CHAPTER 3.

THE TESTING OF OXIDE-COATED CATHODE HIGH VACUUM RECEIVING VALVES

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(i) Fundamental physical properties

The characteristics and operation of a high vacuum oxide-coated cathode- or filament-type valve under normal conditions of operation, initially and throughout life, are determined primarily by the following fundamental general physical properties –

(a) the **vacuum** within the envelope surrounding the cathode and electrode structure.

(b) the total available **cathode emission** and **uniformity of activation of the cathode surface.**

(c) the **geometrical configuration of the electrode system.**

(d) the **electrode contact potentials** with respect to the cathode.

(e) **primary and secondary emission** from electrodes, other than the cathode.

(f) the **interelectrode admittances.**

(g) the **stability of the electrical characteristics.**

(h) the **stability, robustness and durability of the mechanical construction.**

(j) the **external size and shape,** and the **system of electrode connections.**

The maintenance of a satisfactory **vacuum** under maximum rating conditions and continued operation, together with the availability of an adequate cathode emission under all prescribed electrode conditions and normal variations of heater/filament power, are essential to the fundamental operation of a valve, since an activated cathode surface requires a certain degree of vacuum to be maintained for its emissive properties to remain unimpaired, while the emission available from the cathode must always be sufficient to supply the total peak and average space currents required.

At the same time, it is necessary that the cathode surface be uniformly activated over the regions from which emission current is supplied, since the parameter transconductance is directly proportional to the activated cathode area.

The **electrode geometry** determines the electrical static and dynamic characteristics, within the limitations imposed by the available cathode emission, to the extent to which the emission is incompletely space charge limited and the capacity of the gettering to maintain a satisfactory vacuum.

Electrode contact potentials and electrode **primary and secondary emission** depend upon the electro-chemical condition of the electrode surfaces. This is determined usually by the extent to which contamination of these surfaces has occurred during manufacture or operation, due to the deposition of active material from the cathode or getter. **Contact potential** is of importance in the case of a low- or zero-voltage electrode since it may contribute a sufficiently large fraction of the total electrode voltage to modify significantly the characteristics determined by the electrode geometry and applied electrode voltages alone.

Primary and secondary electrode emission may occur if electrode temperatures become sufficiently high and the deposited films of active material in combination with the electrode material have a low work function. The effect on operation of primary or secondary electrode emission depends on the value of resistance in series with the emitting electrode.

The interelectrode short-circuit admittances are determined both by the geometry of the electrode construction, the d.c. and r-f properties of the insulation supporting the electrode system and electrode connections, and the frequency and conditions of operation. The susceptive components are dependent mainly on the interelectrode and lead capacitances and inductances. The conductive components are due to transit-time effects and the interelectrode resistances which are determined mainly by the d.c. resistance of the interelectrode insulation, but may also include a frequency-dependent component. The d.c. insulation resistance is determined by the surface condition of the electrode supports (mica, glass, ceramic), the extent to which contamination of these surfaces has occurred, and also by leakage between electrode leads within the base or between base pins due to leakage over or through the base material. A high value of interelectrode resistance is required throughout the life of a valve in order to avoid—

(1) **uncontrolled changes in electrode voltages** supplied through series resistive circuits from the electrode voltage source, due to the flow of leakage conduction currents through or across the interelectrode insulation from higher to lower voltage electrodes and thence through the externally connected circuits to the negative terminal of the electrode voltage supply. This characteristic is particularly important, e.g., in the case of negatively biased control grids which obtain their bias through a high value of grid resistor, and power dissipating electrodes which obtain their voltages through high resistance series dropping resistors.

(2) **noisy operation** due to intermittent conduction under the conditions described in (1).

(3) **lowering the resistive component** of the interelectrode admittances and thus increasing the damping by the valve on resonant circuits connected between electrodes, either directly or as a result of increased " Miller Effect ".

The interelectrode r-f resistance must also be high throughout the life of the valve up to all normal frequencies of operation, in order to avoid damping high impedance resonant circuits connected between electrodes. In general, it is determined by the r-f properties of—

(a) the interelectrode insulation,
(b) films of active material deposited on the interelectrode insulation,
(c) the base material.

The stability of the electrical characteristics depends on the goodness of the vacuum and its maintenance, stable emission from a properly and uniformly activated cathode surface, stable electro-chemical surface conditions, high interelectrode resistance, and the mechanical stability of the electrode structure. Variations of any of these characteristics throughout life produce changes in the valve parameters and, through them, changes in circuit performance.

Two types of instability of electrical characteristics occur ; initial instability which is sometimes experienced early in life due to incomplete or unsatisfactory processing, and the normal gradual deterioration of characteristics dependent on emission, which continues until the valve is no longer serviceable. Generally, the ultimate electrical life of a valve which has been properly exhausted, which has a properly activated cathode and which has been operated within its maximum ratings, depends mainly on the cathode current at which it has been operated and the ability of the getter to prevent deterioration of the vacuum and consequent " poisoning " of the cathode emission, by absorbing the gases produced in the cathode coating during operation, and also the gases released from the electrodes, the walls of the envelope and other parts of the internal construction during storage, and throughout life.

The stability, robustness and durability of the mechanical construction in general determine the ultimate reliability and effective life of a valve, also the extent to which electrical performance is affected by conditions of vibration or mechanical shock under which it may be transported or operated and the ability of the construction to withstand such conditions without mechanical failure.

(ii) Basic functional characteristics

Space current—When the cathode surface is raised to its normal emitting temperature, by supplying the required power to the filament or heater, and suitable voltages are applied to the other electrodes, an electron space current flows from the cathode emitting surface to the electrode system, its value depending on the electrode geometry and the combined effect of the electrode voltages acting in the plane(s) of the control electrode(s).

For electrode systems consisting of an inner control electrode adjacent to the cathode and one or more outer electrodes, providing that a virtual cathode is not formed between the control electrode and the outermost electrode, the **total space current from the cathode** may be expressed, generally, to a good approximation by the following equation—

$$i_s \approx G\left[(e_{c1} + \epsilon_1) + \frac{e_{c2}}{\mu_{1-2}} + \frac{e_{c3}}{\mu_{1-3}} + \ldots + \frac{e_b}{\mu_{1-b}}\right]^{3/2} \quad (1)$$

where i_s = total cathode space current,
e_{c1} = voltage of the first electrode,
ϵ_1 = contact potential of the first electrode,
e_{c2}, e_{c3}, etc. = voltages of the successive outer electrodes,
e_b = voltage of the outer plate current collecting electrode,
μ_{1-2} = amplification factor of the first electrode with respect to the second electrode,
μ_{1-3} = amplification factor of the first electrode with respect to the third electrode,
μ_{1-b} = amplification factor of the first electrode with respect to the outermost electrode,
and G = perveance of the cathode-control-electrode region

$$\approx 2.33 \times 10^{-6} \times \frac{\text{cathode area}}{(\text{cathode-to-first-electrode spacing})^2}$$

In eqn. (1), the terms within the brackets represent the effect of the various electrode voltages considered as acting in the plane of the first electrode, so that the sum of the terms combined represents an " equivalent electrode voltage ". For purposes of space current calculation, the factors depending on the geometry of the electrode system and on the effect of the electrode voltages may thus be reduced to the perveance of the cathode-to-first-electrode space and the equivalent electrode voltage acting in the plane of the first electrode, so that the space current equation becomes—

$$i_s \approx G\ [\text{equivalent electrode voltage}]^{3/2} \qquad (2)$$

The equations for the total cathode current in diodes, triodes, tetrodes and pentodes follow directly from eqn. (1).

In the case of electrode systems having two control electrodes and which operate with a virtual cathode before the second control electrode, as in converter and mixer valves, the space current cannot be expressed in a simple form. Such systems may be regarded as consisting of two separate but related systems, and reduced to equivalent diodes, with the space current of the outer equivalent diode supplied from, and controlled by, the space current of the equivalent diode adjacent to the cathode.

Generally, it can be stated that whatever the electrode system, the **total space current** from the cathode depends primarily upon the total activated cathode surface area, the total available emission, the cathode temperature, the extent of temperature and space charge limiting of emission, the geometry of the electrode system and the electrode voltages.

The **distribution of the space current** to the various electrodes depends only upon electrode geometry, space charge effects and the electrode voltages and, in general, cannot be expressed in a simple form.

In addition to the electron space current from the cathode, there are always some positive ions present due initially to the presence of the infinitesimal traces of residual gases remaining after the exhausting and gettering processes and, during life, to the release of absorbed gases from the surfaces of the electrode structure and envelope walls, and the gases produced as a result of physical-chemical changes occurring in the cathode coating during the emission processes. The positive ions, so produced, flow to the negative voltage electrodes and are prevented from bombarding the cathode surface during operation, when space current is flowing, by collision effects and the presence of the space charge surrounding the cathode.

A primary or secondary electron emission current may also flow from the surface of an electrode and represents a negative electrode current. Small positive or negative leakage conduction currents, due to conducting or semi-conducting leakage paths over or through the interelectrode insulation, may also contribute to the electrode currents ; their values depend on the voltages of the electrodes concerned, and the conducting properties of the contaminated surfaces or insulating material, and often on their temperature. When the effects above are present, the total current of an electrode is the algebraic sum of the positive and negative components.

Static Characteristics—The various electrical characteristics, which result from the electrode geometry and the application of steady **direct voltages** only to the electrodes, with the cathode emitting, are termed " static characteristics ". These characteristics consist of—

(a) the voltage-current relationship for each electrode, when constant voltages are applied to all remaining electrodes.
e.g., Diode, — $I_b - E_b$,
Triode, — $I_b - E_b$, E_{c1} constant
$I_{c1} - E_{c1}$, E_b constant
and similarly in the case of other types.

(b) the mutual voltage-current relationships between electrodes, when constant voltages are applied to all electrodes except the voltage-varying electrode.
e.g., Triode, — $I_b - E_{c1}$ E_b constant
Pentode, — $I_b - E_{c1}$ E_b, E_{c3}, E_{c2} constant
$I_{c3} - E_{c1}$ E_b, E_{c3}, E_{c2} constant
$I_{c2} - E_{c1}$ E_b, E_{c3}, E_{c2} constant
and similarly in the case of other types.

