TRIODES FOR VERY SHORT WAVES—OSCILLATORS*

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(*The paper was first received* 21*st February, and in revised form* 16*th May*, 1946.)

SUMMARY

Section 1 of the paper deals with the excitation of triode oscillators. The limitations of conventional circuits are discussed and it is shown that the progress in the design of oscillators for very short waves has been mainly due to the reduction of electron transit time and the reduction in the inductance and h.f. resistance of the leads to the electrodes.

The electron transit time has been reduced in two ways, (*a*) by the use of very small inter-electrode spacings—in some types the grid-cathode spacing is between 0·08 mm and 0·1 mm, and (*b*) by increasing the space current density—values as high as 5 amp/cm^2 have been employed under pulse conditions.

Electrode-lead inductance has been reduced considerably by the use of disc seals and other forms of glass-metal joints, whereby the valve becomes an integral part of the circuit.

In general, h.f. oscillators and amplifiers have two adjustable circuit elements, one electrode being common to the two circuits, and another being earthed. Five types of circuit have been used, but the most important are

(*a*) Common-anode earthed-anode using a CV52, VT90, NT99, CV55 or CV240 valve.

(*b*) Common-grid earthed-anode using a CV90, CV153 or CV273 valve.

(*c*) Common-grid earthed-grid using a CV16, CV53, CV88, CV257 or CV288 valve.

(*a*) and (*b*) have been the most commonly used for oscillators, and (*c*) for amplifiers.

Section 2 describes the evolution of transmitting triodes for radar, and of local oscillators for reception. Most of the valves are of metal-glass construction, and several types are described to illustrate the new techniques employed. The anode usually forms the metal component of the glass-metal seal, giving low inductance and good cooling. The grid is mounted directly either on a disc seal or on a copper thimble. The electrode seals are designed so that the valve can be plugged directly into a coaxial-line circuit.

Oxide-coated cathodes are used in all the later designs, including transmitting valves operating at a pulsed anode voltage of 15 kV and a peak input of 500 kW.

Some typical valves are the common-anode transmitting valve NT99—a pair giving 200 kW at 600 Mc/s, the common-grid transmitting valve CV288—a pair giving 100 kW at 1 000 Mc/s, the common-grid receiving valve CV273—giving 4 to 5 watts at 1 000 Mc/s and 0·5 watt at 3 000 Mc/s.

Section 3 summarizes some of the problems associated with testing and specifications.

(1) THEORY

(1.1) Introduction

Oscillation generators and amplifiers for frequencies greater than a few hundred megacycles per second may be divided into two broad but fairly well defined classes, those which make use of finite electron transit-time and those whose performance is adversely affected by the electron transit time. Magnetrons, positive grid triodes and velocity-modulation valves are examples of the first class, in which the electrons describe paths in times which are comparable with the period of the h.f. oscillation. Negative grid valves are the main representatives of the second class, in which one essential design problem is the reduction of the electron transit-time to a sufficiently small fraction of the period. For operation at very high frequencies the negative grid valve is obviously at a disadvantage. However, the frequency range for efficient use of the first class is restricted by the necessity for critical transit times. In addition, the modern triode oscillator is simple in operation, and for many purposes it still remains first choice at frequencies up to a few thousand megacycles per second.

Although it has been necessary to pay due attention to the reduction of electron transit-times, most of the progress in recent years has arisen from a better understanding of the valves as circuit elements. This understanding, together with the new technique for handling combinations of glass and metal, has led to valves which bear little resemblance to their predecessors of ten years ago, but which frequently operate in a simpler and more controllable manner.

Section 1 of this paper considers the theoretical foundation which has been the basis of triode design during the war; Section 2 describes and illustrates some of the new techniques which have enabled the theoretical requirements to be met, and by which several distinct series of novel types of valves have been made.

(1.2) Transit-Time Considerations

There are two effects of finite electron transit-time which are particularly troublesome at very high frequencies. These are (*a*) the introduction of a phase angle into the mutual conductance and (*b*) an increase of the input conductance. These effects have been dealt with before[1, 2, 3] and are not considered further in this paper. It may be noted in passing that they cause a reduction in the efficiency of operation.

The factors determining transit time are the inter-electrode spacings, the electrode voltages and the space-current density. The need for high cathode-emission density is not widely appreciated, but can be fairly easily understood. Reasonable operation requires that the electron transit-time should be a sufficiently small fraction of the period of oscillation. A large part of this transit time is occupied in traversing the grid-cathode space, where the current is limited by space charge; this time is given by

$$T = 6 \cdot 6 \times 10^{-10}(d/\iota)^{\frac{1}{3}} \text{ sec}$$

where ι is the current density in amp/cm^2 and d is the grid-cathode distance in cm.

The maximum frequency of oscillation will be attained when the electron transit-time becomes a certain fraction of the period of oscillation. If this fraction is $1/n$ of a period, then the maximum frequency will be given by

$$1/f = n \times 6 \cdot 6 \times 10^{-10}(d/\iota)^{\frac{1}{3}} \text{ sec} \quad . \quad . \quad . \quad (1)$$

If the frequency is to be increased, then either d must be decreased or ι must be increased. In the latter case, the cathode emission must be increased if space-charge limitation is to be maintained. The ways in which small inter-electrode spacings have been achieved are described in Section 2.

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Transit-time limitations are eased to a large extent in radar transmitters which work under pulsed conditions. The high pulsed voltages give low transit times, and since the mark/space ratio is 1 : 1 000 or less, there is no likelihood of an excessive dissipation.

(1.3) Circuit Limitation Considerations

(1.3.1) Frequency Limitation.

In Fig. 1, the inter-electrode capacitances and the lead inductances of a triode are shown. It will be obvious that the maximum frequency of oscillation of this triode will be that at

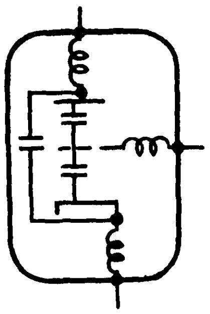


Fig. 1.—Inter-electrode capacitances and lead inductances of a triode.

which these inductances and capacitances resonate together, and at this frequency the whole of the oscillatory circuit is inside the valve envelope. It has previously been shown[3,4] that a considerable improvement in performance can be effected by making the electrodes and their leads parts of transmission lines which are continued through the envelope of the valve to the external circuits. In particular, there are real advantages in arranging the electrodes and leads as integral parts of coaxial line circuits. Such an arrangement is illustrated in Fig. 2, where a triode and

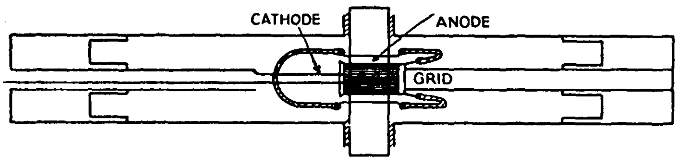


Fig. 2.—Common-anode earthed-anode oscillator.

its circuit are shown. The grid lead is continued through the envelope at one end to form part of the inner conductor of a co-axial line, the anode forming part of the outer conductor. Similarly the cathode and the anode form respectively parts of the inner and outer conductors of a second co-axial line at the other end of the valve. These coaxial lines act as reactances which, in conjunction with the valve capacitances, provide the necessary oscillatory circuit. Such an arrangement will considerably extend the frequency range of a given electrode system.[3]

The length of line having the required reactance may be so short that it does not project outside the valve envelope; in many cases, satisfactory operation may be restored by lengthening the line by half a wavelength or by several half wavelengths, which does not alter its reactance. This expedient is sometimes unsuccessful, since the valve may oscillate at a longer wavelength corresponding to the fundamental mode for the new circuit length. Usually, as in Fig. 2, there are two adjustable lines and if a different number of half wavelengths be added to the two circuits there is less tendency for oscillation at a longer wavelength.

(1.3.2) Excitation of Triode Oscillators.

Before proceeding to a modern triode oscillator, the limitations of the more conventional types will be considered. The essential

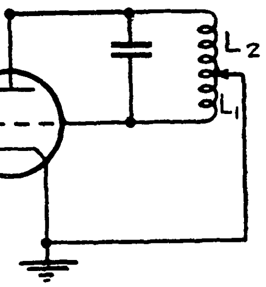


Fig. 3(a).—Hartley oscillator.

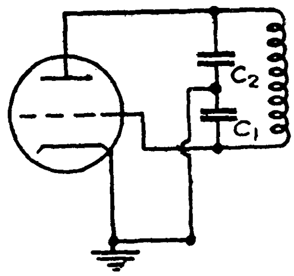


Fig. 3(b).—Colpitts oscillator.

r.f. portions of the Hartley and the Colpitts oscillators are shown in Fig. 3 (*a*) and (*b*). In the former, the grid voltage (the "excitation") is determined by the relative magnitudes of the two inductances L_1 and L_2. In the Colpitts circuit, the excitation is determined by the values of C_1 and C_2. In these two circuits the cathode is assumed to be at earth potential and the susceptances of the valve capacitances and lead inductances to be negligible. These assumptions are quite justified at low frequencies, but at higher frequencies they cannot be maintained. A Hartley circuit taking account of these factors is shown in Fig. 4; C_1, C_2 and C_3

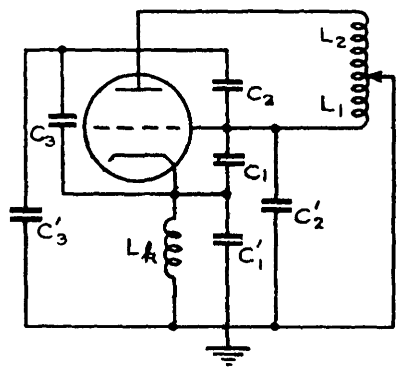
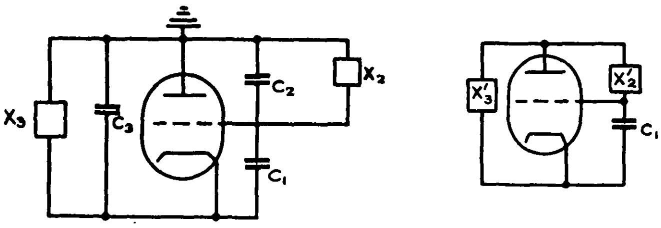


Fig. 4.—Modified Hartley circuit for u.h.f.

are the inter-electrode capacitances; C_1', C_2' and C_3' are the electrode-earth capacitances; L_k is the inductance of the cathode lead (the anode and grid lead inductances are assumed to be included in the external circuit). It can now be seen that the excitation will depend in a most complicated way on the ratio $L_2 : L_1$, on C_1, C_2, C_3, C_1', C_2', C_3' and L_k, and on any stray couplings between the various parts of the circuit. Similar complications obviously arise with a Colpitts circuit.

