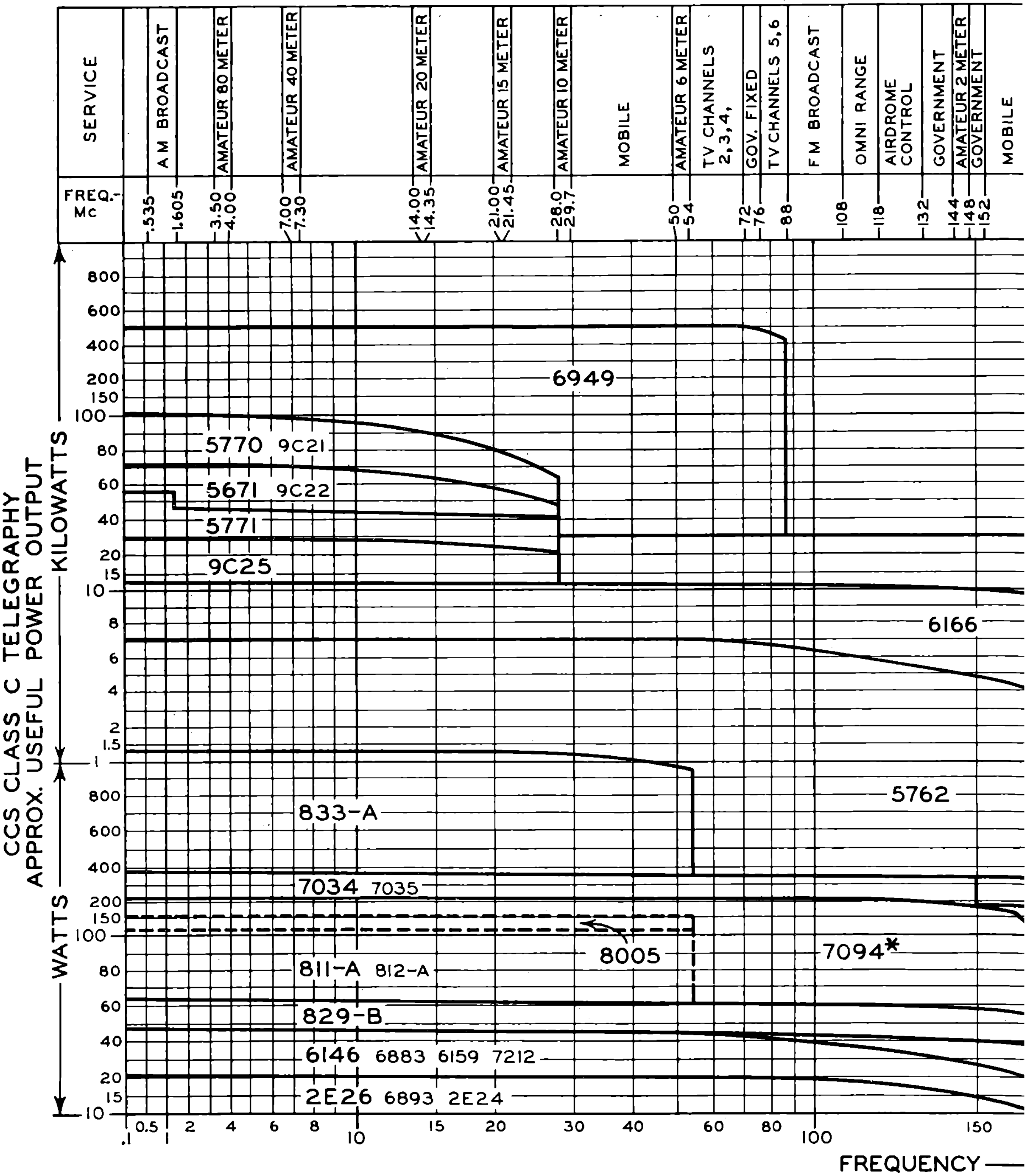
As an example of the use of the conversion table, assume that a grid-modulated class C amplifier capable of delivering an unmodulated-carrier output of 500 watts at a frequency of 2 megacycles is required. The multiplier for grid-modulated class C service is 5. Therefore, a valve capable of delivering 500 x 5 or 2500 watts in class C Telegraphy service at 2 megacycles is required. The indicated valve type in this case, as shown in the Selection Chart, is the 5762.

As another example, assume that the output stage of a television transmitter operating on vhf channel 2, 3, or 4 is required to deliver a power output of 10 kilowatts on synchronizing - signal peaks. The multiplier for class B Linear-amplifier or class C Television service is 1.45. Therefore, a valve capable of delivering 10 x 1.45 or 14.5 kilowatts at 54 to 72 megacycles in class C Telegraphy service is required. The indicated valve type in this case is the 6806.