Derived Characteristic Parameters—By considering infinitesimal changes of voltage and current of the static characteristics, described under (a) and (b) above, the characteristic parameters—amplification factor, transconductance and variational plate resistance are obtained, which are related as follows,

$$\text{Transconductance} = \frac{\text{Amplification Factor}}{\text{Plate Resistance}}$$

These characteristic parameters are derived by the following relations—

$$\text{transconductance} = \frac{\delta I_b}{\delta E_{c1}}\ ;\ E_b, E_{c3}, E_{c2} \text{ constant} \quad (3)$$

$$\text{amplification factor} = \frac{\delta E_b}{\delta E_{c1}}\ ;\ E_{c3}, E_{c2} \text{ constant} \quad (4)$$

$$\text{plate resistance} = \frac{\delta E_b}{\delta I_b}\ ;\ E_{c3}, E_{c2}, E_{c1} \text{ constant} \quad (5)$$

The amplification factor is a function of the electrode geometry only, but becomes also dependent on the control grid voltage as the cut-off condition is approached. The transconductance, as defined by eqn. (3) may be derived from the general space current eqn. (1), and is a function of the electrode geometry, the total cathode space current and uniformity of activation of the cathode surface.

The characteristic parameters normally used to describe the electrode geometry, and in terms of which performance is interpreted, are—the amplification factor, transconductance of the control grid with respect to the plate and the (a.c.) plate to cathode resistance.

Dynamic Characteristics—By superimposing alternating voltages on the direct voltage(s) of the control electrode(s), with suitable impedances in series with the output electrode(s), dynamic characteristics are obtained which depend directly on the static characteristics and characteristic parameters. These dynamic characteristics include rectification, frequency conversion, voltage and power gain, oscillation, and impedance transformation characteristics.

The static characteristics, characteristic parameters and the fundamental properties previously described comprise the basic mechanical and electrical characteristics, which determine the serviceability and application of a valve and its performance under given conditions.

In order to appreciate the significance and limitations of the various tests, which normally are applied to determine the condition of a valve and the probability that it will continue to operate satisfactorily, the performances and individual tests must be properly interpreted in terms of all the relevant characteristics and corresponding fundamental physical properties. The manner and extent of the dependence and interdependence of the various characteristics and fundamental physical properties must also be recognized and understood.

The important basic functional characteristics, together with the fundamental physical properties on which they depend, are shown in the following tabulation :

GENERAL PHYSICAL PROPERTIES	RELATED FUNCTIONAL CHARACTERISTICS
1. **Mechanical**	
Size, shape and material of external construction	Physical dimensions Type of envelope Type of base Type of top cap
System of electrode connections	Base pin and top cap connections
Stability, robustness and durability of mechanical construction	Ruggedness of envelope, basing and internal electrode structure Microphony Noise
2. **Electrical**	
Interelectrode resistance	D.C. interelectrode insulation resistance R-F interelectrode insulation resistance Noise
Vacuum	Gas pressure within the envelope*
Cathode emission	Total available peak cathode current* Total available average cathode current*
Uniformity of cathode activation	Transconductance or dynamic performance characteristic at reduced heater/filament voltage*
Electrode geometry	Electrode currents* Interelectrode transconductances* Interelectrode mu factors* Interelectrode variational resistances* Interelectrode capacitances
Electrode contact potentials Primary and secondary emission	} Modify characteristics dependent upon electrode geometry (see above)
Stability of electrical characteristics	Affect all electrical characteristics.

(iii) Fundamental characteristic tests

The characteristic tests which are of fundamental importance in specifying the performance and determining the condition, acceptability and usability of an oxide-coated cathode- or filament-type valve, are as follows :

(a) Tests common to all valve types

Visual inspection of internal and external construction, and finish.
Maximum overall length.
Maximum diameter.
Interelectrode short-circuits.
Electrode continuity (open-circuits).
Interelectrode insulation resistance (d.c.).*
Heater/filament power.*
Heater/cathode leakage.*
Emission or emission-dependent dynamic test.*
Interelectrode capacitances.*

(b) Tests common to all types except diodes*

Reverse grid current (gas, leakage, grid emission).
{ Control grid current commencement potential, or
{ Positive control grid current.
Electrode currents (d.c.).
Electrode current (d.c.) cut-off.

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*Under specified operating conditions.

Transconductance (see Ref. 47).
Amplification factor.
Plate resistance.
Noise (a-f and/or r-f).
Microphony.

(c) **Tests common to diodes only***

Signal diodes	Plate current commencement or zero signal plate current.
Power diodes	Back emission.

(d) **Dynamic performance tests***

Signal diodes	Rectification (operation)
Power diodes	Rectification (operation)
A-F amplifiers	A.C. amplification
R-F and I-F amplifiers	Stage gain.
Converters	Conversion stage gain or conversion transconductance and Oscillator transconductance or oscillator grid current.
Power output types	Power output.

(e) **Dynamic performance tests at reduced heater/filament voltage***

Dynamic performance tests are also performed at reduced filament/heater voltages during manufacture, in order to control initial characteristics and performance, and also to provide a manufacturing process control of the uniformity of activation of the emitting surface. In some cases, with the reduction of filament/cathode temperature, changes occur in contact potential and/or reverse grid current, which make the normal-voltage tests ineffective or unsatisfactory as a control of activation, depending on the conditions of operation. In such cases a transconductance test is normally used instead.

Notwithstanding the control exercised by such tests over initial characteristics and performance, it is a very difficult manufacturing problem to avoid the wide variations and deterioration of characteristics which often occur under conditions of reduced filament/heater operation throughout life although the characteristics at normal filament/heater voltage may be satisfactory. For this reason, and also as performance may be critically dependent on circuit design and electrode supply voltages, particularly the operation of the oscillator circuits of a converter valve and the power output and distortion of a power output valve, it is not in general normal practice for valve specifications to specify any minimum requirements for characteristics or performance at reduced filament/heater voltage during life. Reasonable performance at reduced filament/heater and electrode voltage conditions is achieved by most manufacturers, however, as a result of the pressure of competition combined with the user's demand for acceptable performance under slump voltage conditions.

Under American practice the reduced heater/filament voltages at which specified dynamic performance tests are normally performed during manufacture are as follows :

0.625 volt types	0.55 volt
1.25 volt types	1.1 volts
1.4 volt types	1.1 volts
2 volt types	1.6 or 1.7 volts
2.5 volt types	2.2 volts
6.3 volt types	5.5 volts
7.5 volt types	6.0 volts
12.6 volt types	11.0 volts
19 volt types	16.5 volts
25 volt types	22 volts
26.5 volt types	23.5 volts

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*Under specified operating conditions.

32	volt types	28.5	volts
35	volt types	31.0	volts
45	volt types	40	volts
50	volt types	44	volts
117	volt types	100	volts

(iv) Valve ratings and their limiting effect on operation

(A) Limiting ratings

In order to assist the designer to obtain the maximum service from a given valve type, within the limits of safe operation, in the various applications in which it may be used, the limiting conditions under which the type can be operated without impairing its performance and normal life are usually specified by the valve manufacturer in the form of maximum (or minimum) ratings for relevant basic characteristics which may only be exceeded at the user's risk. These ratings, unless otherwise stated, apply to valves having bogie values of characteristics. It is therefore the responsibility of the equipment designer to see that a bogie valve will not exceed any of its ratings.

Maximum ratings are established on the basis of life tests and operating performance. It is a matter of experience that when one or more ratings are exceeded for any appreciable time, depending on the period and the extent of the overload, the particular rating exceeded and the capability of the type to withstand such overload, the serviceability of the particular valve may be impaired, its life may be shortened or its performance may be unsatisfactory.

Maximum ratings usually are specified only for those characteristics which normally determine the limits of safe operation in the intended applications for which a particular type has been designed. Generally, the limits of safe operation for any application may be prescribed completely by specifying the maximum ratings for the electrode voltages, peak inverse voltage in the case of rectifiers, electrode dissipations and the maximum peak and average total cathode current.

In the case of high transconductance and power output types it is necessary, in addition, to limit the maximum value of resistance which may be used between the negative control grid and cathode, in order to avoid either excessive variation of circuit performance, excessive space current or excessive electrode dissipations due to reverse grid current. Maximum ratings, in general, can only be determined satisfactorily by extensive life tests.

(B) Characteristics usually rated

The characteristics of individual types for which ratings are required to specify performance are as follows:

(a) General mechanical ratings (common to all types)

Maximum overall length.
Maximum seated height.
Maximum diameter.
Dimensions and locations of top caps, bases and base pins.
Materials and design of external construction.

(b) General electrical ratings common to all types

	Nature of rating
Heater/filament voltage (a.c. or d.c.)	nominal
Heater/filament current (a.c. or d.c.)	nominal
Heater to cathode voltage (d.c.)	maximum
Control grid circuit resistance	maximum
Interelectrode capacitances—	
control grid to plate capacitance	maximum
all other capacitances (single unit)	nominal
capacitances between electrodes of multiple units	nominal or maximum

(c) **Specific additional electrical ratings applied to particular types**

Type	**Application**	**Fundamental rating**	**Nature of rating**
Diodes	Detector	Average (d.c.) plate current per plate	Maximum
		Peak plate current per plate	Maximum
	Power Rectifier	Peak inverse plate voltage	Maximum
		Average (d.c.) plate current per plate	Maximum
		Peak plate current per plate	Maximum
Triodes	Voltage amplifier	Plate Voltage	Maximum
		Plate dissipation	Maximum
		Grid voltage—negative	Maximum
		positive	Maximum
		Cathode current (d.c.)	Maximum
	Power amplifier	Plate voltage	Maximum
		Plate dissipation	Maximum
		Grid voltage—negative	Maximum
		positive	Maximum
		Grid dissipation**	Maximum
		Cathode current (d.c.)	Maximum
		Cathode current (peak)*	Maximum
Pentodes	Voltage amplifier	Plate voltage	Maximum
		Screen voltage	Maximum
		Screen supply voltage	Maximum
		Grid voltage—negative	Maximum
		positive	Maximum
		Plate dissipation	Maximum
		Screen dissipation	Maximum
		Cathode current (d.c.)	Maximum
	Power amplifier	Plate voltage	Maximum
		Screen voltage	Maximum
		Grid voltage—negative	Maximum
		positive	Maximum
		Plate dissipation	Maximum
		Screen dissipation	Maximum
		Grid dissipation**	Maximum
		Cathode current (d.c.)	Maximum
		Cathode current (peak)*	Maximum
Converters	Frequency converter	Mixer plate voltage	Maximum
		Mixer screen voltage	Maximum
		Mixer screen supply voltage	Maximum
		Oscillator plate voltage	Maximum
		Oscillator plate supply voltage	Maximum
		Mixer signal grid voltage—	
		positive	Maximum
		negative	Maximum
		Mixer plate dissipation	Maximum
		Mixer screen dissipation	Maximum
		Oscillator plate dissipation	Maximum
		Cathode current (d.c.)†—	
		mixer	Maximum
		oscillator	Maximum

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*Power amplifier types only, for other than Class A operation.