It will be seen that some of the trouble has been caused by the inductance of the cathode lead, which prevents the cathode from being at earth potential; in some modern designs the cathode lead inductance has been greatly decreased, in spite of the practical difficulties. The cathode itself must be maintained at a temperature of 700° C or more, but the lead through the glass envelope must not be at much more than 200° C. To obtain this temperature drop there must be appreciable lead length. However, there is no reason why the cathode should be earthed, and the circuits of Fig. 3 will operate equally well with any other point earthed. In the circuit for the CV55 shown in Fig. 2, the anode is earthed, and the electrode-earth capacitances and stray couplings have also been eliminated. The equivalent circuit is shown in Fig. 5(*a*) where X_2 and X_3 represent the



(*a*) (*b*)

Fig. 5.—Equivalent oscillator circuits.

(*a*) Equivalent circuit of Fig. 2.
(*b*) Equivalent circuit of Fig. 5(*a*).

anode-grid and cathode-grid reactances provided by the line circuits. The inter-electrode capacitances C_2 and C_3 are in parallel with the line circuits and may therefore be lumped with them, giving the arrangement of Fig. 5(*b*). This is extremely simple and yet is a close approximation to the actual conditions. If X'_2 be considered as the main oscillatory circuit, then the excitation may be adjusted by variation of X'_3. The whole arrangement has become very similar to the l.f. Colpitts circuit of Fig. 3(*b*), and the relative values of the anode and grid voltage will be given numerically by

$$V_g : V_a :: 1/\omega C_1 : X'_3$$

If X'_3 is capacitive, so that $X'_3 = 1/\omega C_3$, then

$$V_g : V_a :: C_3 : C_1$$

For oscillation to take place, the grid voltage amplitude must be at least $1/\mu$ of the anode voltage amplitude, where μ is the amplification factor, so that the condition for oscillation is

$$C_3/C_1 > 1/\mu \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

By adjusting the cathode line, this condition can be achieved.

Before considering some of the other modern circuits the conditions for oscillation will be examined more closely.

(1.4) Theory of the Triode Oscillator

In order to maintain an oscillating current in a tuned circuit, energy must be supplied to the circuit to overcome the resistive losses. In this condition the system behaves as if it had a zero or negative resistance, and an oscillation, once started, persists. Thus a convenient criterion for oscillation is that the effective resistance should be zero or negative.

In the triode circuit of Fig. 6, Y_1, Y_2 and Y_3 are the total

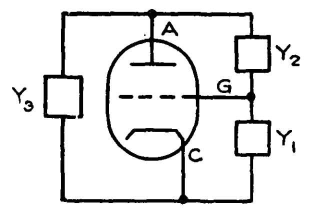


Fig. 6.—Triode admittances.

admittances between the various electrodes. The condition for oscillation is obtained by calculating the effective admittance between any pair of electrodes and inserting the condition that the real part of this admittance should be zero or negative.

It can be shown that the effective admittance Y'_2 between the points A and G is given by

$$Y'_2 = Y_2 + \frac{Y_1Y_3}{Y_1 + Y_3 + g_m} = \frac{Y_1Y_2 + Y_1Y_3 + Y_2Y_3 + Y_2g_m}{Y_1 + Y_3 + g_m} \quad (3)$$

where g_m is the mutual conductance.

In general, the Y's will be complex, so that they may be written in the form $Y = G + jB$; by substituting such expressions for all the Y's in equation (3) and equating the real parts it can be shown that

$$G'_2 = G_2 + \frac{G_1G_3(G_1 + G_3 + g_m) + G_3B_1^2 + G_1B_3^2 - g_mB_1B_3}{(G_1 + G_3 + g_m)^2 + (B_1 + B_3)^2} \quad . \quad . \quad . \quad (4)$$

This expression gives the conductance between the anode and the grid in terms of the circuit parameters, and for self oscillation G'_2 must be negative. Now all the conductances are necessarily positive (transit-time effects are neglected), so that the only term in the numerator of (4) which can be negative is $-g_mB_1B_3$; B_1 and B_3 must therefore be of the same sign, i.e. both must be capacitive or both inductive. Similarly, it emerges from the formula for G'_3 that, for oscillation, B_2 must be of opposite sign to B_1. Thus there are two, and only two, ways of adjusting the circuits attached to a triode so that oscillation takes place The two ways are shown in Table 1.

Table 1

Types of Triode Oscillator

	B_1	B_2	B_3
Class I	+ (C)	− (L)	+ (C)
Class II	− (L)	+ (C)	− (L)

Mutual-inductance coupling has not been considered, since it becomes increasingly difficult to realize at higher frequencies.

(1.5) Relative Merits of the Two Classes of Oscillator

It can be shown that Class I is definitely preferable to Class II for operation at very high frequencies.

Let it be assumed that the oscillators have two tunable circuits. In Class I, one of these must be connected in parallel with the anode-grid capacitance to make B_2 inductive. The other may be connected between grid and cathode or between anode and cathode; in the former case, the circuit may be drawn as in Fig. 7(*a*), in which C_1, C_2 and C_3 are inter-electrode capa-

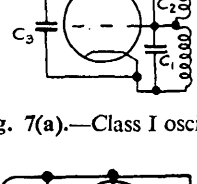


Fig. 7(a).—Class I oscillator.

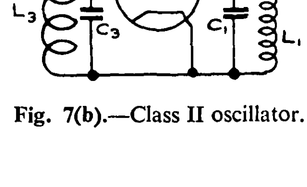


Fig. 7(b).—Class II oscillator.

citances and L_1 and L_2 the external circuits. In accordance with Table 1, B_1 must be capacitive, and this capacitance in series with C_3 gives a resultant less than C_3. Thus it can be seen that the frequency of oscillation is determined by the external inductance L_2 tuned to resonance by the parallel combination of C_2 and some capacitance less than C_3.

In the Class II oscillator, the external circuits must be connected between grid and cathode and between anode and cathode to make B_1 and B_3 inductive [see Fig. 7(*b*)]. The inductive B_1, in series with C_2 gives a resultant capacitance which is greater than C_2 (the combination cannot be inductive since B_3 is inductive). The frequency in this case is determined by the external inductance L_3 tuned to resonance by the parallel combination of C_3 and a capacitance greater than C_2. If this result be compared with that at the end of the last paragraph, it will be seen that for a given external circuit a valve will oscillate at a higher frequency if connected for Class I operation. This conclusion has been verified experimentally (see Section 1.8.2), and it is generally true that for operation at very high frequencies triode oscillators should have an inductance between anode and grid and capacitances between anode and cathode and between grid and cathode.

It may be noted that the Class II oscillator is the familiar tuned-anode tuned-grid oscillator.

(1.6) Circuit with Negligible Losses

When the circuit elements are tuned lines, very high impedances can be realized and it is interesting to discuss the conditions for oscillation when the circuit conductances are small enough to be neglected in comparison with the other parameters.

If in equation (4) $G_2 = G_1 = 0$, $G_3 = g_a (= 1/R_a$, where R_a is the valve anode resistance) then

$$G_2' = \frac{g_a B_1^2 - g_m B_1 B_3}{(g_a + g_m)^2 + (B_1 + B_3)^2}$$

for oscillation,

$$g_m B_1 B_3 > g_a B_1^2$$

and since

$$g_m = \mu g_a$$

$$\mu B_3 > B_1$$

or

$$B_3/B_1 > 1/\mu$$

If $B_3 = \omega C_3$ and $B_1 = \omega C_1$, the condition for oscillation is $C_3/C_1 > 1/\mu$, which is the simple condition already derived in equation (2).

(1.7) Variation of Effective Valve Conductance with Circuit Susceptance

The effective conductance G_2' between anode and grid is given by (4); it consists of two parts, (*a*) the conductance G_2 of the anode-grid circuit and (*b*) the effective output conductance G_0 of the valve, where G_0 represents the second term in (4).

In a Class I oscillator, one of the susceptances B_1 or B_3 is variable, the other being pre-set.

In order to illustrate the way in which the effective conductance varies with B_1 and B_3, values of G_0 have been calculated (see Fig. 8) for a valve in which $g_m = 5$ milliamp/volt, $\mu = 25$, $G_3 = g_a = 2 \times 10^{-4}$ mho and $G_1 = 10^{-3}$ mho. ($B = 0 \cdot 002$ will correspond to a capacitance of $0 \cdot 1$ $\mu\mu$F at a wavelength of $9 \cdot 4$ cm and to 1 $\mu\mu$F at 94 cm.)

It will be seen that as B_1 is increased from zero with B_3 constant, G_0 decreases from an initial positive value, through zero, to a maximum negative value, and then returns to a positive value.

The valve will oscillate if the magnitude of the negative conductance G_0 is greater than the circuit conductance G_2. If, for

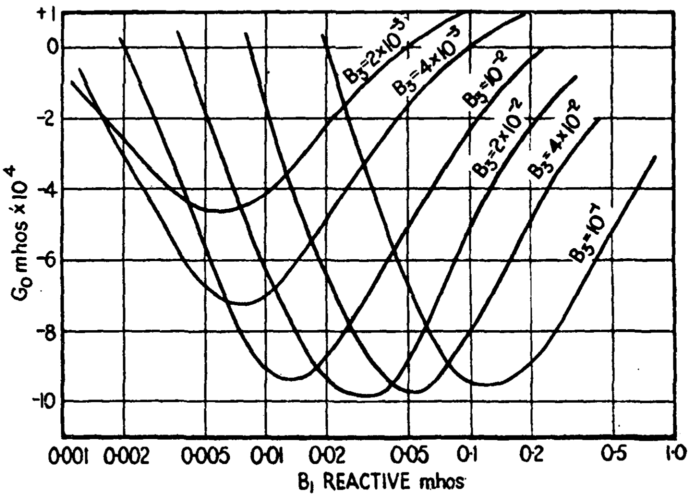


Fig. 8.—Variation of effective grid-anode conductance of a triode.

example, $G_2 = 5 \times 10^{-4}$ mho, oscillation will not take place for $B_3 = 2 \times 10^{-3}$, but the valve can be made to oscillate for all other values of B_3 shown.