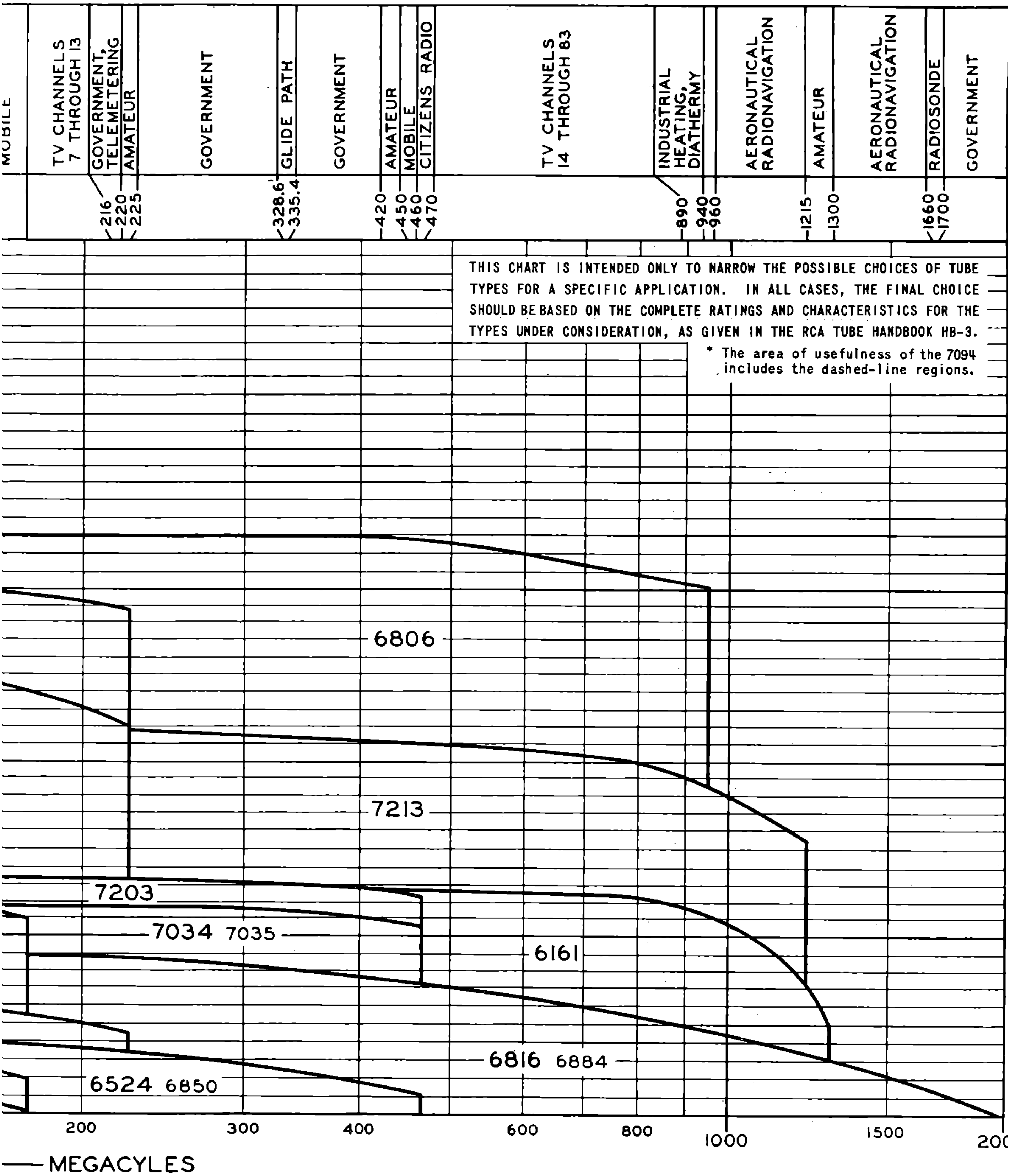
TABLE 1

Type of Service	To Determine CCS Class C Telegraphy Power-Output Requirements Multiply Required	By
Plate-Modulated RF Power Amplifier—Class C Telephony	Carrier Power	1.5
AF Amplifier or Modulator—Class AB_2 or Class B	Maximum - Signal Power Output for Two Valves in Push-Pull	0.7
Linear RF Power Amplifier—Class AB_1—Single-Sideband, Suppressed-Carrier Service.	Peak Envelope Power	1.45
Grid- or Screen-Grid-Modulated RF Power Amplifier—Class C Telephony.	Carrier Power	5
RF Power Amplifier—Class B Telephony.	Carrier Power	5
RF Power Amplifier—Class B Television Service (Bandwidth = 6 Mc).	Synchronizing-Level Power Output	1.45
Grid- or Bias-Modulated RF Power Amplifier—Class C Television Service (Bandwidth = 6 Mc).	Synchronizing-Level Power Output	1.45

POWER VALVE


SERVICE
FREQ.-Mc
A M BROADCAST
AMATEUR 80 METER
AMATEUR 40 METER
AMATEUR 20 METER
AMATEUR 15 METER
AMATEUR 10 METER
MOBILE
AMATEUR 6 METER
TV CHANNELS 2,3,4,
GOV. FIXED
TV CHANNELS 5,6
F M BROADCAST
OMNI RANGE
AIRDROME CONTROL
GOVERNMENT
AMATEUR 2 METER
GOVERNMENT
MOBILE
.535
1.605
3.50
4.00
7.00
7.30
14.00
14.35
21.00
21.45
28.0
29.7
50
54
72
76
88
108
118
132
144
148
152
CCS CLASS C TELEGRAPHY
APPROX. USEFUL POWER OUTPUT
KILOWATTS
WATTS
6949
5770 9C21
5671 9C22
5771
9C25
6166
833-A
5762
7034 7035
8005
7094*
811-A 812-A
829-B
6146 6883 6159 7212
2E26 6893 2E24
FREQUENCY

SELECTION CHART



When the desired operating point is near a power or frequency limit of an area, consideration should be given to parallel or push-pull operation of valves in lower adjacent areas or to single valves in higher adjacent areas. Thus, in the second example given above, it might be more economical or otherwise advantageous to use three parallel-connected air-cooled type 5762 triodes, or push-pull air-cooled type 6166 tetrodes in place of the water-cooled type 6806 indicated in the chart.

Additional Considerations

It is important to emphasize that the power output obtainable from a valve at a given frequency depends upon the conditions under which the valve is operated, and upon the circuit efficiency. The power-output values shown on the chart can be achieved by operation of the indicated valve types within their maximum ratings, in circuits having reasonably high efficiency, but are not guaranteed values. A valve type indicated for use in a particular power-frequency area can be expected to perform as well as or better in any area below or to the left of the one in which it is listed.

Acknowledgement

This chart is reproduced by courtesy of RCA. The class of service listed in the top column of the chart applies to frequency allocations in the U.S.A., and is not necessarily correct in other areas.

NEW PUBLICATIONS

(Continued from page 266)

and is intended to meet the continuing demand for the material. The book is a short course on transistors intended for the technician or engineer with no previous semiconductor experience. It is so written and arranged as to provide a good foundation knowledge of transistors without complex text book operations. Explanations are simple and down-to-earth, and copious diagrams are provided. The text ranges from explanations of the nature of transistors, through the various types and how they work, their use and application in amplifiers, oscillators, radio and TV circuits, through to servicing techniques. A series of review questions at the end of the book not only provides the student with the means to check his studies, but thereby forms a basis for any necessary revision.

"Basic Electronics", Bernard Grob, McGraw-Hill, 523pp. + ix

This volume is stated to be the first of a two-volume package presenting an introduction to the entire field of electronics. It is particularly interesting in that it is written especially for the student with no background of electricity, and little mathematics. The mathematics is limited to simple algebra and trigonometrical functions, and where used, at least one sample problem is solved in each case. Starting with electrons and electricity, topics progress to dc circuits, magnetism, ac circuits, valves and transistors.

The interesting layout of the book, with periodical reviews of the work covered in the preceeding few chapters, with a self-check for the student in the form of a series of "true/false" questions, makes the book eminently suitable for the private student. It obviously reflects the author's teaching experience at RCA Institutes. It is most pleasing to see recently the production of books on technical subjects so written and arranged as to permit of highly-successful private study without the aid of a teacher to help the student over lots of unexplained hurdles. An outstanding book in its class, and an important addition to our recommended list for students.

"Radio Circuits — A Step by Step Survey", 4th Edition, W.E. Miller, Revised by E. A. Spreadbury, Iliffe and Sons Ltd., 8vo, 172pp.

To those of us who are familiar with the literature of the radio art, this book is an old friend, who has now been revitalized. He first appeared in 1941, and his present rejuvenation in the fourth edition (1959) is brought about by a general modernization, and by the addition of six new chapters on transistors, car radio, and FM receivers.

This popular little book explains in simple language and in easy stages the varieties of circuits that are found in radio receivers used for sound broadcasting. It does this by taking separately each stage of the receiver, and explaining it without the complication of all the associated circuits round it. In this manner every detail can be absorbed easily by the reader, who is not obliged to cope with more than he can assimilate at any one time. As he acquires familiarity with several parts, however, he is introduced to their mutual association with one another, and he is finally led to an understanding of the complete circuit of a receiver.

This booklet presupposes some basic knowledge of radio on the part of the reader. It can be confidently recommended for the radio student who

(continued on page 283)

In the presentation of this list, types with a "2N" prefix are placed first, in order according to type number. These are followed by miscellaneous types, in which the letters in the type number are ignored for the purpose of arrangement, and the type is placed in a position in the list determined by the numerals in the type number.

Transistor Interchangeability Guide

This listing is to be used as a guide only. Types shown as replacements are not necessarily electrically and physically identical with the type to be replaced unless marked with an asterisk (*). For more complete information on transistor interchangeability, consult published data on the relevant types.

KEY TO SYMBOLS

* Denotes direct interchangeability.
† Denotes discontinued type.
‡ 2N247 and 2N274 are identical except for case size and interlead capacitances.
• This indicates that the replacement transistor shown is a flying-lead type, and must be soldered into the circuit. This can be done in many cases by passing the leads through the appropriate socket holes and soldering the connections on the underside.