**For operation in the positive grid current region.

†In converters of the 6SA7, 6BE6 class having no separate oscillator positive electrode, the total cathode current is the fundamental rating.

Notwithstanding the ratings shown against each type, the actual ratings of an individual type depend entirely on its intended applications and may not include all those listed. The absence of a rating for a particular characteristic may be taken to indicate either that it has not previously been necessary to specify a rating for this characteristic, or that the type in question was not intended originally for this application and has not been processed accordingly. In the latter case, operation may not be satisfactory, and reference should be made to the valve manufacturer for specific information.

(C) Rating systems

Valves are rated by either of two systems—the " absolute maximum " system, or the " design-centre maximum " system. The absolute maximum system originated in the early days of valve development and was based on the voltage characteristics of battery supplies. Battery voltages could fall below their nominal values but seldom appreciably exceeded them, so that valve maximum ratings set on the basis of specified battery voltages were absolute maximum ratings. This system is still widely used by British and European valve manufacturers and is the system of ratings used in the British Services' Electronic Valve Specification K1001 and the U.S.A. Services' Specification for Electron Tubes, JAN-1A (Ref. S2). With the introduction of power line and car-radio operated receivers and the tendency of many designers to interpret absolute maximum ratings as nominal values, it became necessary to re-rate valves according to a system in which allowance was made in the ratings for the variations which occur under both conditions of operation. Accordingly, the design-centre system was adopted in U.S.A. by the Radio Manufacturers Association in 1939 for the rating of receiving valves and since then has become the standard system for rating most receiver types of American design, manufactured both in U.S.A. and elsewhere.

With either system, each maximum rating for a given valve type must be considered in relation to all other maximum ratings for that type, so that no one maximum rating will be exceeded in utilizing any other maximum rating.

Thus it will often happen that one rating alone will determine the limiting operating conditions while other characteristics are below their maximum ratings.

(D) Interpretation of maximum ratings

In the absolute maximum or " absolute " system (except for filament or heater voltage) the maximum ratings are limiting values above which the serviceability of the valve may be impaired from the viewpoint of life and satisfactory performance. Therefore, in order not to exceed these absolute ratings, the equipment designer has the responsibility of determining an average design value for each rating below the absolute value of that rating by an amount such that the absolute values will never be exceeded under any usual condition of supply-voltage variation, load variation, or manufacturing variation in the equipment itself.

The equipment should be designed to operate the **filament or heater** of each valve type at rated normal value for full-load operating conditions under average voltage-supply conditions. Variations from this normal value due to voltage-supply fluctuation or other causes, should not exceed ± 5 per cent. unless otherwise specified by the valve manufacturer.

Under the " British Standard Code of Practice " B.S.1106, 1943 (Ref. 49) and the British Radio Valve Manufacturers' Association's publication " Radio Valve Practice," August, 1948 (Ref. 48), recommended British practice is that in general it is not permissible that the heater voltage should vary more than 7 per cent. from the rated value.

It is a matter of experience, however, that the heaters and filaments of most modern receiving valve oxide-coated cathode and filament types may be operated at voltages whose maximum fluctuations do not exceed ± 10 per cent. from their rated values, without serious effect on life or marked reduction in performance, provided that the maximum ratings of the other electrodes are not exceeded. In cases where the heater or filament voltage variations exceed, or are likely to exceed, ± 10 per cent., the maximum ratings should be reduced and recommendations obtained from the valve manufacturer as to the maximum ratings permissible under the particular conditions.

In the design-centre maximum or " design-centre " system, the maximum ratings are working design-centre maxima. The basic purpose underlying this system is to provide satisfactory average performance in the greatest number of equipments on the assumption that they will not be adjusted to local power-supply conditions at the time of installation. Under the design-centre system, ratings are based on the normal voltage variations which are representative of those experienced with the three important types of power supply commonly in use, namely a.c. and d.c. power lines, storage battery with connected charger, and dry batteries, so that satisfactory performance from valves so rated will ordinarily be obtained in equipment which is so designed that the design-centre maximum ratings are not exceeded at the supply design-centre voltage.

The following interpretation of receiving valve design-centre ratings is based partly on R.M.A. (U.S.A.) Standard M8-210 entitled " Tube Ratings " (Ref. S11), and partly on established design practice recommended by valve manufacturers.

1. Cathode

The heater or filament voltage is rated as a normal value, unless otherwise stated, so that transformers or resistances in the heater or filament circuit should be designed to operate the heater or filament at the rated value at the supply design-centre voltages, indicated hereunder. Where the permissible heater or filament voltage variations are exceeded, or are liable to be exceeded, maximum ratings should be reduced in accordance with recommendations obtained from the valve manufacturer.

2. Indirectly-heated and a.c. filament types

(2.1) **A.C. or d.c. power line operation**—Maximum ratings have been chosen so that valves will give satisfactory performance at these maximum ratings in equipment operated from power line supplies, the normal voltage of which, including normal variations, fall within ± 10 per cent. of a specified value. Heaters or filaments as well as positive and negative voltage electrodes, unless otherwise specified, may therefore be operated at voltages up to ± 10 per cent. from their rated values, provided that at the specified line design-centre voltage the heater or filament is operated at its rated voltage and the maximum ratings of plate voltages, screen-supply voltages, electrode dissipations, total cathode current and rectifier output currents are not exceeded.

The prescribed power line voltage variation of ± 10 per cent. is based on surveys made in the U.S.A., which have shown that the line voltages delivered fall within 10 per cent. of 117 volts, which is taken as the line design-centre voltage in that country. In using design-centre ratings with other power line systems elsewhere, it is usually satisfactory to regard ± 10 per cent. as being representative of the line voltage variation likely to be experienced under normal conditions, so that it is then only necessary to determine the line design-centre voltage. In extreme cases, where power line variations exceed ± 10 per cent., as for example when operation is in remote areas supplied by long lines subject to variable and heavy peak loading, adjustment to the equipment should be made locally.

(2.2) **Storage battery operation**—When storage battery equipment is operated without a charger, it should be designed so that the heaters or filaments are operated at their normal rated values and published maximum values of plate voltages, screen-supply voltages, electrode dissipations, total cathode currents and rectifier output currents are never exceeded for a terminal voltage at the battery source of 2.0 volts per cell. When storage battery equipment is operated with a charger or similar supplies, the normal battery fluctuation may be as much as 35 per cent. or more, which imposes severe operating conditions on valves. Under these conditions, the equipment should be designed so that the effect of high heater or filament voltages on valve life and performance (due mainly to excessive reverse grid current) is reduced to a minimum, and so that 90 per cent. of the above maximum ratings is never exceeded for a terminal voltage at the battery source of 2.2 volts. In both classes of operation, progressively reduced and unreliable performance is to be expected as the heater or filament voltage falls below 90 per cent. of its rated value and approaches the " slump " value specified for the reduced performance tests of the valve test specification.

(2.3) **" B " battery operation**—The design-centre voltage for " B " batteries supplying positive voltage electrodes is the normal voltage rating of the battery block, such as 45 volts, 90 volts, etc. Equipment should be designed so that under no condition of battery voltage will the plate voltages, screen-supply voltages, electrode dissipations, or total cathode currents ever exceed the recommended respective maximum values specified for each valve type by more than 10 per cent.

(3) 2.0 Volt battery filament types

(3.1) **Filament**—The 2.0 volt battery filament types are designed to be operated with 2.0 volts across the filament. In all cases the operating voltage range should be maintained within ± 10 per cent. of the rated filament voltage, i.e., within the limits of 1.8 to 2.2 volts.

(3.2) **Positive and negative electrodes**—The electrode voltage supplies may be obtained from dry-cell batteries, storage batteries or from a power line and should be chosen so that the maximum ratings of plate voltages, screen-supply voltages, electrode dissipations and total cathode current are not exceeded at the supply design-centre voltages specified under 2.3, 2.2 and 2.1.

(4) 1.4 volt battery valve types

(4.1) **Filament**—The filament power supply may be obtained from dry-cell batteries, from storage batteries, or from a power line.

(4.11) **Dry-cell battery supply**—The filament may be connected either directly across a battery rated at a terminal potential of 1.5 volts, or in series with the filaments of similar valves across a power supply consisting of dry cells in series. In either case, the voltage across each 1.4 volt section of filament should not exceed 1.6 volts. In order to meet the recommended conditions for operating filaments in series it may be necessary to use shunting resistors across the individual 1.4 volt sections of filament.

(4.12) **Storage battery supply**—The filament may be operated either singly or in series with the filaments of similar valves. For such operation in either case, design adjustments should be made so that, with valves of rated characteristics, operating with all electrode voltages applied on a normal storage-battery voltage of 2.0 volts per cell (without a charger) or 2.2 volts per cell (with a charger), the voltage drop across each 1.4 volt section of filament will be maintained within a range of 1.25 to 1.4 volts with a nominal centre of 1.3 volts. In order to meet the recommended conditions for operating filaments in series it may be necessary to use shunting resistors across the individual 1.4 volt sections of filament.

(4.13) **Power line supply**—The filament may be operated either singly or in series with the filaments of similar valves. For such operation, in either case, design adjustments should be made so that, with valves having rated characteristics operating with all electrode voltages applied and on a line voltage equal to the design-centre voltage, the voltage drop across each 1.4 volt section of filament will be maintained within a range of 1.25 to 1.4 volts with a nominal centre of 1.3 volts. In order to meet the recommended conditions for operating filaments in series, it may be necessary to use shunting resistors across the individual 1.4 volt sections of filament.

(4.2) **Positive and negative voltage electrodes**—The electrode voltage supplies may be obtained from dry-cell batteries, storage batteries, or from a power line. For such operation the electrode voltages should be chosen so that the maximum ratings of plate voltages, screen-supply voltages, electrode dissipations and total cathode currents are not exceeded at the supply design-voltages specified under 2.3, 2.2 and 2.1 respectively.

(5) General (all types)

(5.1) **Screen voltage supply**—When the screen voltage is supplied through a screen-dropping resistor, the maximum screen voltage rating may be exceeded provided :

(a) The screen supply voltage does not exceed the maximum plate voltage rating.