As B_3 is increased, the value of B_1 for maximum negative conductance increases, so that the effective susceptance (and therefore capacitance) between anode and grid is increased. A shorter circuit will therefore be needed between anode and grid to obtain oscillation at the same frequency. The optimum value of susceptance may therefore not be the value giving the maximum negative conductance, but will probably be some smaller value.

(1.8) Application of the Theory to Oscillator Design

It has so far been assumed that the triode is a three-terminal network. If this simple form is to be realized in practice, one of the electrodes must be earthed, since otherwise a fourth terminal would be needed at earth potential. Again, if the simple circuit of the theory is to be realized, there must be no mutual inductance coupling between the circuits; this necessitates effective screening. Coaxial-line circuits meet these requirements, since the high frequency field is confined inside the outer conductor; for the same reason, radiation losses are eliminated with such circuits.

In order to tune an oscillator over a frequency band, and at the same time to obtain optimum excitation conditions, it is advisable to have two of the circuit elements adjustable.

In this case, the circuit will consist of a pair of coaxial lines, as in Fig. 2, in which one electrode of the triode is common to both lines. One electrode will also be at h.f. earth potential.* This electrode is frequently, but not universally, the one which is common to both lines. It is therefore convenient to classify oscillator circuits with reference to the common electrode and the earthed electrode.

Five types of triode circuit have been employed as h.f. oscillators, some with more success than others:

(*a*) Common-anode earthed-anode.
(*b*) Common-grid earthed-grid.
(*c*) Common-cathode earthed-cathode.
(*d*) Common-grid earthed-anode.
(*e*) Common-grid earthed-cathode.

(1.8.1) Common-Anode Earthed-Anode Oscillator Valves (see Fig. 2).

Valves which have been designed for use in this circuit are the CV52 and CV78 and the "micropup" series VT90, NT93, NT99, CV55, CV155, CV240.

* Where "at earth potential" or "earthy" is used to describe any electrode or conductor, it means that no lines of the high-frequency field terminate on its outer surface.

In this circuit, the grid-anode line in parallel with C_2 provides the inductive susceptance B_2, the cathode-anode line together with C_3 provides the susceptance B_3, and the grid-cathode capacitance provides B_1. Here B_1 is fixed and B_3 can be adjusted to any value between $-\infty$ and $+\infty$. It has already been shown that B_1 must be capacitive, and that it has an optimum value.

The frequency of oscillation will be determined by the valve capacitances and the two line lengths. The anode-cathode line, however, is part of a susceptance which is in series with the capacitance C_1, and this line has therefore less effect on the frequency than has the anode-grid line. For this reason it is convenient to consider the anode-grid line as the frequency control and the other line as the excitation control.

In practice, many of the "micropup" valves have been used in push-pull circuits. The principles of operation are the same as for the single valve circuit, but in the push-pull arrangement the two anodes are strapped together and parallel wire circuits are connected to the two grids and to the two cathodes.

(1.8.2) **Common-Cathode Earthed-Cathode Oscillator Valves** (see Fig. 9).

In order to realize this arrangement, a cylindrical triode was constructed with an external cathode; a cylindrical cathode lead was taken out at each end of the envelope, and these formed

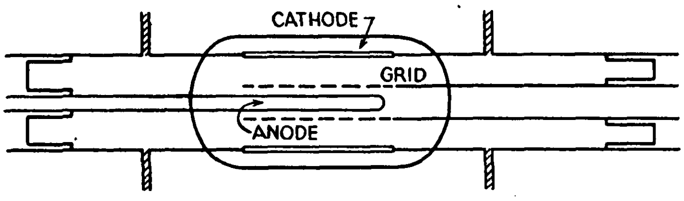


Fig. 9.—Common-cathode earthed-cathode oscillator.

parts of the outer conductors of two coaxial lines. The grid and anode leads were brought out at opposite ends, and one of them formed part of the inner conductor of each line. The performance of this oscillator confirmed the conclusions of Section (1.5). It was found that, for a given wavelength, the circuits were much shorter than for valves in different circuit arrangements with similar capacitances and lead inductances. In addition, the efficiency was low.

(1.8.3) **Common-Grid Earthed-Grid Oscillator Valves** (see Fig. 10).

This circuit has been used with the S27A (CV82) and the E1344, CV257 and CV288. In this case, the grid-anode line determines the frequency and the grid-cathode line controls the excitation.

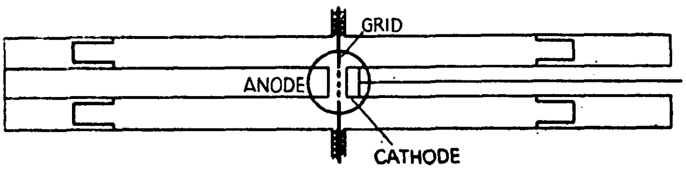


Fig. 10.—Common-grid earthed-grid oscillator.

The fixed susceptance in this case is B_3, which is provided by the anode-cathode capacitance. (In the case of the common-anode oscillator the fixed susceptance was B_1, the grid-cathode capacitance.) In most valves, the anode-cathode capacitance is less than the grid-cathode capacitance, and the former can be reduced to a very low value by suitable design. Now the excitation of the oscillation depends largely on the ratio B_1/B_3. It follows therefore that the total effective circuit capacitance will be less when B_3 is fixed and B_1 is adjusted than conversely. Hence higher frequencies can be obtained with common-grid valves than with common-anode valves.

The common-anode earthed-anode arrangement is capable of greater power dissipation than the common-grid earthed-grid circuit, since in the latter cooling of the anode is more difficult, particularly without the provision of forced cooling.

The common-grid earthed-anode oscillator which is described in the next Section combines the virtues of the h.f. performance of the common-grid type with the high-power performance of the earthed-anode type.

(1.8.4) **Common-Grid Earthed-Anode Oscillator Valves** (see Fig. 11).

The CV90, CV273, CV290 and E1274 valves have been designed for this arrangement. In this case there are again two coaxial

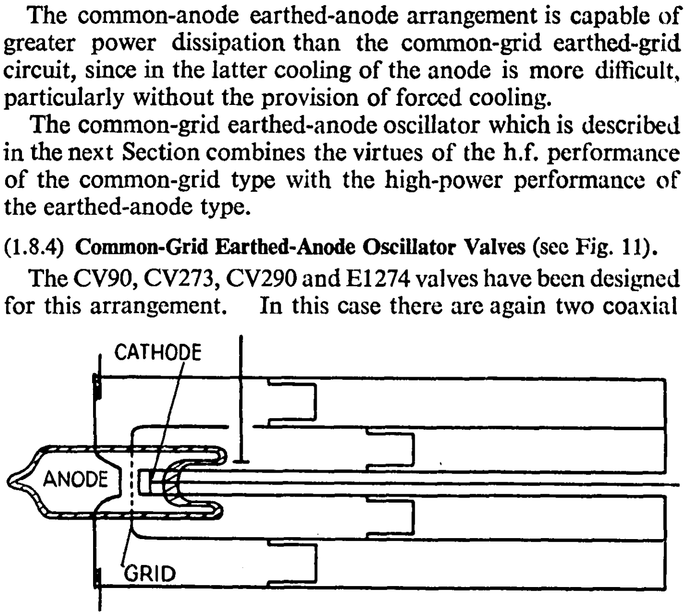


Fig. 11.—Common-grid earthed-anode oscillator using CV90 valve.

lines, the grid conductor acting as the inner member of the anode-grid line and as the outer member of the grid-cathode line. The former is the main frequency control. The anode is now the outermost electrode and can therefore readily be cooled; this increases the power capabilities.

In the previous Section the advantages of a low value of C_3 were mentioned. It is of course possible to have C_3, and therefore B_3, too small to give oscillation (see Section 1.7). In the CV90 construction, the direct anode-cathode capacitance is only about $0{\cdot}02\ \mu\mu$F, and it has been found necessary to increase this artificially by attaching two wires to the cathode which protrude through holes in the grid. For any particular frequency there is an optimum value of this capacitance, but the value is not critical (as can be seen from Fig. 7) and $0{\cdot}07\ \mu\mu$F has been found to be a good compromise for c.w. working over the range 1 000–3 000 Mc/s. In the region of 3 000 Mc/s, however, the performance deteriorates rapidly, partly due to the fact that the wires are attached to the cathode system at a distance of 5 mm from the cathode face and are therefore, at this frequency, very near to the first voltage node on the cathode line.

It is possible to improve the performance of this type of valve at the highest frequencies by applying the feedback between the two circuits by means of a probe outside the valve, as shown in Fig. 11, instead of inside the valve as in the CV90. The probe is attached to the outer member of the coaxial line, passes through a hole in the intermediate member and forms a capacitance with the inner line. If the probe is made in the form of a threaded rod, it can be adjusted to its optimum position while the valve is operating. Its position along the line, however, must be chosen so as to avoid a voltage node on either circuit.

When a valve is operated under pulse conditions, the currents, and therefore the valve conductances, are an order of magnitude higher than in continuous working. Because of this, the optimum anode-cathode capacitance is greater, the ratio for a CV90 valve being about four to one. If the feedback capacitance is too low, under pulse conditions, the oscillations take too long to build up.

(1.8.5) **Common-Grid Earthed-Cathode Oscillator Valves** (see Fig. 12).