TYPE	REPLACE BY	TYPE	REPLACE BY	TYPE	REPLACE BY
2N34	2N408•	2N61	2N270	2N113	2N412
2N34A	2N408•	2N62	2N217•	2N114	2N274
2N35	2N647	2N63	2N217	2N115	2N270
2N36	2N217	2N64	2N217	2N116	2N220•
2N37	2N408	2N65	2N217	2N123	2N404
2N38	2N408	2N76	2N217•	2N125	2N585
2N38A	2N408	2N77†	2N105*	2N126	2N585
2N39	2N217	2N79†	2N331	2N128	2N247‡
2N40	2N217	2N85	2N217•	2N129	2N373
2N41†	2N105	2N86	2N217•	2N130	2N105
2N42	2N217	2N87	2N217•	2N130A	2N105
2N43	2N217•	2N88	2N105	2N131A	2N105
2N43A	2N331	2N89	2N105	2N132	2N105
2N44	2N217•	2N90	2N105	2N132A	2N105
2N44A	2N217•	2N94	2N585	2N133	2N220•
2N45	2N217•	2N96	2N331	2N133A	2N220•
2N46†	2N105	2N104	2N217•	2N135	2N218•
2N47	2N105	2N105	2N105*	2N136	2N218•
2N48	2N105	2N106	2N217•	2N137	2N219•
2N49	2N105	2N107	2N406	2N138	2N406
2N54	2N217•	2N109	2N217•	2N138A	2N406
2N55	2N217•	2N111	2N218	2N139	2N218•
2N56	2N217•	2N111A	2N218	2N140	2N219•
2N59	2N270	2N112	2N218	2N155	2N301*
2N60	2N270	2N112A	2N218	2N156	2N301

TYPE	REPLACE BY
2N157	2N561
2N157A	2N1014
2N167	2N358
2N173	2N301
2N175	2N220•
2N176	2N301
2N180	2N217
2N181	2N270
2N185	2N270
2N186	2N217
2N186A	2N270
2N187	2N217•
2N187A	2N270
2N188	2N217•
2N188A	2N270
2N189	2N408
2N190	2N408
2N191	2N270
2N192	2N217
2N195	2N217
2N196	2N217
2N197	2N217
2N198	2N217
2N199	2N217•
2N200	2N331
2N204	2N331
2N205	2N331
2N206	2N331*
2N207	2N105
2N207A	2N105
2N207B	2N105
2N215	2N217
2N217	2N217*
2N218	2N218*
2N219	2N219*
2N220	2N220*
2N223	2N270
2N224	2N270
2N226	2N270
2N231	2N218
2N232	2N218
2N234	2N301*
2N234A	2N301*
2N235	2N301*
2N235A	2N301*
2N236A	2N301
2N237	2N220
2N238	2N217
2N240	2N582
2N241	2N217
2N241A	2N270
2N242	2N301A*
2N247	2N247*‡
2N248	2N247‡
2N249	2N270
2N250	2N301*
2N251	2N301A*
2N252	2N219
2N255	2N301*
2N256	2N301*
2N257	2N301*
2N265	2N408
2N267†	2N247‡
2N268	2N301A
2N269	2N269*
2N270	2N270*
2N271	2N404
2N271A	2N404
2N272	2N217•
2N273	2N217•
2N274	2N274*‡
2N279	2N217
2N280	2N217
2N281	2N217
2N283	2N217
2N285	2N301
2N285A	2N301
2N291	2N270
2N296	2N301A
2N297A	2N457
2N301	2N301*
2N301A	2N301A*
2N302	2N269
2N303	2N269
2N307	2N301*
2N307A	2N301*
2N308	2N218
2N309	2N218
2N310	2N373
2N311	2N404
2N312	2N585
2N315	2N578
2N316	2N579
2N317	2N582
2N319	2N270
2N320	2N270
2N321	2N270
2N322	2N406
2N323	2N270
2N324	2N408•
2N325	2N301
2N326	2N301
2N331	2N331*
2N344	2N274‡
2N345	2N274‡
2N346	2N384
2N350	2N301
2N351	2N351*
2N352	2N301*
2N353	2N301*
2N356	2N356*
2N357	2N357*
2N358	2N358*
2N362	2N406
2N367	2N406
2N368	2N217
2N369	2N217
2N370	2N370*
2N371	2N371*
2N372	2N372*
2N373	2N373*
2N374	2N374*
2N375	2N561
2N376	2N376*
2N377	2N357
2N378	2N561
2N379	2N561
2N380	2N561
2N381	2N270
2N382	2N270
2N383	2N270
2N384	2N384*
2N385	2N357
2N386	2N301A
2N388	2N357
2N394	2N404
2N395	2N581
2N396	2N404
2N397	2N582
2N398	2N398*
2N399	2N456
2N400	2N456
2N401	2N456
2N402	2N406
2N403	2N217
2N404	2N404*
2N405	2N406•
2N406	2N406*
2N407	2N408•
2N408	2N408*

TYPE	REPLACE BY	TYPE	REPLACE BY	TYPE	REPLACE BY
2N409	2N410•	2N525	2N586	2N637B	2N561
2N410	2N410*	2N526	2N586	2N638	2N561
2N411	2N412•	2N527	2N586	2N638A	2N561
2N412	2N412*	2N536	2N578	2N638B	2N561
2N413	2N218	2N544	2N544*	2N639	2N561
2N413A	2N218	2N554	2N301*	2N639A	2N561
2N414	2N218	2N559	2N645	2N639B	2N561
2N414A	2N218	2N561	2N561*	2N640	2N640*
2N415	2N374	2N576	2N585	2N641	2N641*
2N415A	2N374	2N576A	2N585	2N642	2N642*
2N416	2N247‡	2N578	2N578*	2N643	2N643*
2N417	2N247‡	2N579	2N579*	2N644	2N644*
2N418	2N301	2N580	2N580*	2N645	2N645*
2N419	2N561	2N581	2N581*	2N647	2N647*
2N420	2N561	2N582	2N582*	2N659	2N578
2N421	2N561	2N583	2N583*	2N660	2N643
2N425	2N404	2N584	2N584*	2N661	2N643
2N426	2N578	2N585	2N585*	2N662	2N579
2N427	2N579	2N586	2N586*	2N1010	2N1010*
2N428	2N580	2N591	2N591*	2N1014	2N1014*
2N438A	2N356	2N597	2N578	2N1017	2N582
2N439A	2N357	2N598	2N579	2N1021	2N1014
2N440A	2N358	2N599	2N580	2N1022	2N1014
2N444	2N356	2N602	2N643	2N1038	2N586
2N445	2N356	2N603	2N644	2N1043	2N561
2N446	2N357	2N604	2N645	2N1044	2N561
2N447	2N358	2N605	2N384	2N1045	2N1014
2N456	2N456*	2N606	2N384	2N1058	2N412
2N457	2N457*	2N607	2N384	2N1059	2N270
2N458	2N561	2N608	2N384	2N1067	2N1067*
2N460	2N331	2N609	2N217	2N1068	2N1068*
2N461	2N331	2N610	2N217	2N1069	2N1069*
2N464	2N270	2N611	2N217	2N1070	2N1070*
2N465	2N270	2N612	2N217	2N1090	2N1090*
2N466	2N270	2N613	2N270	2N1091	2N1091*
2N481	2N371	2N614	2N373	2N1092	2N1092*
2N482	2N373	2N615	2N373	2N1101	2N647
2N483	2N373	2N617	2N374	2N1102	2N647
2N484	2N412	2N618	2N561	AO1	2N218
2N485	2N374	2N623	2N645	HA1	2N105
2N486	2N372	2N628	2N561	J1	2N217•
2N499	2N371	2N629	2N561	JP1	2N217•
2N504	2N373	2N630	2N1014	TS1	2N406
2N518	2N404	2N631	2N408	A2	2N274‡
2N519	2N578	2N632	2N408	HA2	2N105
2N520	2N578	2N633	2N270	J2	2N217•
2N521	2N579	2N635	2N1091	TS2	2N408
2N522	2N580	2N636	2N1091	HA3	2N105
2N523	2N643	2N637	2N561	HS3	2N269
2N524	2N586	2N637A	2N561	J3	2N217•