(b) At any signal condition, the average screen dissipation does not exceed the maximum rating.

(c) At the signal condition which results in maximum screen current, the screen voltage does not exceed the maximum rating.

(5.2) **Grid voltage limits**—Where a grid voltage is specified as " positive bias value 0 maximum " or " never positive ", this indicates that grid dissipation is not permitted. In such cases it may be inferred that the grid has not been suitably treated to permit dissipation.

(E) Operating conditions

Typical operation—In addition to maximum ratings, information is published on typical operating conditions for most of the various types, when used in particular applications. These typical operating conditions are intended to provide guiding information for the use of each type. They must not be considered as ratings, because each type can, in general, be used under any suitable conditions within its rating limitations.

Datum point for electrode potentials—In published data, it is standard practice for the values of grid bias and positive-potential-electrode voltages to be given with reference to a specified datum point, as follows :—For types having filaments heated with direct current, the negative filament terminal is taken as the datum point to which other electrode voltages are referred. For types having filaments heated with alternating current, the mid-point (i.e., the centre tap on the filament transformer secondary, or the mid-point on a resistor shunting the filament) is taken as the datum point. For types having equi-potential cathodes (indirectly heated) the cathode is taken as the datum point.

Grid bias for a.c. or d.c. filament excitation—If the filament of any type whose data are given for a d.c. filament voltage is to be operated from an a.c. supply, the grid bias given for d.c. filament operation should be increased by an amount approximately equal to one half the rated filament voltage and be referred to the filament mid-point. Conversely, if it is required to use d.c. filament excitation on any filament type whose data are given for an a.c. filament voltage, the value of grid bias given should be decreased by an amount approximately equal to one-half the rated filament voltage, and be referred to the negative filament terminal, instead of the mid-point as in a.c. operation. This rule is only approximate and does not, in general, provide identical currents for both types of filament excitation.

(v) Recommended practice and operation

The following additional limitations on valve practice and operation are based partly on the recommendations of the British Standard Code of Practice (Ref. 49) also on the B.V.A. Radio Valve Practice (Ref. 48), and on established design practice.

(a) **Mounting**—(1) Unless otherwise stated it is desirable that valves should be mounted base down and in a vertical position. Where it is necessary to depart from vertical mounting, the plane of the filament of directly heated valves should be vertical. Similarly, the plane of the grid side rods (or major axis of the control grid) of indirectly heated valves having a high transconductance and/or a long unsupported cathode, should be vertical. This reduces the possibility of filament- and cathode-to-grid short circuits and microphony in filament valves.

It is particularly undesirable that valves having high plate dissipation ratings should be mounted base upwards without agreement from the valve manufacturer, as this method of mounting seriously affects the flow of air around the bulb and may result in the limiting temperature being exceeded.

Depending on the distribution of the bulb temperature, gas may be released from the getter deposit under these conditions and the vacuum and emission affected.

(2) It is particularly important that the connections to floating contacts of sockets for glass based valves should be as flexible as possible and that the contacts themselves should float properly and not become rigidly locked in position. The use of a wiring jig, having the nominal specified dimensions for the base type, inserted in the valve socket during wiring, is desirable in order to locate the socket contacts correctly, so that strain on the base pin seals is minimized when the valve is inserted. Prior to insertion, the base pins of miniature valves should be straightened by means of a pin-straightener, if misaligned. The pin-straightener may consist simply of a steel block drilled with countersunk holes of the correct diameter and location, to slightly larger tolerances than those specified for the pins of the base type. For specific information and design, reference should be made to the valve manufacturer.

(3) It is undesirable to use socket contacts as connecting tags in circuit wiring because of circumstances which may arise if the valve is subsequently replaced by another

having different or additional pin connections. In particular, contact No. 1 of octal sockets should not be used in this connection, as frequently internal base shielding is brought out to pin No. 1 of octal-based valves, which should be connected to chassis. Furthermore, in glass-based valves the above-mentioned practice may adversely affect the valve characteristics by the application of a voltage to pins which are not connected to any valve element, but which project into the envelope.

(4) Valves with rigid pins in glass bases and valves without bases which have short rigid lead-out wires are normally intended to be mounted in sockets, and it is recommended that such valves should not be soldered directly into the wiring, as such connections can impose sufficient strain to endanger the seals.

(5) If valves are to be subjected to continuous vibration, means should be employed to damp out such vibration by the use of cushioned valve socket mountings.

(b) Ventilation

(1) The layout and design of equipment should afford sufficient ventilation to ensure a safe bulb temperature under all conditions. As a general guide, the maximum temperature of the hottest part of the bulb under operating conditions in the equipment should not exceed by more than 20°C. that temperature which would be attained if the valve were operated at its maximum ratings under conditions of free air circulation in an ambient temperature of 20°C. Where exceptional increases of temperature may occur (e.g., when valves are used in screening cans or in equipment working in tropical conditions) the valve manufacturer should be consulted on each type concerned.

The present trend in valve design is to reduce dimensions with the object of saving space and of improving efficiency at high frequencies, and the extent to which the reduction can be made is usually limited by the amount of heat which can be dissipated from the exterior surface of the bulb.

For valves of present day sizes operating at normal temperatures, about half the heat is dissipated by convection and half by radiation. It is therefore necessary to allow free convection of reasonably cool air past the bulb and free radiation from the surface of the bulb to cooler surroundings.

The increase in the temperature of air in convective cooling is very small and it is therefore more important that the flow of air should be copious and unimpeded than that it should be particularly cold. No great risk is incurred if the air is slightly warmed by passing near other components if this allows it to flow through a less obstructed path.

In order to improve radiation from a valve, surrounding surfaces should not be polished but should be kept as cool as possible. The temperature of a valve surrounded by a plated shield can, or by components at about its own temperature, may rise seriously.

(2) When valves are mounted in other than upright vertical positions, greater care should be taken to ensure that adequate ventilation is provided.

(3) Adequate ventilation is particularly important in the case of output valves and rectifiers.

(c) Heater-cathode insulation

(1) It is generally desirable to avoid a large potential difference between heater and cathode. This potential should not normally exceed 100 volts except in the case of certain indirectly-heated rectifier valves and valves specially designed for a.c./d.c. operation. Where a design necessitates higher heater-cathode potentials, a recommendation of the maximum permissible value should be obtained from the valve manufacturer. For convenience, the maximum heater-cathode voltage rating is usually given as a d.c. value.

(2) The insulation resistance between the heater and the cathode should not be included in r-f circuits where frequency stability is required or in a-f circuits followed by a high gain amplifier.

The leakage currents make themselves apparent as noise or hum, which may assume serious proportions if the valve in which they originate is followed by a large degree of amplification. Moreover, if the heater-cathode insulation is included in a tuned circuit, any alteration to the physical or electrical properties of the insulation will alter the frequency to which the circuit is tuned, and if both r-f and mains frequency voltages exist across the insulation, there is a risk of modulation hum, particularly in cathode-coupled oscillators and the like.

(d) **Control grid circuit resistance**

In all cases where published recommendations are available from the valve manufacturer, they should be followed. The maximum value of grid circuit resistance in the case of a particular type of valve cannot be specified without knowledge of the valve characteristics and conditions of operation. In no circumstances should valves be operated without a d.c. connection between each electrode and cathode.

The maximum value of control grid circuit resistance which may be used under any condition of operation depends initially upon the stability of performance required but ultimately upon the transconductance under that condition, the increase in cathode current and electrode dissipations which may occur due to the cumulative effects of reverse grid current (gas, grid emission and leakage) permitted by the specification, the maximum ratings for these characteristics, and the limiting effect of resistances in series with the cathode and in the electrode circuits in series with the various electrode supply voltages. The following formulae, expressing the relationships between the various resistances, direct currents and electrode parameters in typical grid controlled triodes, tetrodes and pentode circuits hold providing the control grid current is negligible in comparison with the total cathode current.

For pentodes and tetrodes (Ref. 41)

$$R_{g1}=\frac{\Delta I_k}{\Delta I_{c1}}\left[\frac{1}{g_k}+R_k\left(1+\frac{1}{\mu_{g1\cdot g2}}\right)+P\frac{R_{g2}}{\mu_{g1\cdot g2}}\right] \tag{6}$$

For triodes (Ref. 41)

$$R_{g1}=\frac{\Delta I_b}{\Delta I_{c1}}\left[\frac{1}{g_m}+R_k\left(1+\frac{1}{\mu}\right)+\frac{R_L}{\mu}\right] \tag{7}$$

where ΔI_k = change in cathode current permitted by maximum ratings of plate dissipation and/or cathode current ; or change in performance which can be tolerated.

ΔI_b = change in plate current permitted by maximum ratings of plate dissipation and/or cathode current ; or change in performance which can be tolerated.

ΔI_{c1} = change in control grid (No. 1) current which is likely to occur or is permitted by the valve specification.

R_{g1} = grid resistor (ohms).

R_{g2} = series screen resistor (ohms).

R_k = cathode resistor (ohms).

R_L = series plate load resistor (ohms).

$\mu_{g1\cdot g2}$ = triode amplification factor of pentode or tetrode.

μ = amplification factor of triode.

P = ratio of screen current (I_{c2}) to cathode current

$$=\frac{I_{c2}}{I_{c2}+I_b}$$

g_m = grid-plate transconductance (mhos).

g_k = grid-cathode transconductance (mhos)

$$=g_m\frac{I_k}{I_b}.$$

To determine the limiting value of grid resistor which may be used, ΔI_{c1} should be taken as the maximum value of reverse grid current permitted by the specification, under maximum electrode dissipation and cathode current conditions ; ΔI_b and ΔI_k are the changes in plate and cathode currents which result in maximum rated plate and/or screen dissipations and/or maximum cathode current.

The maximum rating which is reached first determines the limiting value of the grid resistor.

If the specified value of ΔI_{c1} is not available, the highest typical value of reverse grid current given in Sect. 3(iv)A for each major group of valve types may be used with discretion. In cases where the valve is being operated below maximum rated conditions and at a total cathode current less than that for the grid current test conditions, the value of ΔI_{c1} may be taken as varying approximately as the cathode current.*

It should be clearly understood that equations (6) and (7) are fundamental, and, in cases where no maximum grid circuit resistance values are published, may be used to calculate maximum safe values. These equations are based on the margin (ΔI_b) between the operating plate current and that value of plate current which gives maximum plate dissipation or maximum cathode current or which gives the maximum tolerable change in performance, the limiting condition of operation being determined by the rating which is reached first. It may happen that the published typical operating conditions give maximum rated plate dissipation—in this case ΔI_b or ΔI_k is zero, and the equations cannot therefore be applied to calculate R_{g1} directly. In such a case the procedure is to assume reasonable values of R_{g1} and ΔI_{c1}, and then to use the equations to derive ΔI_b or ΔI_k. The operating plate or cathode current would then be made less than the permissible maximum by the margin ΔI_b or ΔI_k. Alternatively a lower value of R_{g1} may be chosen and the conditions of operation recalculated.