The main representatives of this class are the valves of the American "lighthouse" series, such as the ZP446. This type of circuit has the good frequency performance of the other common-

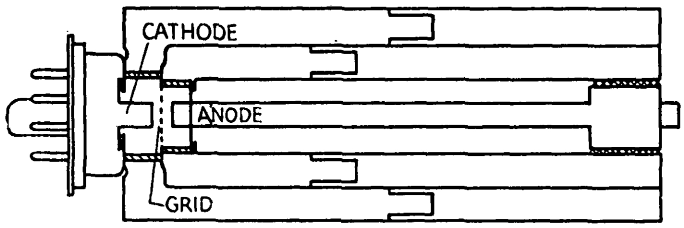


Fig. 12.—Common-grid earthed-cathode oscillator using ZP446 valve.

grid types, but it is not so readily suited to anode cooling as the earthed-anode types.

(2) DESIGN, CONSTRUCTION AND PERFORMANCE

(2.1) Introduction

It will be clear from the preceding section that, in considering the design of valves for operation at frequencies greater than a few hundred megacycles per second, the valves themselves cannot be considered independently of the circuits in which they are to operate. It is therefore convenient in describing the new valves which have been made to meet the requirements of the previous section, to classify them according to the type of circuit in which they are used. Of the five types of circuits listed in Section 1.8, only the common-anode earthed-anode, common-grid earthed-grid and common-grid earthed-anode types are in common use, and the valves used in them are described below.

(2.2) Common-Anode Earthed-Anode Oscillator Valves

(2.2.1) Construction.

The general form of construction adopted for transmitting valves of this class is shown in Fig. 13. It consists of an outer

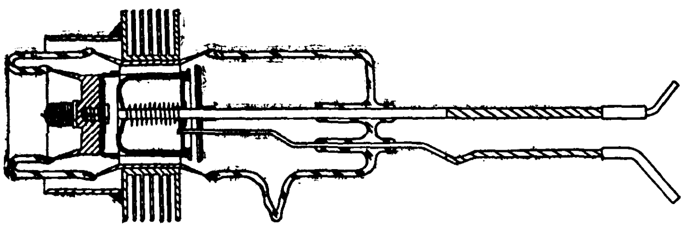


Fig. 13.—Section through NT99 triode.

cylindrical anode with fins attached for air cooling. This copper anode forms part of the envelope, and to each end of it is sealed a short length of glass tubing. The grid is rigidly mounted on a glass-metal seal at one end, and the filament or cathode is supported from the other end. The construction gives a geometrical arrangement which is suitable for use with coaxial lines.

(2.2.2) History.

The first valve designed along these lines specifically for pulse operation was made in 1939; it was known as the "Micropup," and later as the VT90. Valves for pulse operation must withstand a high anode voltage and pass a large anode current during the pulse, which is usually of a few microseconds' duration. However, since the off-period/on-period ratio is usually greater than 500 : 1, the mean dissipation at the electrodes is small.

The micropup in its original form operated at frequencies up to 600 Mc/s. The upper limit of frequency of the VT90 itself, however, was limited to about 300 Mc/s, because the length of glass between the anode and grid seals had to be great enough to avoid flash-over at high altitudes when used at the full anode voltage in airborne equipment.

To increase the power output from this class of valve without simultaneously reducing its maximum frequency, the principle of radial enlargement was adopted. Thus, by increasing the diameter of the electrodes whilst keeping their lengths and spacings the same, a series of valves of ever increasing output was developed. In this way, the power output at 600 Mc/s was increased from about 5 kW given by a pair of the original micropups to some 400 kW given by a pair of the largest experimental valves of the series. All these valves were used in concentric line circuits, and care had to be taken to arrange that the electrodes, particularly the grid and anode, and their seals, formed a smooth continuation of the external circuit without any abrupt change in characteristic impedance. The inter-electrode capacitances increased with the radius, and the characteristic impedance of the tuned lines had therefore to be reduced. This was important from the point of view of grid-seal design.

(2.2.3) Anodes.

The anode design remained unaltered throughout the whole of the "micropup" series. It consists of a short length of copper tube, flared and feather-edged at both ends. The active portion varies in diameter from $\frac{1}{2}$ in in the smallest valve to 2 in in the largest. The copper-glass seals present no difficulty, but the glass must completely enclose the sharp edge of the copper; otherwise there is danger of discharge from this edge at the high anode voltages employed. The glass is a standard boro-silicate glass having a coefficient of linear expansion of $3 \cdot 7 \times 10^{-6}$/deg C.

(2.2.4) Grids.

In valves for pulse operation, where the mean power is usually small, grid emission does not present such a serious problem as in valves for c.w. use. Nevertheless, avoidance of grid emission is an important factor in grid design, particularly in valves with oxide coated cathodes, where the operating grid temperature must not appreciably exceed 300° C if grid emission is to be avoided. In the types of valve under consideration, cooling of the grid by thermal conduction has been found to be the best method of achieving this result. The alternative of cooling by radiation is often impracticable, because of the large surface area required to radiate the energy at such a low temperature; this would increase capacitances and would load the lines, thereby reducing the maximum frequency of operation.

When the grid is cooled by conduction, it must be in good thermal contact with its support or seal member, which in turn must be able to conduct the heat to the outside of the envelope where it can be removed, e.g. by a stream of air. It is also necessary for the grid wires themselves to be as short and thick as possible.

These considerations led to the adoption of the "squirrel cage" form of grid, consisting of a number of wires uniformly spaced around a cylinder, and attached to a narrow ring at the open end and to a shallow dish at the closed end. The grid wires are usually of molybdenum, because of its relatively high thermal conductivity and good mechanical properties, but the end ring and dish may be of nickel for ease of spot welding.

Grids of tantalum wire can sometimes be used to advantage in valves with thoriated-tungsten filaments. The gettering action of tantalum when properly pre-treated is useful, and the fact that the thermal conductivity is lower than for molybdenum is unimportant, since the temperature for the onset of grid emission is so much higher with the thoriated-tungsten filament.

In most of the valves, the grid is designed for an amplification factor of the order of 20. To avoid a long tail in the characteristics, it is desirable that the spacing between grid wires should not exceed the grid-cathode distance; the latter is determined by transit time considerations, and it is therefore often necessary to effect a compromise between the conflicting requirements of good thermal conductivity and good electrical characteristics. In the smaller grids, the wire diameter is 0·05 mm.

(2.2.5) **Filaments and Cathodes.**

Filaments of thoriated-tungsten wire were used in the early valves. The filament in the VT90 consisted of a single helix of thoriated-tungsten wire, 0·35 mm in diameter. Its rating was 8·25 volts, 7 amp, and it gave a peak emission of more than 5 amp. The radial enlargement principle mentioned earlier depends on the use of a larger filament to yield more power.

As the diameter of the filament spiral is increased, so the tendency to sag becomes greater. The stability of these larger diameter filaments was improved by using thicker wire and by reducing the length of wire in the spiral. The total filament area was increased by using a double instead of a single helix, which was possible because of the increased pitch. However, this type of filament could clearly not be enlarged indefinitely, and other forms had to be explored. A satisfactory construction, which was used in large numbers of experimental valves, consisted of a number of limbs, made in the form of zig-zags, uniformly spaced around a cylinder. The largest filament structure of this type was 20 mm long and 35 mm in diameter; it consumed 700 watts and gave an emission of over 100 amp.

At about this time, experimental pulse valves were being made with oxide-coated cathodes, in order to increase the emission still further. It was found that pulse-operating conditions were conducive to emission maintenance; in fact it was usual for the cathode emission to increase during operation. A change in operational technique was necessary, however, before valves with oxide-coated cathodes could be introduced. The thoriated-filament valves, being capable of withstanding high d.c. anode potentials, were usually grid-modulated in operation. Those with oxide-coated cathodes, however, would not withstand such high voltages because of their tendency to flash-arc, and it was therefore necessary to anode-modulate them. Application of anode voltage in pulses of a few microseconds' duration does not allow time for the flash arc to build up, and it is possible in this way to operate the oxide-coated valves at at least as high an anode voltage as their thoriated-tungsten counterparts.

When the oxide-coated cathode technique was proved by life tests to be satisfactory and reliable, several types of valve were designed to meet Service needs and to replace thoriated-filament valves already being developed.

In chronological order, these were the CV55, NT99, and CV240. Of these, the NT99, which is intermediate in size, has been the most widely used. Its cathode consists of a circular nickel cylinder, closed at both ends and heated by a central tungsten spiral. Only the cylindrical surface of the cathode is coated; the coated area is 8 cm^2, and the rejection emission limit is 40 amp. The cathodes in the other valves are similar in design and differ only in size.

(2.2.6) **Assembly.**

The same method of assembly is used for all the valves in this series. The final sealing operation in which a glass-glass joint has to be made whilst holding the cathode central within the grid may call for the highest accuracy. In the larger valves, where the grid-cathode clearance is of the order of one millimetre, the problem is not so difficult, but a very high degree of precision is necessary for example in the CV55, in which the clearance between the cathode coating and the inside of the grid wires is 0·15 mm.

The main steps in the assembly process are as follows. First, the anode and grid seals are glassed; this is done in a miniature glass lathe which ensures accuracy of alignment. Next, the glassed grid seal is sealed to one of the glass tubes. The grid seal must be accurately disposed with respect to the anode, both axially and radially, and this is assured by the use of suitable jigs. The metal-glass envelope is now complete. After chemical cleaning, the grid is fixed in position by screwing to the grid seal through a small hole in the centre of the dish at the closed end of the grid. There is no adjustment in this operation, hence the need for accuracy in sealing the grid seal to the envelope. The final operation is the sealing of the filament or cathode-heater assembly into the glass tube on the end of the anode remote from the grid seal. The filament or cathode-heater system is first mounted on two tungsten wires which pass through a glass button, or small flared pinch. The button is preferred because the glass does not project towards the hot region of the valve, and is therefore cooler. The method successfully adopted for holding the cathode accurately central within the grid during the sealing is shown in Fig. 14. Each component is mounted on the end of an

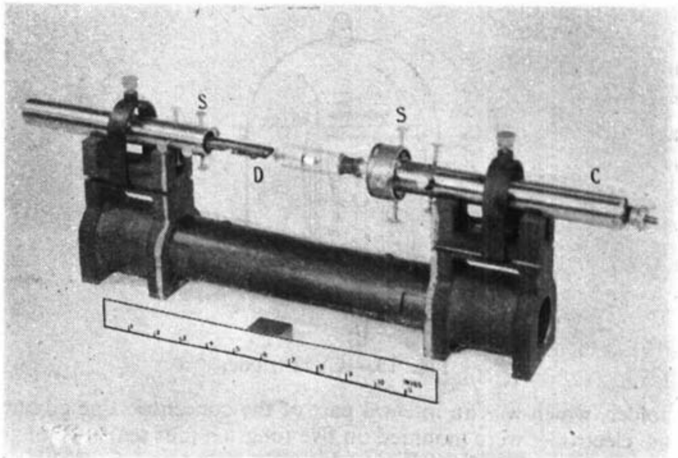


Fig. 14.—V-block centring arrangement.

accurately-ground steel mandrel C, both mandrels being of the same diameter. The glass-metal envelope containing the grid is mounted on its mandrel by means of the grid-seal. The cathode system is held by gripping the short tungsten support wires in a special clamp D. The cathode and grid are then adjusted by means of the screws S to lie accurately along the axis of their mandrels, an optical method being used to carry out this adjustment.