TYPE	REPLACE BY	TYPE	REPLACE BY	TYPE	REPLACE BY
TS3	2N217	OC44	2N219	CK722	2N217•
HS4	2N269	OC45	2N218	CK725	2N217•
V6R2	2N412	OC57	2N105	CK727	2N217•
V6R4	2N412	OC58	2N105	CK751	2N217•
V6R4M	2N219	OC59	2N105	CK759	2N218•
8D	2N218	OC60	2N105	GT759	2N218•
8E	2N218	OC65	2N105	CK760	2N218•
8F	2N218	OC66	2N105	GT760	2N218•
HA8	2N105	OC70	2N406	CK761	2N218•
HA9	2N105	OC71	2N408	GT761	2N218•
10A	2N270	ZJ71	2N247‡	CK762	2N219•
10B	2N270	OC72	2N217•	GT762	2N219•
10C	2N270	ZJ72	2N247‡	CK766	2N219•
AR10	2N301	OC73	2N217	CK766A	2N219•
HA10	2N105	ZJ73	2N247‡	830	2N219•
TS13	2N408	OC74	2N270	CK872	2N408•
CK13	2N247‡	OC75	2N217	CK878	2N270
ZJ13	2N217•	OC76	2N586	1032	2N217•
CK14	2N247‡	OC77	2N398	1033	2N217•
GT14	2N217	GT81	2N217•	1034	2N217•
GT14H	2N105	GT81H	2N105	1035	2N217•
TS14	2N217	SB100	2N247‡	1036	2N217•
V15/20P	2N301	GT109	2N217•	T1040	2N301*
OC16	2N301	GT122	2N269	T1041	2N301*
OC16G	2N301	DR126	2N105	CTP1104	2N301*
CK17	2N247‡	DR128	2N105	CTP1109	2N301*
GT20	2N217•	OC139	2N356	CTP1132	2N561
GT20H	2N105	OC140	2N357	CTP1135	2N561
MN24	2N301	OC141	2N358	CTP1136	2N561
MN25	2N301	TS161	2N217	T1164	2N384
V25/50B	2N217	TS162	2N217•	T1166	2N384
MN26	2N301	TS163	2N217•	1320	2N217•
OC28	2N561	TS164	2N217•	1330	2N217•
OC29	2N301A	TS165	2N217•	1340	2N217•
OC30	2N301	TS166	2N220•	1350	2N217•
V30/10P	2N301	OC170	2N384	1360	2N217•
V30/20P	2N301	OC171	2N384	1390	2N218•
OC32	2N217•	TS176	2N301*	1400	2N218•
TS32	2N270	206	2N105	1410	2N218•
OC33	2N217•	GT222	2N215	L5108	2N247‡
OC34	2N217•	300	2N217	L5121	2N247‡
T34A	2N105	301	2N217	L5122	2N247‡
T34B	2N105	302	2N217		
T34C	2N105	310	2N217		
T34D	2N217•	350	2N217		
T34E	2N217•	352	2N217		
T34F	2N217•	353	2N217		
GT36	2N105	TS620	2N218•		
OC41	2N581	TS621	2N219•		
OC42	2N218	CK721	2N217•		

VACUUM MEASUREMENT

GENERAL

Whilst the measurement of high vacuum is part of the radio valve manufacturer's everyday work, many other industries use high vacuum, both as an operational and a research tool. The research laboratory in particular has many uses for extremely low pressures, and hence for devices to measure these pressures.

The atmosphere exerts a pressure at sea-level of approximately 14 pounds per square inch, enough to support the weight of a column of mercury some 760 millimetres high—the "barometric height". Pressures below the normal atmosphere pressure are customarily measured in terms of the height of the mercury column they will support.

The range of pressures met with in vacuum technique is very wide. Devices employing gas discharges such as fluorescent lamps, Geiger-Muller tubes, cold-cathode gas valves and the like operate with gas pressures in the range from several millimetres up to several hundred millimetres of mercury. The drying of biologically-active substances by the drug industry uses even lower pressures, down to the order of one-thousandth of a millimetre. Pressures used in radio valve manufacture are very much lower again, less than one-millionth of a millimetre; this is less than one-thousand-millionth of normal atmospheric pressure.

With pressures down to a few millimetres, devices working on the barometer principle are commonly used as gauges, and with certain refinements they can be used down to about one-thousandth of a millimetre. This system however, as in the case of the McLeod gauge, makes it impossible to measure the pressure of water and other compressible vapours in the vacuum system.

AWV Vacuum Gauges

Two vacuum gauges have been developed by AWV, the ionisation type AV26 and the thermocouple type AV34. These two types have complementary ranges, and both measure total pressure.

In the pressure range of about one-thousandth of a millimetre up to several millimetres, a hot wire loses heat faster at a higher pressure than at a lower pressure, due to conduction of heat by the gas. A device using this principle may be calibrated as a vacuum gauge for this pressure region. This has been done in the case of the AV34, and this gauge measures "total" pressure, including the pressure of all vapours present in the system.

In the pressure range from one-thousandth down below one-millionth of a millimetre, use can be made of the fact that an electron current passed through a gas creates positive ions by bombardment, and these positive ions may be collected at a negative-potential electrode to give measurable current. Positive ion current is proportional to the gas pressure.

This principle is used in the AV26. A tungsten filament emits electrons to a positive helical grid. A platinum coating on the bulb wall is made negative with respect to filament. Electrons travel from the filament to the grid, but because of the open grid structure many, before arrival, oscillate backwards and forwards through the grid many times. This gives a long electron path length and hence good efficiency in hitting gas molecules to create ions. The ions travel to the negative platinum coating, and the ion current, measured with a microammeter, is then interpreted in terms of gas pressure, which includes vapour pressure.

The AV26 incorporates a spare filament. A further important feature is the provision in the design of the gauge for passing a heating current through the helical grid. This current may be applied to heat the grid to about 1000°C, thus achieving the baking of the whole tube under vacuum, necessary to de-gas the tube and give accurate readings at high vacuum. This feature eliminates the necessity of providing a special baking oven.

AV26 IONIZATION VACUUM GAUGE

The ionization gauge is a thermionic device consisting of three electrodes mounted in an envelope, which can be connected to a vacuum system by means of a glass tube. It supplements the AV34 Thermocouple Vacuum Gauge, being most useful when measuring extremely high vacua below, say, 1 micron*. The basic principle of operation has been described in the introductory paragraphs.

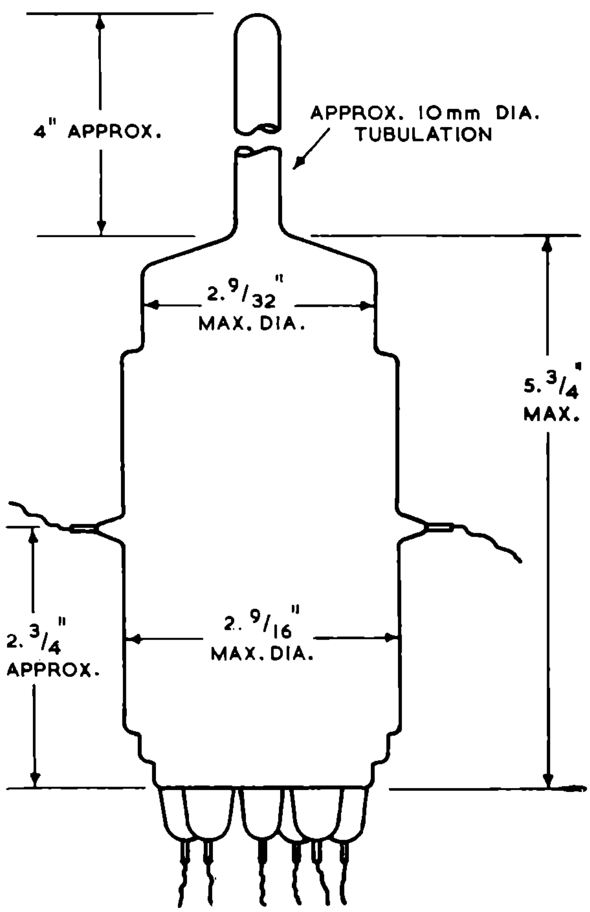


Fig. 1 — Outline and Dimensions of AV26.

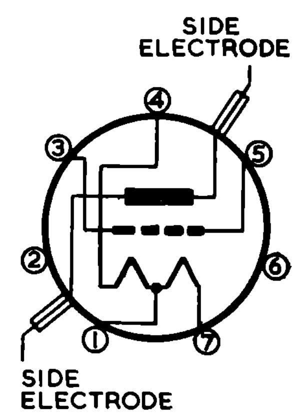
The normal maximum operating pressure is 1 micron, although the positive ion current is directly proportional to both the surrounding gas pressure and the grid electron current at pressures up to 10 microns. Higher pressures up to 10 microns may be measured provided that the grid current is reduced to 2 milliamperes, otherwise the life of the filament would be shortened. Under normal circumstances, for pressures up to 1 micron, the valve is operated at a grid current of 20 milliamperes to obtain a large ion current and hence good pressure sensitivity.