If a maximum value of R_{g1} is published for fixed bias operation, then the value for cathode bias may be determined from equations (8) to (13):

For pentodes and tetrodes—general case

$$\frac{R_{g1}\text{ for cathode bias}}{R_{g1}\text{ for fixed bias}} = 1 + g_k\left[R_k\left(1+\frac{1}{\mu_{g1\cdot g2}}\right)+\frac{PR_{g2}}{\mu_{g1\cdot g2}}\right] \tag{8}$$

$$\text{or approximately} \approx 1 + g_k\left[R_k+\frac{PR_{g2}}{\mu_{g1\cdot g2}}\right] \tag{9}$$

$$\text{(or when } R_{g2}=0\text{)} \approx 1 + g_k R_k \tag{10}$$

For triodes—general case

$$\frac{R_{g1}\text{ for cathode bias}}{R_{g1}\text{ for fixed bias}} = 1 + g_m\left[R_k\left(1+\frac{1}{\mu}\right)+\frac{R_L}{\mu}\right] \tag{11}$$

$$\text{or approximately} \approx 1 + g_m\left[R_k+\frac{R_L}{\mu}\right] \tag{12}$$

$$\text{(or when } R_L=0\text{)} \approx 1 + g_m R_k \tag{13}$$

In the case of resistance-loaded triodes and pentodes with series screen resistors, the values of R_{g1} as derived from eqn. (6) or (7) respectively will be very high. In such cases the limiting factor is the effect of the reverse grid current on the operating bias. This effect is considered in detail in Chapter 12, Sect. 2(iv) for triodes with fixed bias and Sect. 2(iii) with cathode bias also Sect. 3(v) for pentodes with fixed bias, and Sect. 3(iv)C with cathode bias.

A high value of resistance between the control grid and the cathode should be avoided wherever possible. In B.S.1106, 1943 (Ref. 49) it is recommended that, in general, 1 megohm with self-bias and 0.5 megohm with fixed bias are suitable maxima and that with receiving valves having an anode dissipation exceeding 10 watts the grid-circuit resistance should not exceed 0.5 megohm when self-bias is used and 0.1 megohm with fixed bias. These values must be reduced when one resistor is common to more than one control grid circuit.

The maximum values of grid circuit resistance with r-f pentodes controlled by a.v.c. is covered in Chapter 27 Sect. 3(iv)b.

Some valve types have an inherent negative resistance region in the positive portion of the grid characteristic, due to secondary emission from the grid as a result of the deposition or evaporation of active material from the cathode or deposition from the getter during manufacture. In such cases the resultant grid current may change sign from positive to negative as the grid voltage increases from zero in a positive direction, ultimately becoming positive again. The maximum value of grid circuit resistance

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*This assumes that the grid leakage current is small compared with the ionization current, and that the latter does not increase appreciably during operation.

which may be used under these conditions without **grid blocking** occurring, is that value of resistance represented by the line drawn from the operating bias point on the abscissa, tangential to the cross-over loop of the grid current characteristic below the abscissa as shown in Fig. 2.11.

If the grid circuit resistance is such that the line cuts the loop of the characteristic below the abscissa, blocking will occur if the instantaneous values of grid voltage exceed the voltage of the point at which the line crosses the grid characteristic nearer to the origin. See also Chapter 2 Sect. 2(iii).

Because of the difficulty of controlling the grid current commencement point of oxide-coated cathode and filament valves during manufacture, due mainly to **contact potential variations** caused by variable control grid surface conditions, it is desirable that operating conditions should be chosen, such that the control grid bias is always sufficiently large in relation to the contact potential, so that variations of the latter produce only minor effects on performance. In general, the grid current commencement voltage of indirectly heated cathode types is negative and may have a value up to −1.0 volt but as a rule varies during life. The grid current commencement voltage of filament types is usually positive and seldom exceeds about +0.5 volt, but usually becomes less positive during life and may even become negative. The plate current commencement voltage of diodes due to contact potential behaves in a similar manner.

(e) Operation at low screen voltages

As the grid current commencement voltage may in certain cases be dependent on the value of screen voltage and may become more negative as the screen voltage is reduced, it is in general undesirable to operate valves having low or zero control grid-bias at low screen voltages. In the case of zero-bias operated filament types, operation at low screen voltages may result in the grid current commencement voltage becoming negative and in the flow of positive current, causing either a change in operating conditions due to additional negative bias developed across the grid resistor or damping of tuned grid circuits due to lowered input resistance. In either case undesirable and often wide variations in performance may result.

(f) Microphony

Small variations of electrode spacing cause corresponding variations in the output of the valve, and it is desirable to ensure that little or no vibration reaches the valve. Such vibration may reach the valve by way of the valve socket or acoustically, and it should be noted that microphonic trouble may originate in the converter or i-f stages through modulation of the signal or i-f carrier at audio frequencies. It is recommended that, if possible, the position of the valve in relation to the source of vibration be so chosen that microphony effects will be at a minimum. Methods which may be used to minimize microphony effects are described in Chapter 35 Sect. 3(iv).

(g) Hum

Hum due to conditions within the valves is analysed in Chapter 31 Sect. 4(i). See also Ref. 91 on heater-cathode leakage as a source of hum.

(h) Stand-by operation

Where it is necessary to maintain cathodes and filaments at normal operating temperatures during stand-by periods, better life in general will be obtained when the equipment is so designed that **some,** rather than no, cathode current flows during such periods. It is also essential that the heater or filament voltage be maintained as close to the rated value as possible. Continuous operation of heaters or filaments at voltages exceeding their rated values by more than 10 per cent., without cathode current flowing, will result, generally, in progressively short life being obtained.

In equipments which are designed so that no cathode current flows during stand-by periods for periods of less than 15 minutes, the filament voltage of quick-heating filament types should be reduced to 80 per cent. of normal, while the heater voltage of indirectly heated cathode types should be maintained at normal rated value. For longer periods, both filament and heater power should be turned off.

SECTION 2: CONTROL OF CHARACTERISTICS DURING MANUFACTURE

(i) Importance of control over characteristics (ii) Basic manufacturing test specification (iii) Systematic testing (iv) Tolerances on characteristics.

(i) Importance of control over characteristics

The successful design and continued satisfactory operation of electronic equipment require that the valves used have certain prescribed characteristics, the initial values of which do not vary from valve to valve sufficiently to affect operation seriously and which, throughout life, remain within a prescribed range with only gradual change until the end of useful life is reached Owing however to the highly complex nature of the physical-chemical processes involved in manufacture and the difficulty of controlling the variations of many of these processes under mass production conditions, the ultimate degree of uniformity obtainable in the final product, both in initial characteristics and their variation throughout life, must always be a compromise between the performance required by the equipment designer and user and the manufacturing cost in obtaining that performance. In any individual case, however, the degree to which variation of one or more characteristics affects operation, either initially or during life, depends entirely on the particular application and the critical features of the circuit design. For good circuit performance, it therefore is essential to take into consideration the range of variation of the various characteristics on which operation depends and to ensure that operation, so far as is practicable, is independent of the variation of characteristics, particularly of critical characteristics and characteristics over which limited or no control is exercised in manufacture by the valve test specification.

(ii) Basic manufacturing test specification

Owing to the relatively limited range of variation of mechanical and electrical characteristics for which usability and performance of the various types of valves in their intended applications may be satisfactory, it is necessary to apply tolerances, or " limits " to control the range of characteristics obtained under mass production conditions. For commercial applications these tolerances are chosen to be both satisfactory to the equipment designer and sufficiently wide to be economical and thus enable valves to be manufactured in large quantities at a reasonable cost. **These requirements are embodied in the complete manufacturing test specification, which normally comprises—**

(1) Maximum permissible conditions of operation or **ratings,** as determined by emission capability, goodness of vacuum maintenance and interelectrode insulation.

(2) Nominal values for the principal physical dimensions and electrical **characteristics,** relevant to intended applications under specified operating conditions.

(3) A schedule of mechanical and electrical **tests** (including tolerances and sequence) sufficiently comprehensive to ensure that the prescribed dimensions, and electrical characteristics are maintained in production, and sufficiently severe to indicate likely failure, during life, when operated under maximum ratings.

(4) A **life test** schedule sufficiently severe in conditions of operation and permissible deterioration of the main functional characteristics, to indicate reliability and performance of the product on life, under both normal recommended and maximum rating conditions.

As most valve types are designed to give a certain performance and life in a specific application or limited range of applications, it is important to note that each type is processed accordingly and that, in general, the test specification for a particular type normally includes only those tests which are necessary for adequate and economic control of the characteristics, and are required for satisfactory performance and life in the intended applications. Unintended applications not covered by the maximum ratings or test specification should be referred to the valve manufacturer, as performance and life in many cases can often be decided only by laboratory investigation and special life tests.

Reference to quality control: Ref. 45. Reference to life testing: Ref. 97.

(iii) Systematic testing

For the purpose of systematic testing, valve characteristics may be divided into the following three categories.

(a) **Primary characteristics,** which are fundamental to the basic operation and life of the valve as a thermionic device and its functional operation and usability. These include the mechanical stability of the envelope and electrode structure, external physical dimensions and construction, continuity of electrode connections, characteristics indicating the goodness of the vacuum and emission and the principal functional characteristics dependent on the electrode geometry.

(b) **Secondary characteristics,** which are not fundamental to the operation of the valve, but are, in general, dependent on the primary functional characteristics and essentially determine the degree of performance obtainable in intended applications of the particular type.

(c) **Tertiary characteristics,** which are not fundamental to the operation of the valve, but are dependent on, and are in general controlled by the primary and/or secondary characteristics and either affect performance in a minor degree only, seldom vary sufficiently to affect performance or are important only in certain applications or for purposes of valve design.

In order to control the above-mentioned characteristics after manufacture in accordance with their specification, the acceptance testing procedure is usually organized into the following group of tests, the functions of which are described in detail in the following subsections.

(A) Production Tests.
(B) Design Tests.
(C) Recorded Readings.
(D) Life Tests.
(E) Warehouse Tests.