The two mandrels are then clamped in two V-grooves which have previously been scraped to give accurate alignment on a test-bar. The cathode is then gently inserted into the grid until it reaches the correct axial position, when the mandrel is clamped. The whole is then hung vertically, and the glass button is sealed to the glass tube without rotation by means of an oxy-coal-gas hand torch.

(2.2.7) **Performance.**

The performance under pulsed conditions of the various valves in this series is shown in Table 1. Only those types used in Service equipment are included.

(2.2.8) **The CV52.**

In the early days of the war, the only types of receiving valve suitable for use as h.f. local oscillators were the "acorn" triode and, later, the RL18. Both of these had an upper frequency limit of about 600 Mc/s, and it was clear that any improvement would necessitate following the procedure adopted in transmitting valves by designing a triode as part of the circuit. Several attempts were made with external (earthed) cathode designs, but were abandoned in favour of an earthed anode construction in the form finally adopted in the CV52 (Fig. 15).

In order that the valve might be plugged directly into its

Table 1

PERFORMANCE OF COMMON-ANODE EARTHED-ANODE OSCILLATOR VALVES

Type No.	Type of cathode*	Heater or filament voltage	Heater or filament current	Total emission, minimum	Anode voltage	Anode dissipation	Maximum frequency for useful output	Peak pulse r.f. output per pair
		volts	amp	amp	kilovolts	watts	Mc/s	kilowatts
VT90	Th	8·25	7·0	5·0	9·0	100	300	10
CV15	Th	3·25	6·75	1·75	4·0	1	300	1
NT93	Th	10·6	12·0	15·0	9·0	100	600	25
NT97	Th	11·0	12·25	17·5	9·0	100	300	30
NT99	Ox	6·0	6·5	40·0	12·0	150	600	200
CV55	Ox	6·3	2·7	20·0	4·5	50	1 200	40
CV240	Ox	6·0	17·0	125·0	15·0	1 000	100	500

* Th—Thoriated tungsten. Ox—Oxide-coated.

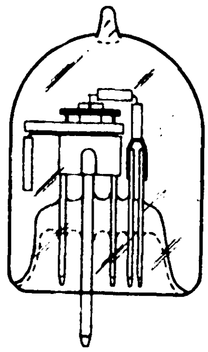


Fig. 15.—CV52 triode.

holder, which was an integral part of the concentric line circuit, the electrodes were mounted on five tungsten pins sealed through a re-entrant glass base, the grid pin being 2·5 mm in diameter and the two anode pins, the cathode pin and the heater pin each 1 mm in diameter.

(2.2.8.1) *Electrodes.*

The anode consists of a "monel" metal plate, 18 mm in diameter and 2 mm thick, pierced with an eccentric hole 5·76 mm in diameter; it is carbonized on its outer surfaces to increase thermal radiation. The squirrel-cage grid, similar to those used in the larger valves, consists of 60 molybdenum wires 0·05 mm in diameter on a pitch circle of diameter 4·95 mm, held between nickel bands 2·2 mm apart. The cathode is a nickel shell 2 mm long, coated on its cylindrical surface, the diameter (coated) being 4·72 mm, which leaves a grid-cathode clearance of 0·09 mm.

(2.2.8.2) *Assembly.*

Fig. 16 shows a plan and sectional elevation of the electrode system. The grid is mounted and welded on the thick tungsten pin, and the anode is welded to a flanged nickel shell fixed to the two anode pins. It is thus possible by means of a tubular spacing member to ensure that the anode and grid are accurately concentric. The cathode is fixed to a short thin-walled cylinder of nichrome (to reduce heat conduction), provided with a flange at one end which is sandwiched between two thin mica plates. These mica plates, provided with two accurately spaced holes which engage two short pins mounted on the anode, are held down on a castellated nickel ring also mounted on the anode. Thus the cathode is held concentric with the anode and grid without any insulating members directly between cathode and grid, which might provide a path for inter-electrode leakage. The lead connecting the cathode and one end of the heater to their pin is in the form of a U-shaped strip enclosing the second heater lead, to ensure that both leads are at the same h.f. potential.

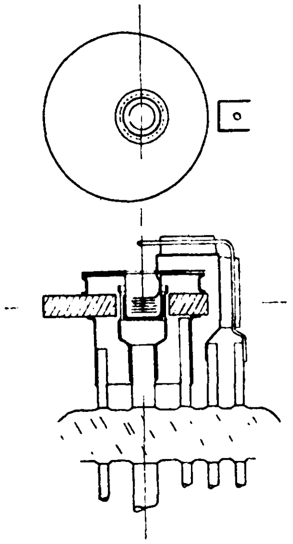


Fig. 16.—Electrode arrangement of CV52.

(2.2.8.3) *Characteristics and Performance.*

The characteristics and performance of the CV52 are shown in Table 2.

Table 2

DETAILS OF THE CV52

E_f	I_f	Amplification factor	g_m at 55 mA	W_a (max)	Maximum frequency	Efficiency	
						1 200 Mc/s	600 Mc/s
6·3 V	0·75 A	12	8 mA/V	12 watts	1 350 Mc/s	4%	27%

(2.3) **Common-Grid Earthed-Grid Oscillator Valves**

The performance of the CV16 disc-seal amplifier triode at 600 Mc/s in a common grid-earthed grid circuit suggested the possibility of using the disc-seal technique at even higher frequencies, both in amplifiers and, with suitable anode-cathode coupling, in oscillators.

In designing such valves, close attention had to be given to the electron transit-time and circuit considerations outlined in the earlier part of this paper. It appeared that space-current densities up to 1 amp/cm^2 were required even in receiving valves. With the knowledge available at the time (1941), there was a reasonable expectation that with some refinements in technique valves could be made capable of amplifying and oscillating in concentric line circuits at frequencies up to about 3 000 Mc/s.

The copper-disc-seal manufacture had already been established as a production process in velocity-modulation tubes, and it was only required to extend the technique to the use of thicker copper, so as to ensure the maximum possible conduction of heat away from the electrodes.

It was decided to construct the low-power, short-wave triodes with plane rather than cylindrical electrodes, because of the smaller stray capacitances in such a construction. The chief difficulty was that of maintaining accurately the small grid cathode clearance necessary to give the required mutual conductance and low transit time, bearing in mind the expansion of the cathode towards the grid during heating. The successful manufacture of the CV58 axial diode, in which an anode-cathode clearance of 0·05 mm was maintained to an accuracy of ± 15%, had already provided one solution to this problem.

(2.3.1) **History.**

The first valves to be made were the E1321, with an amplification factor of 90 for use as an amplifier, and the E1344, with an amplification factor of 35 for use as an oscillator (Fig. 17). In the latter, two probes were attached to the cathode supports and projected through the grid plate, to provide extra feedback capacitance between anode and cathode.

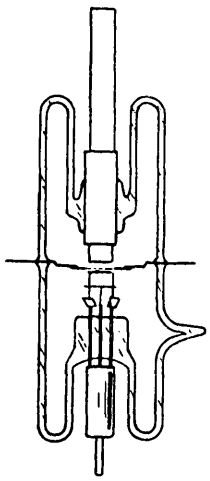


Fig. 17.—E1321 triode.

The performance of these valves was encouraging. An amplification of about 8 db was obtained at 3 000 Mc/s with the E1321, although the signal/noise ratio in the amplifier was no better than that of a crystal mixer above about 1 600 Mc/s; the E1344 oscillated up to about 3 000 Mc/s with one or two blank spots in the spectrum in the neighbourhood of 2 000 Mc/s, due to resonance in the grid support wires.

Following the success of the low-power common-grid triodes, two higher-power common-grid earthed-grid valves were designed for use as transmitters. These two valves, the CV257 and CV288, have anode dissipations of 75 watts and 250 watts respectively, and operate either as oscillators or amplifiers at frequencies up to 1 000 Mc/s. Both were designed for operation under c.w. as well as under pulsed conditions, and grid cooling was therefore a major factor in the design. In both valves, however, the cathode emission is adequate to exploit the characteristics fully under pulsed conditions.

(2.3.2) **The CV257.**

The CV257 is a disc-seal triode with plane electrodes. It has an indirectly-heated oxide-coated cathode of area 2 cm². The cathode-grid distance is 0·25 mm and the grid-anode distance is 0·5 mm. The anode is cooled with forced air, a flow of 5 ft³/min being required.

The construction of the valve is shown in Fig. 18.

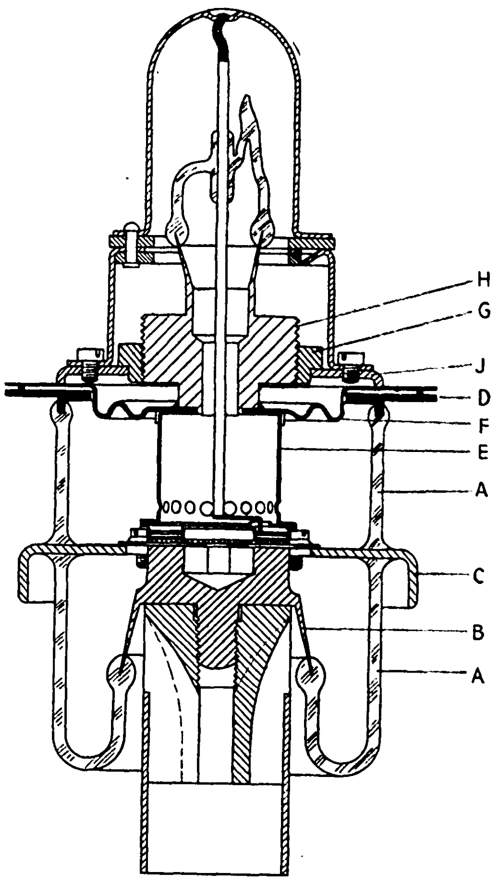


Fig. 18.—CV257 valve.