By applying 7 volts to the two grid leads the tungsten grid helix may be heated to about 1000°C. This bakes the gauge, driving out absorbed and adsorbed vapours and gases from internal surfaces. Usually five minutes of such "degassing" is sufficient, but when the gauge has been exposed to high pressure or when low pressure (say below 0.01 micron) are to be read further degassing is required. Degassing at pressure exceeding 10 microns is not advisable due to the risk of grid burn-out or the formation of films on internal glass surfaces. Leakage films so deposited can cause incorrect readings of the ion current meter. The AV26 is constructed with shading discs in the stem leads which minimise this effect.

A hard glass tubulation is provided on the gauge but connection to vacuum systems of other materials is still possible by use of a wax seal, graded glass seal, or a glass-to-metal joint. A spare filament is provided, for use in case of burnout. The AV26 has flying-lead connections, and may be mounted in any position.

ELECTRODE CONNECTIONS

(Flexible Leads)



Lead 1: Heater (Com.).
Lead 2: No Conn.
Lead 3: Grid.
Lead 4: Heater 1.
Lead 5: Grid.
Lead 6: No conn.
Lead 7: Heater 2 (Spare filament).
Side electrodes; Ion collector.

* 1 Micron = 10^{-3} mm. of mercury pressure.

RATINGS AND CHARACTERISTICS

Maximum Ratings

Filament Voltage	3.3 volts
Grid Degas Voltage	8.0 volts
Operating Pressure*	1 micron

Typical Operation

Filament Voltage	3.1 volts
Approx. Filament Current	4.7 a
Grid Voltage (DC)	+150 volts
Grid Current †	20 ma
Grid Degas Voltage ‡	7.0 volts
Grid Degas Current ‡	11 a
Ion Collector Voltage (DC)	−40 volts
Approx. Gauge Sens.	50μa/micron/ma

(i.e., 50μa grid current per micron pressure per milliampere grid current.)

NOTES:

* 1 micron = 10^{-3}mm. of mercury pressure. The max. operating pressure limit of 1 micron is at a grid current of 20 ma. Higher pressures up to 10 microns may be read if the grid current is reduced to 2 ma.

† For normal operation with pressures not exceeding 1 micron.

‡ The grid consists of a tungsten helix which may be degassed by applying 8 volts to the two external grid leads provided. Five minutes of such heating is usually necessary to degas the gauge after exposure to high pressures. To attain the lowest pressures, however, further degassing may be needed.

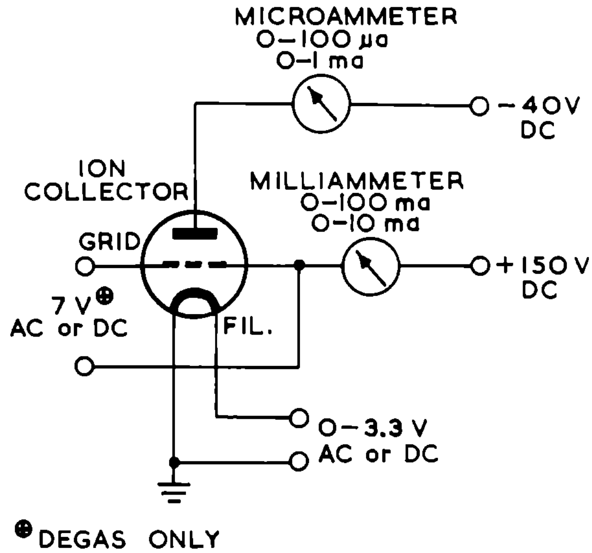


Fig. 2 — Basic circuit for AV26 Ionization Vacuum Gauge.

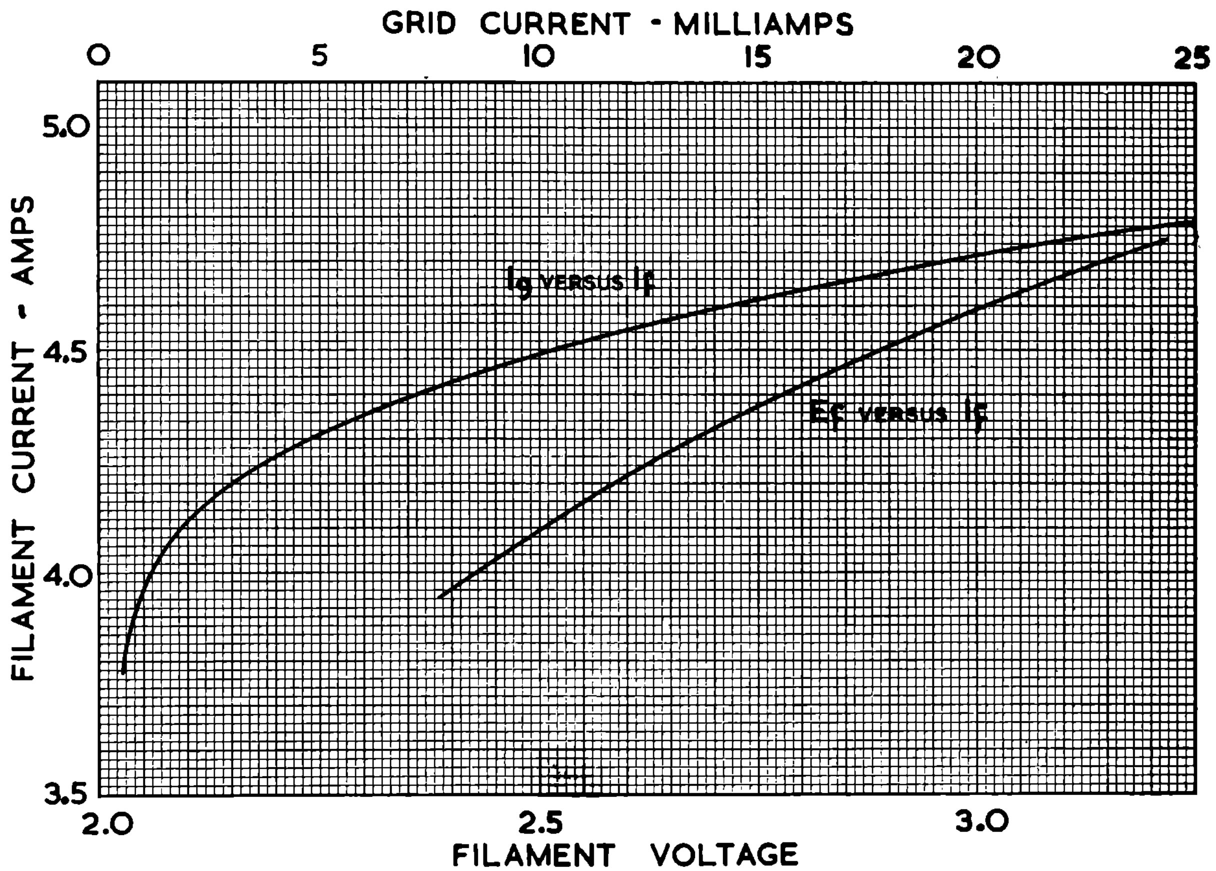


Fig. 3 — AV26, Curves of Grid Current and Filament Voltage versus Filament Current.

AV34 THERMOCOUPLE VACUUM GAUGE

The basic principle of operation of this gauge has been described in the introductory paragraphs. The small size of this gauge enables it to be used in confined spaces, and its small volume results in rapid response to pressure changes.

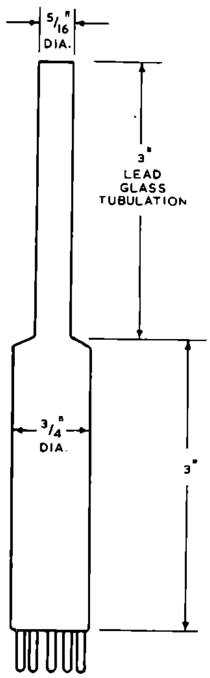


Fig. 4 — Outline and Dimensions of AV34.