(A) Production Tests

(1) First Testing

All primary characteristics, except those which are subject only to minor variation from valve to valve, are usually tested 100 per cent. in the factory after manufacture Tests performed on this basis are designated Production or Factory Tests and failure of any valve to meet the prescribed test limits for any production test constitutes cause for total rejection of that particular valve. When characteristics are uniform and quality satisfactory, production tests are usually limited to primary characteristics only and particular characteristics which cannot be otherwise controlled satisfactorily. The normal production tests are performed in the sequence prescribed by the specification and for all types the tests normally include interelectrode shorts and continuity, reverse grid current (gas, grid emission, leakage), cathode current, series-resistance-supplied electrode currents, transconductance, emission or equivalent dynamic characteristic test, noise and microphony.

(2) Holding period

After the schedule of production tests has been completed, it is usual for all valves to be held in storage for periods varying from 24 hours upwards to allow any deterioration of mechanical or electrical characteristics, due to unsatisfactory manufacture, to develop.

(3) Second testing

Following the holding period, all, or the most important production tests are usually repeated either on all valves 100 per cent. or on a representative sample using statistical sampling procedures which have been established as reliable, economical methods of determining either that the maximum percentage of defectives in a given quantity shall not exceed a certain value, or that the average percentage of defectives in the outgoing product shall not exceed a certain level.

When statistical sampling is used, if the product fails to meet the sampling acceptance criteria in one or more tests, or totally, the batch in question is then re-tested 100 per cent. for those tests in which failure occurred, and all defectives screened out. In addition to repeating first-production tests, tests are often included at the second production-sampling test to control characteristics, 100 per cent. testing of which may not be warranted or necessary.

Subject to the product having passed the design and life test criteria to be described, it is now usually transferred to the warehouse for shipping and distribution to manufacturers and wholesalers.

(B) Design tests

All important secondary characteristics are controlled by regularly testing and recording the characteristics of a relatively small sample selected at random, either from each production batch, or each day's production in the case of continuous production, after all the first-production tests have been performed and the defectives for these tests screened out. The sample size is determined by the production batch size on the daily production level, provided characteristics are reasonably uniform. Typical sample sizes used are 1 per cent. (minimum 5 valves) of each batch, or a fixed sample size of 5 to 10 valves per type per day for types in continuous production.

The tests performed on the characteristics included in this group, on the above basis, are called Design Tests and the usual procedure is that failure of more than a stipulated percentage of the valves in the sample to meet the prescribed test limits for a particular characteristic, or failure of more than a stipulated percentage of all the characteristics to meet their prescribed limits, constitute cause, initially for retesting a larger sample—usually 100 valves—for the characteristic(s) failed, and in the event of the failure being confirmed, for 100 per cent. testing of the complete batch for those characteristics in which failure occurred. Failure of any valve of the batch to meet the specification for the characteristic(s) in question is then cause for rejection.

In the case of continuous production, the usual practice is for the failed design tests to be made production tests temporarily until satisfactory control of the characteristics in question has been re-established and the design test criteria for these characteristics can again be met consistently.

Typical design test acceptance criteria require that not more than 10 per cent. of the valves of the sample fail for any one design test or that all the design tests failed do not exceed 20 per cent.

In addition to essential secondary characteristics, other characteristics which are often controlled on a design test basis include those characteristics which are not independent parameters but have their values determined by characteristics which are tested 100 per cent., also characteristics which require to be controlled for particular applications.

Design tests are performed only on valves which meet the prescribed production tests. To this end, the latter normally are repeated and recorded when design tests are performed.

(C) Recorded readings

Tertiary characteristics are controlled, in general, on the basis of criticism and correction from recorded readings of all important characteristics obtained from the design test samples, taken either daily, weekly or monthly, depending on the importance of the characteristic and its liability to variation.

Failure of characteristics tested on this basis to meet the requirements of the specification (or, where not specified, to meet the average range of variation usually maintained) in respect of the design test criteria is cause for criticism only, and not rejection; individual valves having the characteristics indicated are not screened from the product, unless the effect of their variation on performance is likely to be serious.

Where a recorded reading test indicates continuing unsatisfactory control of any particular characteristic, it is usual for that recorded reading to be made a design test temporarily, if considered warranted, until satisfactory control has been re-established.

(D) Life tests

Due to the varying extent to which the mechanical and electrical characteristics may be affected by undetected and consequently uncontrolled variations of manufacturing processes, it is not possible to predict reliably by any schedule of instantaneous tests, however comprehensive, the performance obtainable from any particular valve under operating conditions, and it is necessary to rely on recorded observations of characteristic variation during continuous or intermittent operation under controlled test conditions, to determine ultimate performance. Such tests are known as Life Tests.

Provided maximum ratings have not been exceeded, the life of most oxide-coated cathode high vacuum valves, assuming that the initial emission and electrode insulation are satisfactory, is determined almost entirely by the extent to which the initial vacuum is maintained during storage and during periods of operation and non-operation, as in general the supply of emission-producing material available on the average filament or cathode greatly exceeds that required for the lives normally obtained in practice.

The average rate and uniformity of deterioration of the vacuum- and emission-dependent characteristics which normally occur slowly and uniformly in all valves during operation, and which vary from valve to valve, and any excessive deterioration of mechanical and electrical characteristics due to defective manufacture are controlled by regular life tests of small samples of each type. These life tests are operated normally under maximum rating conditions, for a specified period during which the performance determining characteristic(s) may not deteriorate beyond prescribed values, or for the period (which may not be less than a prescribed minimum) required for such deterioration to occur.

Owing to limitations of equipment and cost, regular control life tests are run usually for periods of 500 to 1000 hours on small samples of the order of 5 valves per type per week for types in continuous production. As variations in characteristics are most liable to occur early in life, readings are usually spaced at increasing intervals to give an indication of the complete life characteristic over the control periods.

A typical life test acceptance criterion of satisfactory life is that the average life obtained per valve, considering all valves of the sample, must be not less than 80 per cent. of the specified duration of the life test. The valves used must also be selected at random and comply with the production and design test acceptance criteria.

In the event of the completed product failing to comply with the life test criteria, delivery of the product is then withheld from the warehouse, until satisfactory life has been re-established.

(E) Warehouse tests

When quality is uniform, the controls normally imposed prior to packing are retests of electrode mechanical stability and continuity, and maintenance of the vacuum, by means of a suitable interelectrode hot " shorts and continuity " test during which each valve is tapped lightly with a specified mallet. Each valve is also re-inspected for any deterioration of the envelope in the case of glass valves, cementing of phenolic bases and top caps, dry or badly soldered pin and top cap connections, type designation and general mechanical finish. Pins of miniature valves are also straightened, if necessary.

(iv) Tolerances on characteristics

(a) Initial characteristics

The tolerances on types of American origin to-day are substantially those published for these types in the American JAN-1A Specification which is based on common valve manufacturing practice in that country and was compiled by a committee which included the major valve manufacturers (Ref. S2 ; for tabulated characteristics see Ref. 65).

(b) Life test end points

Apart from the information published in the relevant American and British Service Specifications, no information is generally available concerning accepted life test end points. In R.M.A. Standard Specification ET-107 (Ref. S7) there is published a list of life test end points which may be regarded as typical of the practice followed by American valve manufacturers. A valve is considered to have reached its life test end point when, at rated filament or heater voltage and specified electrode voltages, the following values have been reached :

1. 65% of rated transconductance for r-f and i-f amplifiers.
2. 50% of rated conversion transconductance and 65% of rated oscillator grid current for converter and mixer types.
3. 50% of rated transconductance for general purpose triode types.
4. 50% of rated power output for power output types.
5. 40% of minimum rated direct current for diode types.
6. 80% of rated current or voltage for rectifier types.
7. 70% of normal alternating output voltage for resistance-coupled amplifier types.

Note.—Rated values are those referred to on R.M.A. Electron Tube Characteristic Sheets under maximum typical operating conditions.

SECTION 3: METHODS OF TESTING CHARACTERISTICS*

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*The assistance of A. H. Wardale, Member I.R.E. (U.S.A.) and D. H. Connolly, A.S.T.C., is acknowledged.

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(i) General conventions

The methods described in this section are typical of good practice and should only be taken as a guide of good practice. They represent, in general, the main operational tests which are used to control the performance of various types of receiving valves.

The valve under test should have its heater (or filament) operated at the specified voltage for constant voltage types or at the specified current for constant current types. Direct current is generally specified for all characteristic testing, although a.c. may be used for indirectly heated types and directly-heated a.c. power types, but it is essential that the filaments of all directly-heated battery types be operated from direct current.

The positive electrodes (e.g., plate, screen) should be supplied from suitable direct-voltage sources the voltages of which can be adjusted to the values specified. Good regulation (i.e., good voltage stability) is highly desirable for characteristic testing but is expensive to attain with valves drawing high cathode currents. The recommended source is an electronic voltage regulator such as that of Fig. 33.10, the output terminals being shunted by a r-f by-pass capacitor (e.g., 0.01 μF mica). A large capacitance should not be used since this results in a tendency for the voltage regulator to " hunt ". In other cases all supply voltages should be adequately by-passed for a.c. components.

In the case of emission testing, a special low voltage high current source of low internal resistance is essential. Where operation is required from a.c. mains, a selenium rectifier supply is usually the most suitable and inexpensive for high current emission testing.

The negative electrodes (e.g., control grid, suppressor) do not normally draw much current, and the voltage regulation of the current source is therefore not very important, but the voltage applied to the terminals of voltage divider supplies, as normally used, must be well stabilized. Either an electronic voltage regulator or a gas type voltage regulator tube, or both, may be used. If the characteristics are to be tested with the grid positive, the " screen " source may be used for triode grids ; otherwise an additional electronic voltage regulator (of the same type as for the plate and screen) should be used. All direct electrode voltages are to be measured with respect to the cathode. In dynamic tests the voltages are to be measured under operating conditions.

In all methods of testing, depending upon the particular characteristic, well filtered supplies both positive and negative should be used.

The basic circuit for testing electrode currents with variable applied voltages is indicated in Fig. 3.1 for use with diode, triode or pentode valves and negative grid voltages. If instability is experienced with valves having high transconductance, a screen stopper of 50 to 100 ohms with or without a control grid stopper of say 500 ohms should be connected directly to the electrodes concerned. It is very important that these resistors be non-inductive and, in the case of the screen stopper, of sufficient rated dissipation. The screen stopper should be by-passed directly from the supply side to the cathode using a mica capacitor of, say, 0.01 μF capacitance.