(2.3.2.1) *The Envelope.*

The metal-glass envelope, comprising the two glass portions A to which are sealed the flared copper thimble B which forms the anode, the copper-plated nickel-iron grid disc C, and the copper-plated nickel-iron cathode flange D, is made in one operation on a specially designed jig which ensures that the metal components are both coaxial and parallel. In this valve the grid-cathode spacing can be adjusted after the valve has been assembled, so that the initial spacing need not be accurate. It is important, however, that the planes of the discs should be parallel.

(2.3.2.2) *The Electrodes.*

The anode surface is an annulus of outer diameter 2 cm and inner diameter 1 cm. It is made of copper, and is integral with the thimble which forms the anode seal.

The type of grid used is shown in Fig. 19; it consists of a flat molybdenum plate, suitably pierced, and wound with molybdenum wire. The same metal is used for wire and plate to avoid differential expansion. The strap across the middle of the grid improves the mechanical rigidity and also, since it reduces the span of the wires, gives improved thermal conduction.

The cathode surface is an annulus of the same size as the anode face; this form was chosen to reduce distortion of the cathode on heating. The cathode is mounted on a short cylinder of nichrome E, which minimizes conduction of heat away from it.

The method of adjusting the grid-cathode distance from out-

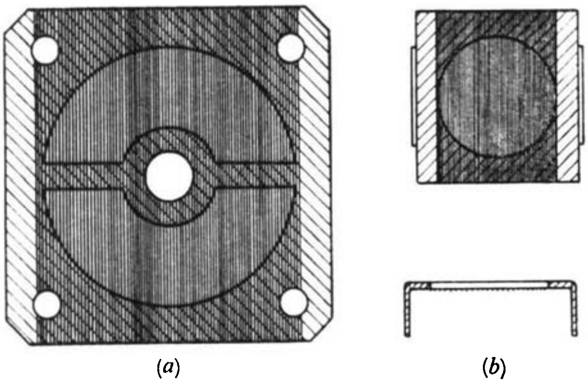


Fig. 19.—Planar grid construction.
(a) CV257. (b) CV90.

side the envelope can also be seen in Fig. 18. The cathode support tube E is carried on a flexible copper diaphragm F which forms the end wall of the envelope. When the valve is evacuated, atmospheric pressure tends to push the diaphragm inwards, reducing the grid-cathode distance. This movement is controlled by the nut G on the threaded member H attached to the outside of the diaphragm. A flange on this nut bears against the rigid member J, so that by turning the nut clockwise the cathode is withdrawn from the grid and vice versa. Usually the clearance is kept large during assembly and adjusted to its final value during testing.

(2.3.2.3) *Assembly.*

The assembly operations are relatively simple. The grid is fixed to its disc by means of four screws. A washer of pure tin is placed between the grid frame and the disc; this tin melts during the exhaust processes and "solders" the grid to the disc. The final assembly process is to mount the cathode in the envelope, thereby completing the vacuum-tight enclosure. The seal is made between the cathode flange and the flexible diaphragm by the well-known gold-wire process.

After exhaust, the cathode-heater cap and the anode cooler are fitted. The latter is soft-soldered to the base of the anode thimble.

(2.3.3) **The CV288.**

The CV288 differs considerably from the CV257 in design, but the same techniques are used in its construction and manufacture. The electrodes are short cylinders, and not planes as in the CV257. The cathode, which is an indirectly-heated oxide-coated nickel cylinder, has an area of 8 cm^2. The cathode-grid distance is 0·25 mm and the grid-anode distance 1·0 mm. An air flow of 20 ft^3/min is required for anode cooling; a little air is also necessary to cool the grid seal.

The construction of the CV288 is shown in Fig. 20.

(2.3.3.1) *The Envelope.*

The envelope is made in the same manner as for the CV257. As there is no external clearance adjustment, however, a very high degree of accuracy is necessary in the concentricity and spacing of the metal flanges. The precision required is much greater than can be obtained by normal glass-working methods, and much thought has therefore been devoted to the design of jigs which control the accuracy and yet require no skill on the part of the operators.

(2.3.3.2) *The Electrodes.*

The anode A of the CV288 is re-entrant; it consists of a short length of thick-walled copper tube, hard-soldered to a copper disc B. This disc closes the end of the envelope after the grid and cathode have been assembled inside. The thick-walled tube ensures a small temperature drop between the radiator and the active portion of the anode.

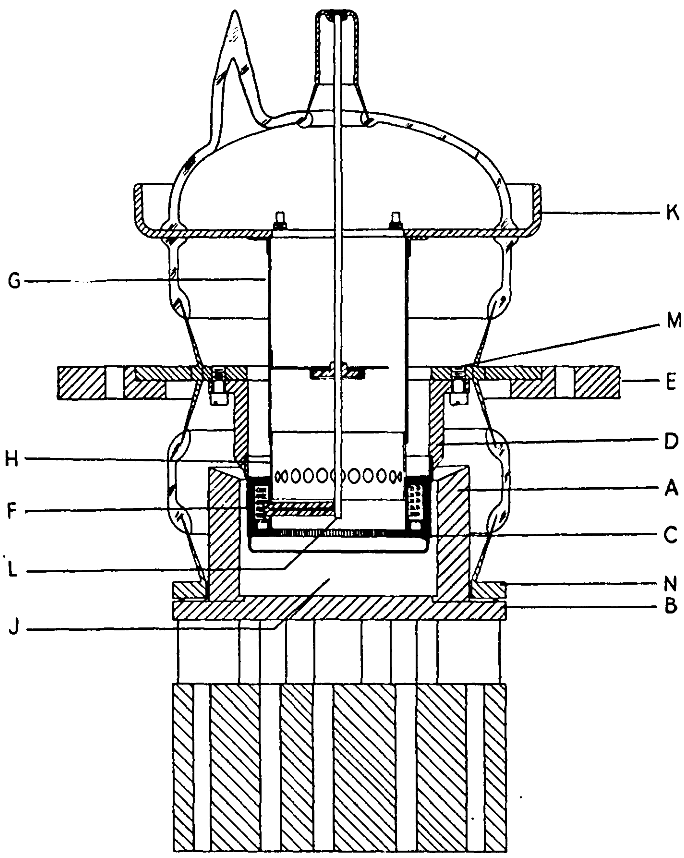


Fig. 20.—CV288 valve.

A squirrel-cage grid C of the type previously described is used. The grid is made as short as possible, to minimize the temperature drop along the wires. In order to conduct away as much heat as possible, the grid is mounted on a copper tube D, so that the temperature drop between the supported end of the grid and the external grid radiator E is only a few degrees, even when the grid is dissipating 50 watts.

The cathode F is an annular box, only the outside surface of which is coated. It is mounted on a nickel tube G, separated from the cathode by a short length of nichrome tube H to provide thermal insulation.

(2.3.3.3) *Assembly.*

The heater is assembled inside the cathode box before the cathode is assembled in the envelope. The cathode-heater assembly is introduced into the envelope through the open end J, and fixed to the disc K by means of four small bolts. The live end of the heater is then spot-welded to the end of the heater lead L. The grid is inserted over the cathode and fixed to the flange M by means of four small bolts. Lastly, the anode is assembled in the envelope by the gold wire process, the vacuum-tight seal being made between flanges N and B. The grid and anode radiators are attached after exhaust.

(2.3.4) **Characteristics and Performance of the CV257 and CV288.**

The properties of the CV257 and the CV288 are summarized in Table 3. Anode-voltage/anode-current characteristics covering the c.w. working region are shown in Figs. 21 and 22.

Both valves are normally used in concentric line circuits of low characteristic impedance, and give satisfactory performance at

Table 3
CHARACTERISTICS OF CV257 AND CV288

Valve type	Heater voltage	Heater current	Minimum cathode emission	Maximum d.c. anode voltage	Anode dissipation	Amplification factor	Capacitances, μμF		
							Anode-grid	Grid-cathode	Anode-cathode
	volts	amperes	amperes	volts	watts				
CV257	6·3	4·0	15	600	75	23*	6	14	0·3
CV288	15	3·0	60	1 000	250	42·5†	17	21	0·15

* At 100 mA. † At 250 mA.

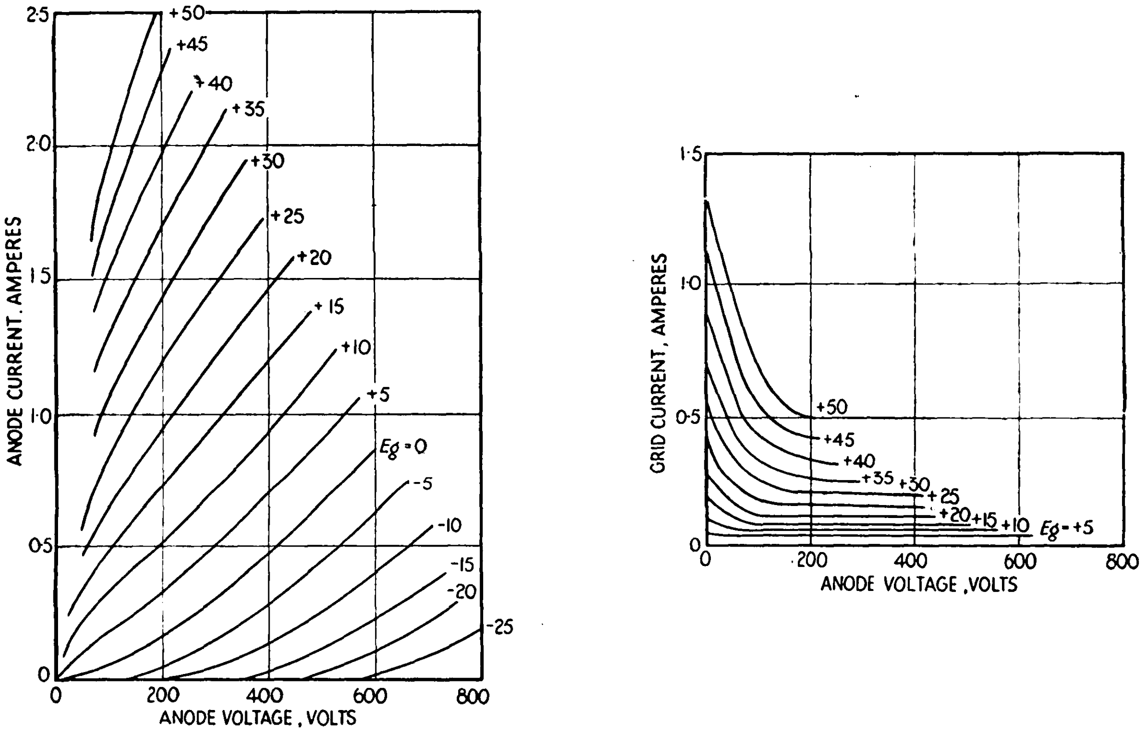


Fig. 21.—Typical anode-current and grid-current characteristics of CV257.