The AV34 is mounted on a 7-pin miniature base, and is provided with a lead glass tubulation which can be sealed directly to similar glasses. Connection to either a hard glass or metal vacuum system can be made by:—

(a) Wax joint;

(b) Graded glass seal;

(c) Metal-glass seal.

The AV34 consists essentially of a Eureka-Nichrome thermocouple junction welded to the midpoint of a platinum heater wire. The heater temperature is dependent on the following factors:—

(a) Radiation losses;

(b) Conduction losses through the connecting leads;

(c) Conduction losses through the surrounding gas.

Over the pressure range of 1mm to 10^{-3} mm of mercury, only the last factor is significant. The gas conductivity is a function of the density and therefore of the pressure of the surrounding gas. Thus the thermocouple emf, which is determined by the heater temperature, is a measure of the surrounding gas pressure.

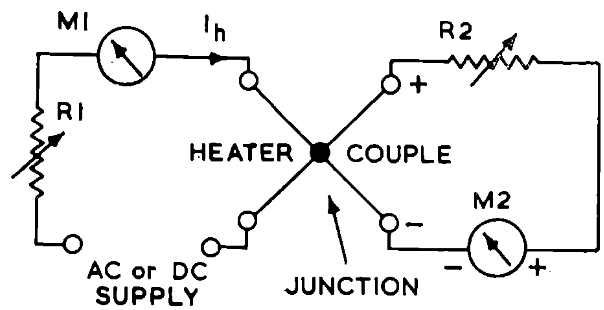


Fig. 5 — Basic Gauge Circuit for AV34.

A basic circuit for the gauge is shown in Fig. 5. The required heater current (Ih) is set by the variable resistor R1. The series meter resistor R2 must be chosen to ensure full scale deflection of the microammeter M2 at zero pressure. At pressures greater than zero the couple output will be less and the meter will read less than full scale deflection due to the lower temperature of the heater wire.

In Fig. 6 calibration curves for dry air are given covering two separate values of heater current. The lower value (140 ma) is more suitable over the pressure range 10^{-3} mm to 10^{-1} mm of mercury whereas above 10^{-1} mm of mercury pressure the higher value (250 ma) is the better.

These curves are for dry air only in an average gauge and differences between individual gauges may be up to 20%. This accuracy is adequate for general vacuum work, particularly as the gauge covers the large pressure range of 1mm to 10^{-3} mm of mercury.

A complete circuit for the gauge is given in Fig. 7. A suitable transformer (T) is one used in electric bell systems; a 240-volt primary giving a secondary output of approximately 8 volts. It is recommended that an 8 millivolt, 50-ohm meter movement (M2) be used in the couple circuit.

The value of the series meter resistor R2 is specified by the manufacturer for each gauge (assuming that the meter movement specified above is used). Other meters may be used having

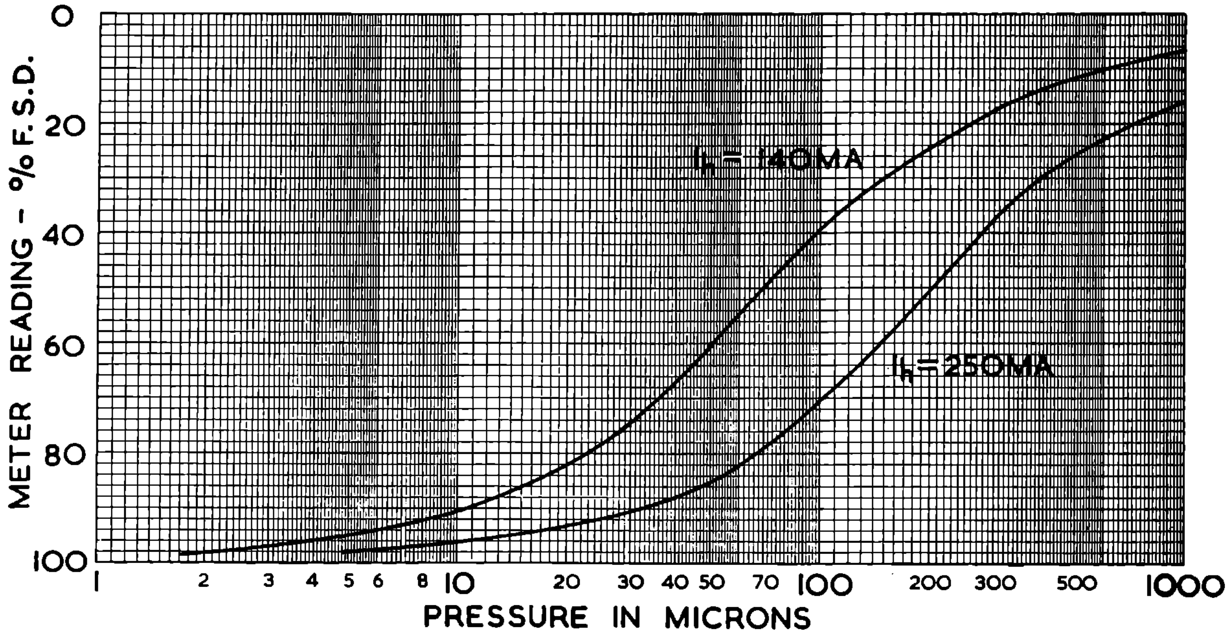


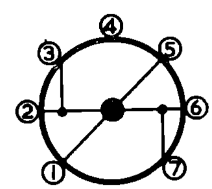
Fig. 6 — Calibration Curves for AV34.

a sensitivity of less than 8 millivolts full scale deflection, but a different value of R2 from that specified by the manufacturer must be used. It is possible to check the heater current with the meter M2 by a suitable switching arrangement and so eliminate M1.

The couple output is sensitive to changes in heater current, a 10% change in the latter giving approximately 12% variation in couple output. With an unregulated supply voltage, frequent adjustment of the heater current may be necessary. This can be reduced by use of the circuit shown in Fig. 8, which incorporates two OC3 voltage regulator tubes. The resistor R1 shown must be adjusted to limit the peak current through the OC3's to less than 40 ma. The heater current waveform in this circuit is not sinusoidal and an rms ammeter (of the moving iron, dynamometer, or thermocouple type) must be used to set the heater current to the correct value).

BASE CONNECTIONS

Pin 1: Couple —
Pin 2: Heater
Pin 3: Heater
Pin 4: No conn.
Pin 5: Couple +
Pin 6: Heater
Pin 7: Heater



RATINGS AND CHARACTERISTICS

Maximum Rating

Heater Current (rms)		300	ma

Typical Operation

Heater Current	140	250	ma
Approx. Heater Resistance	1.8	2.2	ohms
Approx. Couple EMF at Zero Pressure	10	22	mv

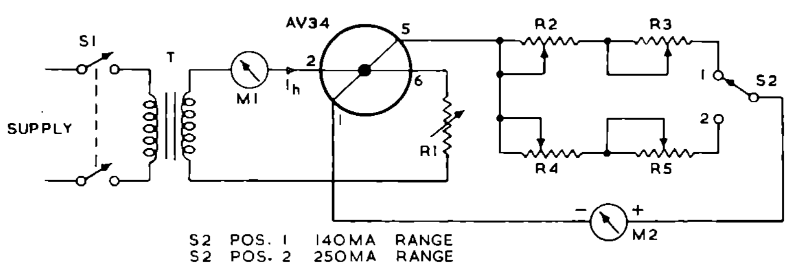


Fig. 7 — Typical Gauge Circuit, AV34.