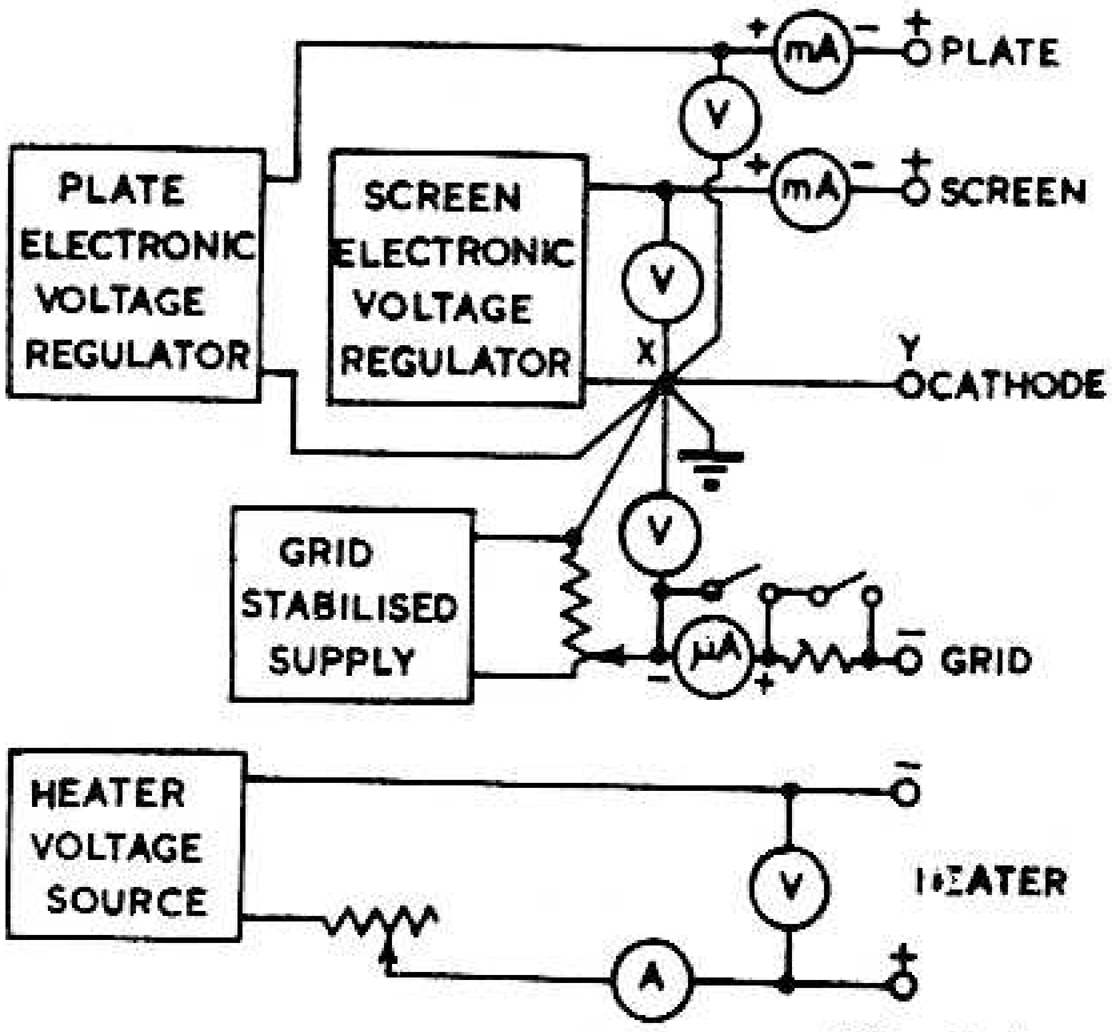

FIG. 3.1

Fig. 3.1. *Basic circuit for testing electrode currents.*

Pre-heating

Pre-heating with heater voltage applied to the heater only is generally adequate for all ordinary purposes where it is necessary to conserve time, except where full electrode dissipation pre-heating is required by particular valve specifications under acceptance testing conditions, or when testing for reverse grid current (gas, grid emission and hot leakage). When full electrode dissipation is applied, the time of pre-heating is normally 2 minutes (JAN-1A) to 5 minutes (R.M.A.). Maximum valve ratings should not be exceeded during pre-heating.

See References S2, S7.

(ii) General characteristics

(a) **Physical dimensions**—Valves may be checked for overall length and maximum diameter either by the use of " go/not go " gauges or by an adjustable length gauge and outside calipers respectively.

Standard ring gauges for checking maximum and minimum base and sleeve diameters, also pin alignment gauges, are specified by R.M.A. Standard ET-106 (Ref. S6).

(b) **Shorts and continuity**—It is important to ensure that electrodes such as control and signal grids and suppressors, which do not normally dissipate any power, should not be subjected to any appreciable power dissipation during the shorts and continuity test, otherwise the valve may be damaged as the degassing treatment of these grids during manufacture is normally much lighter than that of electrodes which are required to dissipate power. In addition, the cathode current drawn, particularly in filament types, should not be excessive. It is also important that shorts be checked between the various electrode pin connections and pins designated as no connection, also that the continuity of internal jumper connections between base pins be checked.

The circuit arrangement accepted as the most generally satisfactory for both shorts and continuity with regard to sensitivity and speed of testing is that known as the hexaphase shorts and continuity test. This circuit is now widely used, particularly by valve manufacturers (e.g., Ref. 1, Fig. 54). A modification is shown in Fig. 3.2 which uses 6 110 volt ½ watt neon lamps and is entirely satisfactory for valves not requiring more than 6 independent electrodes. The values shown for this circuit have been chosen to suit the majority of receiving type valves in that the dissipations of the normally negative electrodes are kept low for reasons previously stated—see (b) above—and may not be satisfactory for all valve types. In the case of a semi-universal tester it is essential that the requirements above be observed, and also that all electrode dissipations and peak and average currents be kept within their maximum ratings, otherwise valves may be damaged. **It is also essential as in any shorts tester that the cathode-to-grid voltage, and battery-type filament-to-grid voltage particularly, be kept to a value not exceeding approximately 100 volts,** owing to the small spacing between these electrodes resulting in unreliable " flick " indications of the neon lamps in normally good valves. The test is carried out with the cathode hot, and the resistor R_1 is for the purpose of limiting the peak cathode current to a safe value (3 mA per 50 milliamp. filament strand for 1.4 volt battery valves). The tester uses split anode neon lamps and continuity of each valve electrode is indicated by the glowing of one half of the split-anode neon lamp connected to that electrode. In the case of a short-circuit to cathode, one lamp will light on both electrodes, while in the case of a short-circuit between two or more other electrodes, two or more lamps will so light. There is an optimum arrangement of connections from the terminals A, B, C, D and E to give fairly low voltages between cathode and control grid or other low-dissipation electrodes and to give uniform illumination on all lamps. In some cases, experimenting may be necessary in changing over connections to obtain fairly uniform illumination on all lamps. It is necessary that the insulation of the sockets and wiring be sufficiently good to avoid residual glows on the neon lamps when a valve is not in the socket. This is particularly important in humid climates.

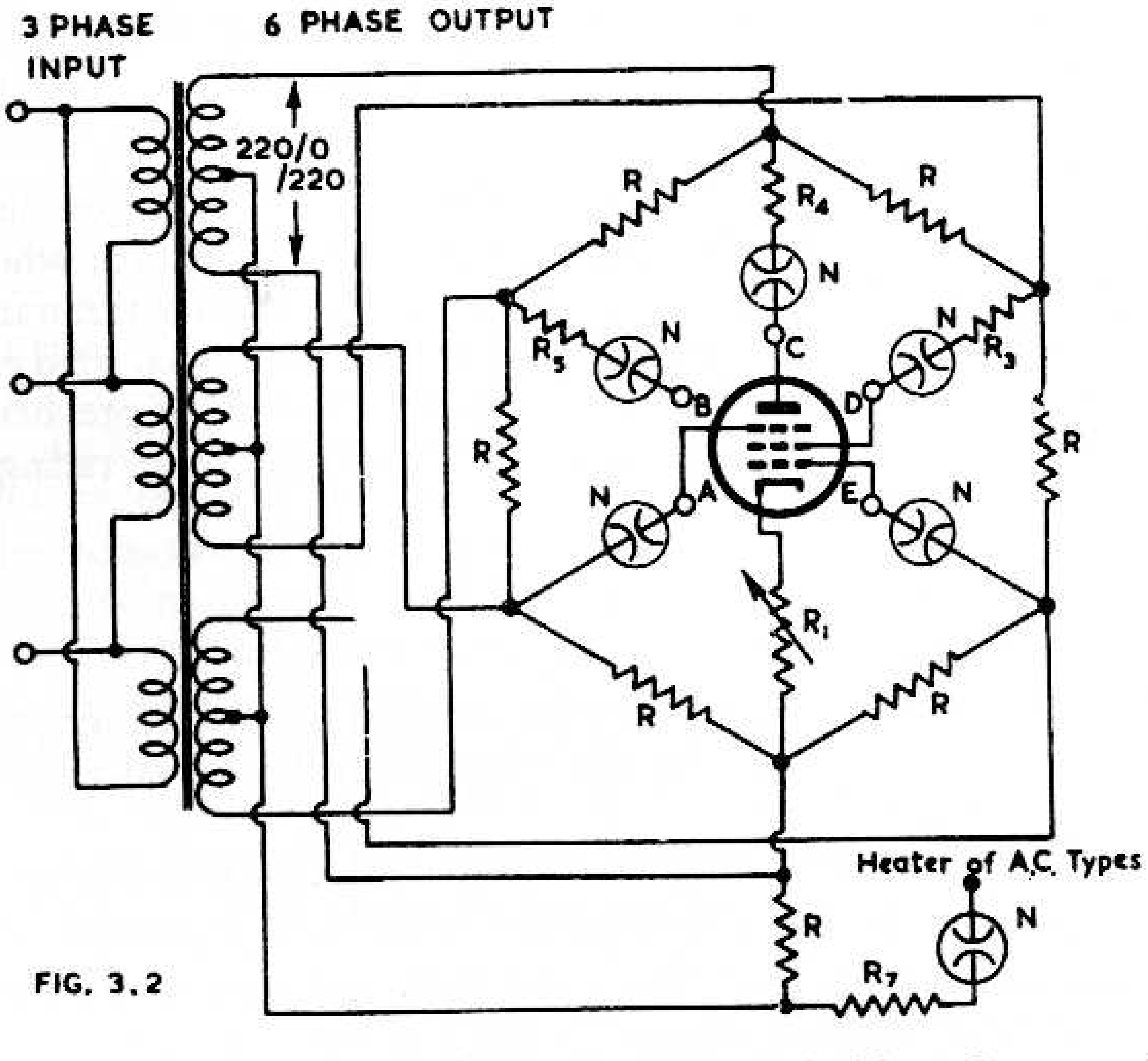

FIG. 3.2

Fig. 3.2. *Hexaphase shorts and continuity tester. Suitable values are* $R=5000$ *ohms*, $R_3=R_5=7500$ *ohms*, $R_4=$ 1500 *ohms*, $R_7=5000$ *ohms*, $R_1=50\,000$ *ohms for battery valves other than power output*, 33 000 *ohms for normal a.c. types, or* 15 000 *ohms for power output valves. Lamps* (*N*) *are* 110 *volt* ½ *watt split-anode neon.*

If more than six lamps are required, additional lamps may be incorporated at suitable points in the " ring " network, but all such arrangements have the limitation that one or more conditions exist where no shorts indication is possible on one or more pairs of lamps.