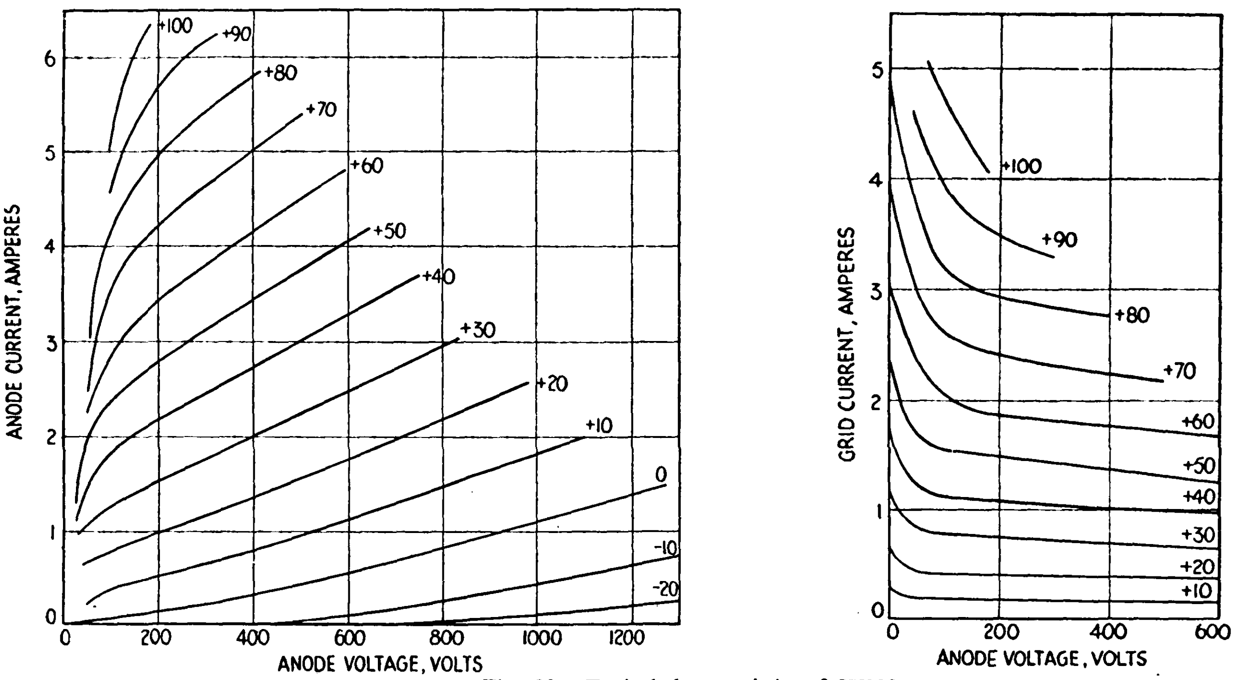


Fig. 22.—Typical characteristics of CV288.

frequencies up to 1 000 Mc/s. Under c.w. conditions their maximum output and efficiency are maintained at frequencies up to 600 Mc/s. At higher frequencies the efficiency falls; the limiting frequency for oscillation is 1 500 Mc/s for the CV288 and somewhat higher for the CV257. Little difference has been found between the amplifier and oscillator performance and a summary of the r.f. ratings under c.w. conditions is given in Table 4.

Table 4

PERFORMANCE OF CV257 AND CV288

Valve type	Frequency	Output per valve	Efficiency
	Mc/s	watts	%
CV257	600	110	65
	750	90	55
	1 000	60	45
CV288	600	300	60
	750	250	50
	1 000	150	30

Under pulse conditions, the CV288 gives a peak output of 50 kW and the CV257 gives 20 kW.

(2.4) Common-Grid Earthed-Anode Oscillator Valves

In the E1321 and E1344 mentioned earlier, the anode dissipation was limited to about 3 watts unless forced-air cooling was supplied to the small anode inside the concentric-line circuit. A further disadvantage was the necessity to take the circuit apart for valve fixing or replacement.

(2.4.1) The CV90.

Both of the above problems associated with small common-grid earthed-grid valves have been solved in the CV90 (Fig. 23),

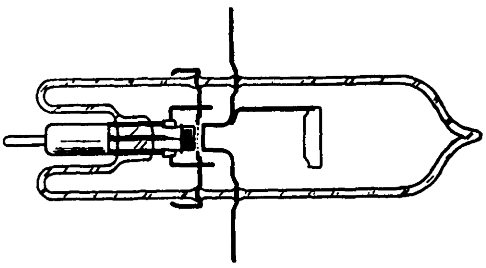


Fig. 23.—CV90 triode.

in which the anode is made integral with a second copper disc sealed through the glass envelope. The valve can be plugged directly into a double concentric-line circuit, the anode-grid circuit being outside and concentric with the grid-cathode circuit (Fig. 11). The anode, being attached to the outer member, can now easily dissipate 10 watts without forced-air cooling, and this is adequate for all local-oscillator and some low-power transmitter applications.

The CV90 has the following principal electrode dimensions:

Cathode area 0·12 cm^2 (4 mm diameter),
Grid-cathode spacing 0·08 mm, and
Grid-anode spacing 0·45 mm.

To achieve the required characteristics the grid wires must be 0·03 mm in diameter with a spacing of 0·145 mm.

(2.4.1.1) *Grid Design.*

One of the first problems was to decide how to make such a grid sufficiently rugged to withstand handling during assembly and to avoid buckling and distortion during operation. The method adopted, and later employed in similar valves with plane electrodes both in this country and in America, was to wind the grid wires on a rectangular metal plate, copper-plate the edges of the frame, braze the wires in position in a hydrogen furnace and then remove the wires from one side of the plate (Fig. 19). Alternatively, two grid frames were wound back to back. It is necessary for the thermal expansion coefficients of the wire and frame materials to be the same, and molybdenum has been chosen for both because of its low expansion, high thermal conductivity and good mechanical properties. During the brazing operation, which is well above the annealing temperature for molybdenum, any initial tension applied to the grid wires is removed and, provided the cooling is sufficiently slow for the temperatures of the wires and the frame to remain equal throughout, the wires will be free from strain when cold.

When the valve is in operation, the grid wires are heated by radiation from the cathode, and in an oscillator also by electron bombardment, and will therefore be under compression strain. Buckling will not however occur until a critical mean temperature is reached, given by

$$T_c = \pi^2 r^2 / \alpha l^2 \ ^\circ\mathrm{C} \text{ (above the temperature of the frame)}$$

where r and l are the radius and length of a grid wire, and α is the coefficient of thermal expansion of the material. The power per unit length of grid wire corresponding to this critical temperature is

$$W_c = 50 k \pi^3 r^4 / \alpha l^4 \text{ watts/cm}$$

where k is the coefficient of thermal conductivity of the wire.

For the CV90 grid, this corresponds to a maximum power of 0·1 watt; by stretching the grid wires just beyond the elastic limit this figure is increased by a factor of about 10, the yield strain for molybdenum being greater than 0·1% even at the highest temperature (400° C) to which the grid is subjected during pumping. This stretching operation is quite simply performed by squeezing the grid plate along a diameter at right angles to the grid wires.

(2.4.1.2) *Cathode design.*

The cathode for this type of valve consists of a short nickel cylinder, closed at one end by a flat surface coated with barium-strontium carbonates, and provided at the other end with a narrow annular flange to which a flat baffle is welded after the insulated helical heater has been inserted. The flange also serves to locate the cathode in a jig during assembly.

(2.4.1.3) *The Anode and the Grid Disc.*

The anode and the grid disc, the latter pierced with a central hole, are made of copper and are sealed to short lengths of glass tubing to form one unit (Fig. 24), with the discs accurately

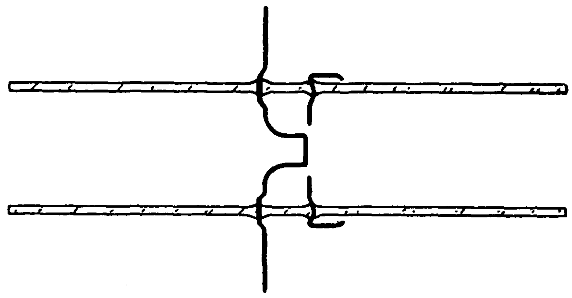


Fig. 24.—Disc seal unit of CV90.

located in relation to each other. Final adjustment to a high order of accuracy ($\pm$ 0·002 mm) is effected by distorting the copper in a suitable jig after the unit has been annealed. Copper has been chosen, rather than any of the special alloys which match the expansion of the glass, because of its good thermal conductivity; no difficulty is experienced with 0·35 mm copper, provided that the seals are made with a high circumferential compression in the glass adjacent to the copper. The temperature drop between the anode face and the seal in the CV90 is approximately 6° C per watt, and the anode rating of 10 watts was conservative even for operation under tropical conditions. At this dissipation the relative movement between anode and grid is only 0·005 mm, which is less than 2% of the anode grid spacing, so that a high order of frequency stability has been achieved.