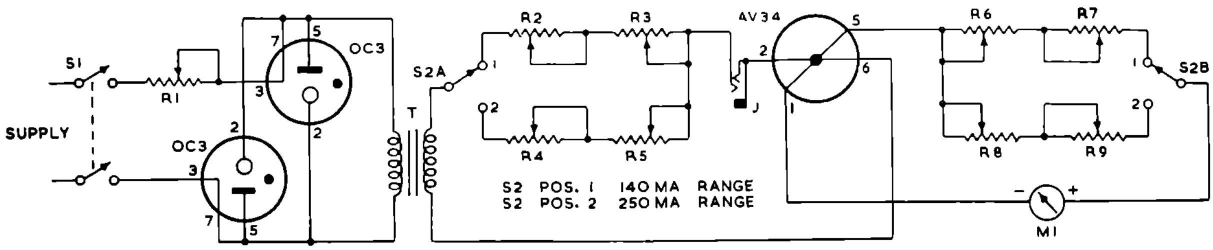


Fig. 8 — Regulated Gauge Circuit, AV34.

COMPONENT LIST FOR TYPICAL GAUGE CIRCUIT (FIG. 7)

S1 Switch, 240 v, 1 a, DPST.

S2 Switch, 240 v, 1 a, SPDT.

T. Transformer. Primary: 240 volts. Secondary: 8 volts at 1 a.

M1 Meter, 0-0.5 a ac.

M2 Meter, 0-8 mv dc, 50 ohms.

R1 Resistor, 100 ohms, 50 w, variable.

R2 Resistor, 5 ohms, 20 w, adjustable.

R3 Resistor, 25 ohms, 20 w, adjustable.

R4 Resistor, 10 ohms, 20 w, adjustable.

R5 Resistor, 100 ohms, 20 w, adjustable.

COMPONENT LIST FOR REGULATED GAUGE CIRCUIT (FIG. 8)

S1 Switch, 240 v, 1 a, DPST.
S2 Switch, 240 v, 1 a, DPDT.
M1 Meter, 0-8 mv dc, 50 ohms.
J Jack, norm. closed.
T Transformer. Primary: 240 volts. Secondary: 8 volts at 1 a.
R1 Resistor, 6000 ohms, 10 w, adjustable †.
R2 Resistor, 5 ohms, 20 w, adjustable.
R3 Resistor, 25 ohms, 20 w, adjustable.
R4 Resistor, 1 ohm, 20 w, adjustable.
R5 Resistor, 15 ohms, 30 w, adjustable.
R6 Resistor, 10 ohms, 20 w, adjustable.
R7 Resistor, 100 ohms, 20 w, adjustable.
R8 Resistor, 5 ohms, 20 w, adjustable.
R9 Resistor, 25 ohms, 20 w, adjustable.

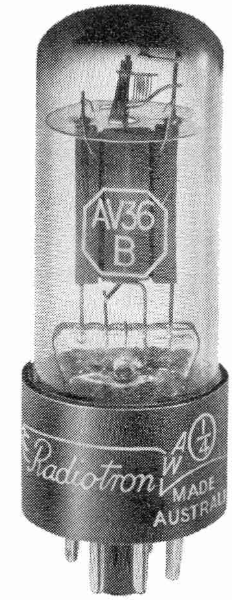
† Typical value. Absolute value dependent on magnetising current of T. See text.

ZENER DIODES

(Continued from page 259)

operation. For one thing the designer's problem is simplified in that a continuously-varying dc operating voltage is converted in effect to a series of steps. Furthermore, operation and release currents of the individual relays offer less problems in that it is easy to arrange the associated diode to pass ample current once the zener voltage is reached, and the relay will of course operate and release at the same applied voltage.

Other applications which come to mind are dc inter-stage coupling devices in amplifiers, temperature-sensing devices, gating devices and protection devices. The zener diode is particularly useful in protecting meters. It is interesting to note that when the zener diode first appeared it was referred to by some as the "backward diode", because it is always connected so that the applied voltage is a reverse voltage. It is obvious however that in other respects this small, light, hardy device is anything but "backward", and is destined to go even further "forward" in versatility and usefulness.



AV36B

Tungsten Filament

Control Diode

DESCRIPTION

Type AV36B is a control diode intended for use in ac regulator circuits. Besides retaining the plate-to-filament short circuiting feature it is designed to give more reliable operation, superseding the AV36A in most applications. A new feature is the larger-diameter filament as compared to its predecessor; consequently the response time is slightly greater and the filament current is higher for the same operating voltage. However the advantages are greater stability and resistance to burnout, mechanical vibration and shock, and longer life expectation.

As regards operation, the AV36B directly replaces the AV36A provided the necessary adjustments are made to the series filament resistor. If any trouble is experienced in making this substitution the user should contact the equipment manufacturer for further advice.

GENERAL DATA

Mechanical:

Mounting position	Any
Overall length	$3\frac{3}{4}''$ max
Seated height	$3\frac{1}{8}''$ max
Diameter	$1\frac{1}{4}''$ max
Bulb	T9
Base	Intermediate Octal, 7 pin

Maximum Ratings:

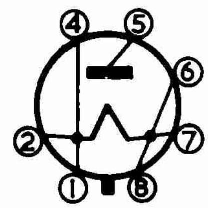
Filament voltage (ac or dc)	3.0 volts
Filament current	2.2 amps
DC plate voltage	250 volts

Typical Operation:

AC filament voltage	2.5 volts
AC filament current	2.0 amps
DC plate voltage	100 volts
DC plate current	3.5 ma

Socket Connections:

(Bottom View)



Pins 1, 2 and 4 Filament
Pin 5 Plate
Pins 6, 7 and 8 Filament

To reduce contact resistance each end of the filament is brought out to three base pins, all of which should be used.

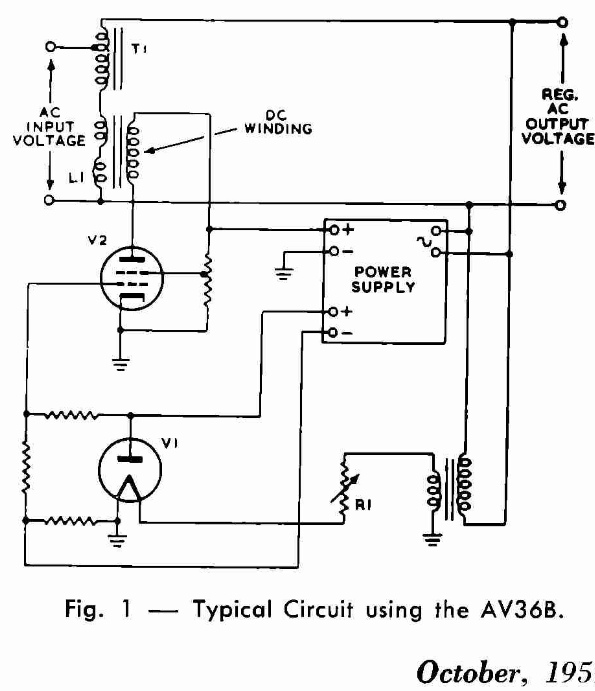


Fig. 1 — Typical Circuit using the AV36B.

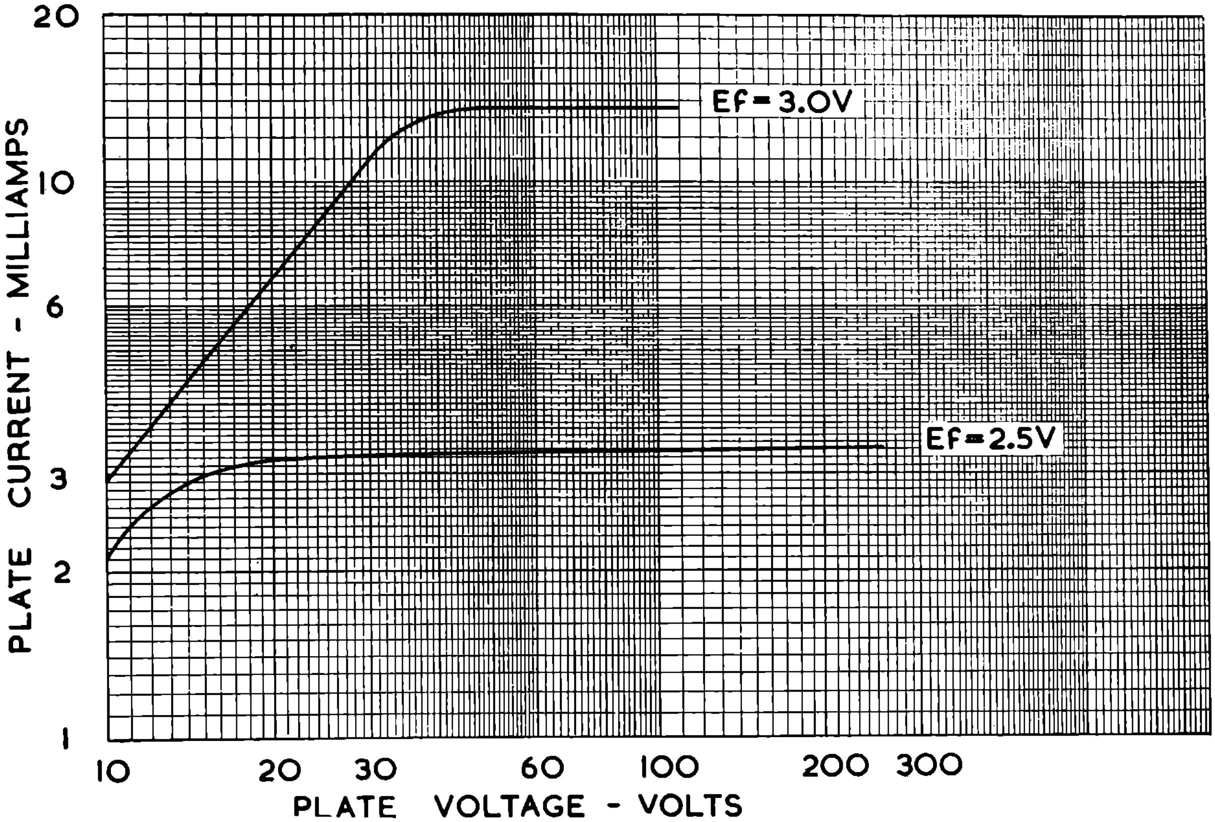


Fig. 2 — Plate Voltage/Plate Current Characteristic of the AV36B.

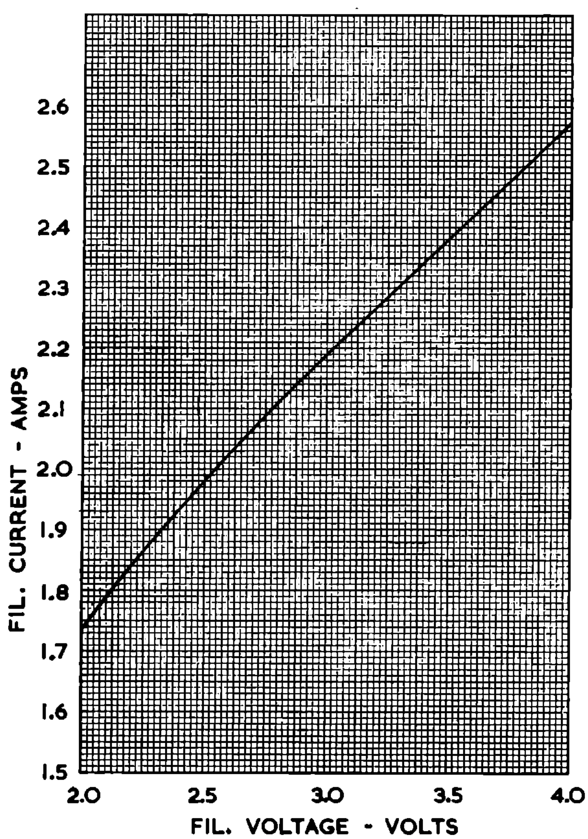


Fig. 3 — Filament Voltage/Filament Current Characteristic of the AV36B.

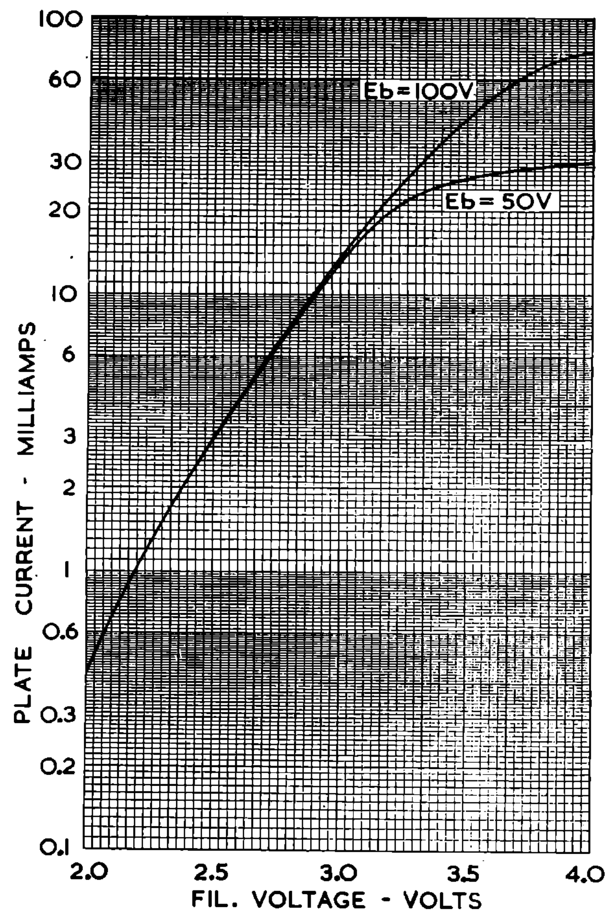


Fig. 4 — Filament Voltage/Plate Current Characteristic of the AV36B.

APPLICATION DATA

AC voltage regulators generally include a sensing element which detects voltage deviations from the desired output voltage. The output of this sensing element is, after amplification, applied at some point in the circuit to minimize the initial deviation, so returning the output to the correct value.

Temperature-limited diodes having a pure tungsten filament are very satisfactory sensing elements because of their rapid change of saturated plate current with changing filament voltage. A typical example is shown in Fig. 1.

If the filament of an ordinary control diode open-circuits, so causing its plate current to vanish, it can be seen from the above explanation that the output voltage must rise to the maximum extent allowed by T1. This is very undesirable in certain applications and, in the AV36B control diode, is avoided. The built-in switch shorts the plate-to-filament automatically when the filament opens so causing the output voltage to drop to the lowest extent allowed by T1. No damage due to excessive regulator voltage can thus occur.

Typical regulators of this type will maintain the output voltage accurately to 0.5% or better over a wide range in load current, and input voltage variations. The AV36B is insensitive to frequency changes.

NEW PUBLICATIONS

(Continued from page 270)

has reached the "Circuits" stage, and for the serviceman and technician wishing to extend his technical horizon. The book is of course based on English practice, but the minor differences will not worry the Australian student at this stage.

"Principles of Transistor Circuits", S. W. Amos, Iliffe and Sons Ltd., 8vo, 167pp.

The subtitle of this new book is "Introduction to the Design of Amplifiers, Receivers and Other Circuits". The author is well known as a member of the Engineering Training Department of the BBC, and the latest work is intended for professional designers, students and amateur constructors. Assuming no previous knowledge of the subject, it devotes the first two chapters to explaining the physical processes occurring in transistors. Subsequently the main emphasis is on the application of these principles to the practical problems of design.

A large number of worked examples is included, the mathematics of which is confined to simple algebraic manipulation. These show the order of the practical magnitude of the various quantities. Although the design of amplifiers and receivers is given the greatest prominence, some details are also included of photo-sensitive devices, transistor relaxation oscillators, and the newer types of transistors.

There have been a large number of books published recently dealing with transistor principles, and selection is difficult. This present volume is outstanding however for the clarity of the treatment and the concise, direct approach. A book from which the serious student could derive much benefit.

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