(2.4.1.4) *Assembly.*

The cathode, provided with two short nichrome strips, the grid and the feedback wires are assembled in a jig, which locates the cathode flange in relation to the face of the grid frame; these electrodes are then welded to support wires in a cruciform pinch (see Fig. 25). The support wires for the grid are made

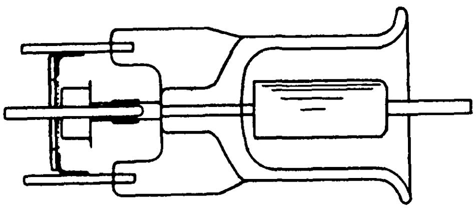


Fig. 25.—CV90 grid-cathode assembly.

as short as possible by sealing them into two glass pillars integral with the pinch, so that the frequency of any resonance due to these supports and associated capacitances is above the maximum frequency for which the valve is designed. Although the assembly jig gives accurate location, welding operations result in some mechanical strain, which together with unavoidable tolerances on electrode dimensions necessitates some slight adjustment of the grid-cathode clearance.

The manner in which this final measurement and adjustment of the grid-cathode clearance are made is illustrated in Fig. 26. The grid-cathode assembly A is mounted vertically in a holder, and is viewed normal to the cathode surface by a low power microscope B. The grid and cathode are illuminated by a parallel beam of light from a source C, which can be rotated about A as centre in a vertical plane at right angles to the grid wires so that shadows of the grid wires are thrown on the cathode surface. Then if p is the pitch of the grid and d is the distance between the centres of the grid wires and the cathode surface the shadow of one wire will be eclipsed by the neighbouring wire when the beam of light makes an angle $\theta = \arctan d/p$ with the plane of the cathode. A vertical scale S is mounted at a horizontal distance of 1 000 $\times$ p from the grid-cathode unit, and the reading at the point where the light beam intersects this scale then measures directly 1 000 $\times$ d. The clearance d can be increased or decreased by slightly squeezing the grid or cathode support wires in jaws provided for the purpose. In this manner, the grid can be set parallel to the cathode and the clearance adjusted quite rapidly to an accuracy of $\pm$ 0·001 mm.

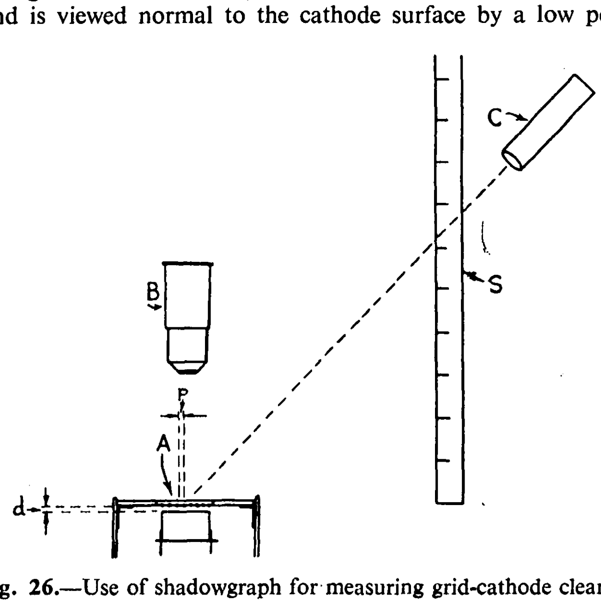


Fig. 26.—Use of shadowgraph for measuring grid-cathode clearance.

The grid-cathode assembly is sealed into the envelope with the grid frame located on the copper grid disc, good electrical and thermal contact being made by attaching to the grid supports short strips of tin, which melt when the valve is baked during pumping. Getter is provided in the part of the envelope remote from the grid and cathode, so that the getter deposit is away from any h.f. fields.

(2.4.1.5) *Pumping and Activation.*

Pumping and activation of the CV90 follows the usual practice except that, as indicated above, a very much higher emission-density has to be established (nearly 1 amp/cm^2 for c.w. and 10 amp/cm^2 for pulse operation) than in normal receiving valves. It was found that some of the early valves failed to oscillate at the highest frequencies. In these valves it was noticed that the grid current did not increase in the expected manner with positive grid voltage, and that the anode current tended to saturate. An exhaustive study of the effect showed it to be due to the deposition on the grid wires of a semi-conducting film (barium oxide and barium) which at the low temperature achieved in this type of grid could have a resistance of several thousand ohms; the film had a high negative temperature coefficient, and its resistance above 200° C was negligible, which may account for the effect not having been previously noticed in valves with oxide-coated cathodes. Special precautions are necessary during pumping to avoid these resistive films in the CV90 and similar valves.

(2.4.2) **The CV153.**

The CV153 is almost identical with the CV90, but since it is designed as an amplifier, the amplification factor has been increased to 80 and, to obtain the lowest possible equivalent noise resistance, the mutual conductance has been increased to 7 mA/V at 10 mA anode current. Using the CV153, amplifiers have been made to give a noise factor of 8 to 9 db at 1 000 Mc/s, which is about 3 db better than a crystal mixer; at 1 700 Mc/s, however, no improvement over a crystal is obtained and at 3 000 Mc/s there is a loss in signal/noise ratio of a few db.

(2.4.3) **The CV290.**

As stated earlier in this paper (Section 1.8.4) the value of the feedback capacitance in the CV90 was chosen as the best value for a frequency range of 1 000 to 3 000 Mc/s. In the CV290, which is otherwise identical with the CV90, no additional feedback is provided in the valve, but with suitable feedback in the circuit, the valve will operate as an oscillator or an amplifier over the whole frequency spectrum up to 3 500 Mc/s.

(2.4.4) **The CV154.**

The CV154 is similar in external appearance and construction to the CV90, but the cathode has three times the emitting area in order to provide sufficient space current to satisfy the requirements of a low-power pulse oscillator or amplifier giving about 1 500 watts at 1 000 Mc/s.

(2.4.5) **The CV273.**

The CV273 (see Fig. 27) is the latest type to be developed in

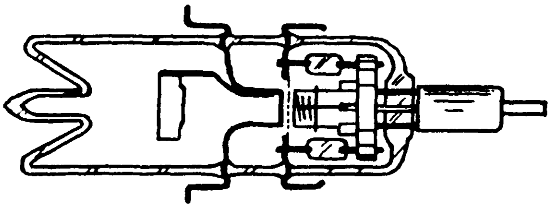


Fig. 27.—CV273 triode.

this series of low-power oscillator valves, and has been designed to meet the requirements of smaller size and higher frequency limit than those of the CV90 and CV290. It is suitable for use in concentric lines or tunable cavity-resonators of the butterfly type.

The principal improvement, apart from size, is in the cathode seal, which is in the form of a glass button through which pass four wires carrying the cathode and a central wire connected to the heater. Thus, not only is the cathode inductance reduced but a very much smaller resonator can be attached to the cathode, and external feedback can be applied closer to the cathode face than in the CV290. The cathode dimensions are the same as in the CV90, but the inter-electrode clearances have been reduced (grid/cathode 0·07 mm and grid/anode 0·25 mm) and the grid wires are 0·03 mm diameter spaced 0·127 mm apart.

(2.4.6) **Characteristics and Performance.**

The characteristics and performance of the above oscillator valves are given in Table 5.

Table 5

PROPERTIES OF VARIOUS COMMON-GRID EARTHED-ANODE VALVES

Type	I_f *	Maximum E_g	Amplification factor	g_m at 25 mA anode current	Maximum frequency	Power output, watts	
						3 000 Mc/s	1 000 Mc/s
	amp	volts		mA/V	Mc/s		
CV90	0·6	350	35	6·0	3 000	—	4
CV290	0·45	350	30	6·0	3 500	0·5	5
CV154	1·0	2 000 (pulse)	35	6·0	$>$ 3 000	500 (pulse)	1 500 (pulse)
CV273	0·45	350	30	7·0	3 700	0·5–1	5

* Voltage—6·3 in all types.

(3) TESTING AND SPECIFICATIONS

No account of short-wave oscillators would be complete without some mention of test procedure, which absorbed so much effort during development and manufacture.

The achievement of the objectives was not a matter of making a valve to suit a particular circuit or of designing a circuit for an existing valve. Development on both these lines proceeded in parallel and, in the early stages, adjustments had to be made both to circuit and valve to get the best results and obtain some estimate of the performance to be expected. This called for the closest collaboration between valve and circuit designers at all stages.

After the manufacture of a prototype equipment, it was nearly always necessary for a considerable period to make operational h.f. tests on 100% of the pre-production valves, while correlation was being established on a statistical basis between performance and valve characteristics. In most cases, this correlation resulted in a specification being agreed in terms of measurable valve parameters, but the valve manufacturer usually made additional operational tests on the overall performance of a percentage of valves. With some of the valves designed for very special purposes, however, assessment in terms of simple tests was not possible, and elaborate equipment had to be designed to reproduce very closely operational conditions for the purpose of testing and life testing.

The evolution of a new type of valve divides itself naturally into a number of fairly well defined stages, which are very much the same whatever the nature of the particular device or of its particular application. These stages are:

(*a*) The experimental stage, in which it is found how to make the valve and to apply it to the project for which it is needed. This establishes the desired performance of the types, usually for one particular application.

(*b*) The standardization of the type, which makes use of a tentative production of about a thousand specimens, which go into service with the first issue of the equipment.

This "pre-production" stage serves both to establish sound production methods, and also to provide a body of facts, both about the variations to be expected among the valves, and about the corresponding effects on the equipment, which is being standardized at the same time. Concurrently, the necessary special tests are tried in practicable form. The information so obtained defines all tolerances, and forms the basis of the official specification, the final determination of which normally marks the end of development.

(*c*) The early stages of full scale production. Preparations for this will have begun during the pre-production, but it remains to verify that a satisfactory proportion of samples does meet the specification, and that the production valves give good performance and life under service conditions.

(4) ACKNOWLEDGMENTS

Much of this work was done on behalf of C.V.D. The authors wish to acknowledge the helpful co-operation of the experimental establishments of the three Services, and to thank the Director of Scientific Research, Admiralty for permission to publish this paper.

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