In addition to the neon shorts and continuity test, filament type lamps may be used to indicate continuity from shield to cathode or along a " jumper " linking two pins.

Continuity of heaters and filaments is indicated by means of a current meter of suitable scale in series with the heater or filament, an open-circuit being indicated by zero current. In the absence of a current meter and where a rheostat is used to drop the filament/heater source voltage, the voltmeter reading may be used to indicate open-circuited filaments or heaters since the voltmeter reading will then be much higher than normal.

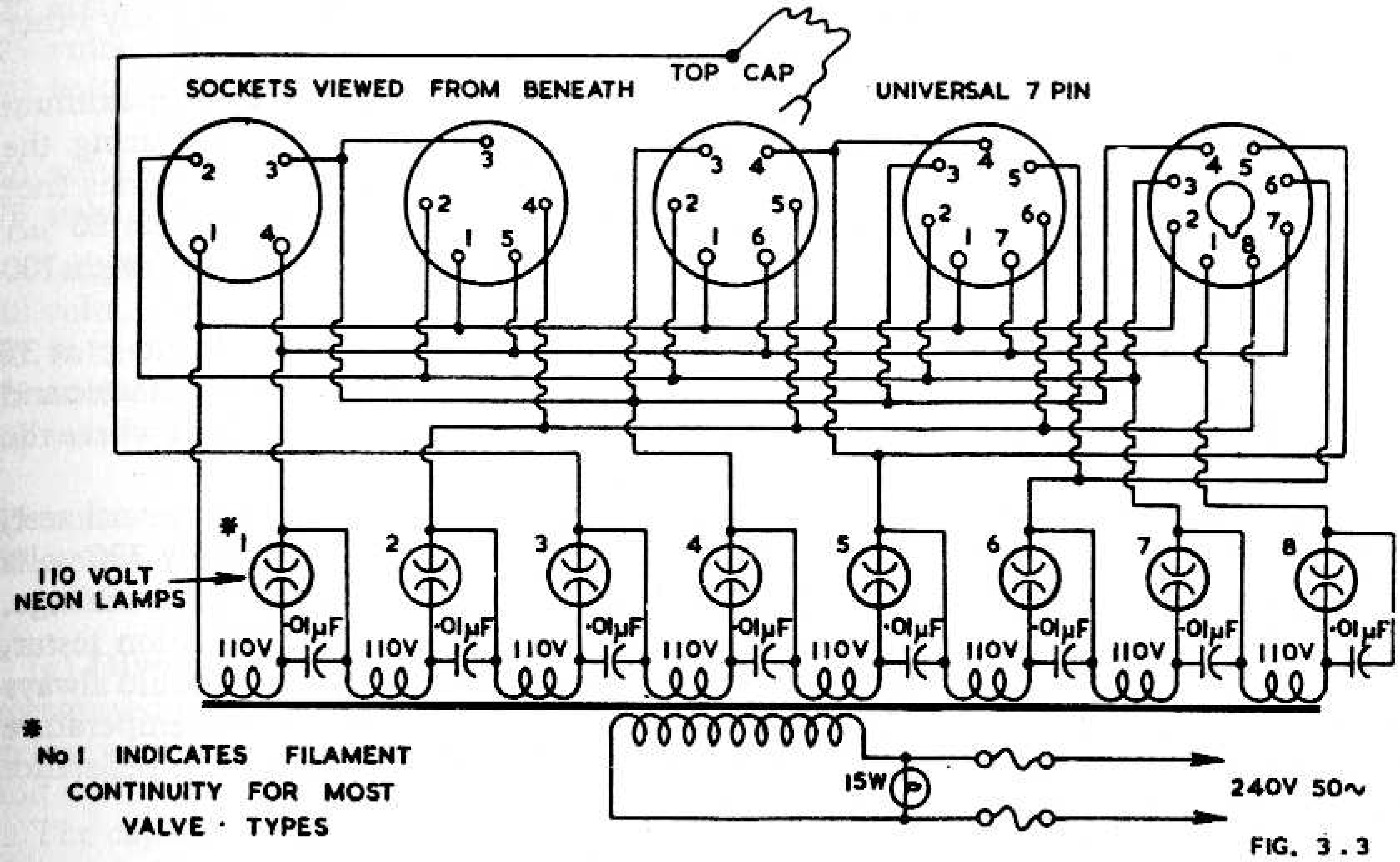

FIG. 3.3

Fig. 3.3. *Older type of shorts and continuity tester.*

The older type of shorts tester is shown in Fig. 3.3 and operates on single phase and requires a total voltage of 880 volts for 8 lamps. This may be used as a hot or cold cathode shorts tester, but has the disadvantages that it only indicates electrode continuity of those electrodes which draw sufficient current to operate lamps to which they are connected. It also has the severe disadvantage that the voltages cannot be arranged conveniently with regard to the electrode configuration for semi-universal testing, as all voltages are in phase, and quite high voltages may be developed between adjacent electrodes in the absence of complicated switching.

When using this type of tester with either hot or cold filament (or cathode), it is essential to connect grid No. 1 to the lowest voltage in the chain with respect to earth, otherwise damage may be done to the valve, or else good valves may indicate as having a short circuit. The other points in the chain should be connected in the same sequence as the grids and plate.

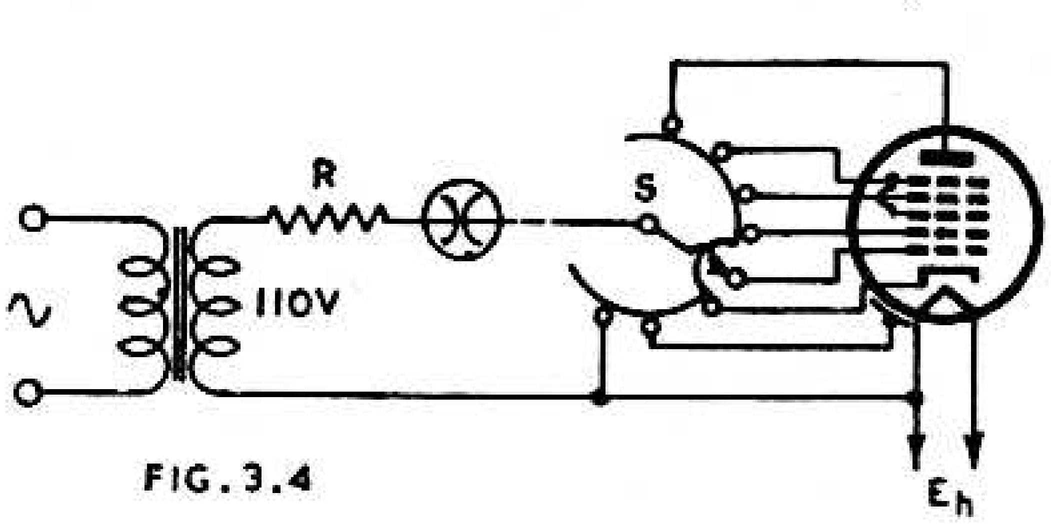

Fig. 3.4. *Simpler type of shorts and continuity tester, employing a single lamp.*

A fairly satisfactory form of single lamp shorts and continuity tester commonly used in service testers is shown in Fig. 3.4. The electrode switch *S* is rotated with the cathode heated. If the neon lamp glows on one side only the particular electrode is connected; if on both sides a short-circuit is indicated. If only one electrode indicates short-circuit, the short is to heater (filament); if two or more electrodes indicate a short-circuit, they are shorted together. The continuity test only works well for the electrodes close to the cathode, the sensitivity decreasing towards the anode.

The same circuit Fig. 3.4 may also be used for a cold cathode shorts test.

(c) **Heater (or filament) current**—This is measured with a d.c. heater source, using the heater circuit as in Fig. 3.1. The heater voltmeter current passes through the ammeter *A*, so that it is necessary for greatest accuracy to subtract the voltmeter current from the current reading. However, with a 1000 ohms-per-volt meter, the current is less than 1 mA and the error is quite small with heater currents of the order of 0.3 A. When measuring filament currents of small battery valves (e.g., 50 mA), the ammeter zero may be set to read zero when the voltmeter is at its nominal reading (e.g., 1.4 volts). The current is normally measured with no connections to any other electrodes. See also Ref. S12, Sect. 2.1.

(d) **Heater-to-cathode leakage**—This may be tested by applying the maximum rated direct voltage between one heater terminal and cathode and measuring the current with a microammeter (say 0-500 μA) with a safety resistance in series (not greater than 100 000 ohms). The leakage current should be not greater than 20 μA for ordinary 6.3 volt 0.3 ampere valves, or 50 to 100 μA for power valves, with 100 volts applied.

The heater may be operated with either a.c. or d.c. supply if below 35 volts ; at 35 volts and above it is usual to operate it on a.c. supply. The voltage between heater and cathode should be applied with both polarities, except in the case of rectifiers where the heater must be negative with respect to the cathode.

(e) **Inter-electrode insulation**—This is not normally a regular commercial test, except to meet service specifications. The test voltage specified is normally 300 volts for small valves or 500 volts for those which are able to stand the higher voltage. The insulation resistance may be measured by any ordinary type of insulation tester, but preferably by an electronic megohm-meter. In this test, the cathode should always be positive. The test is carried out on a valve which has reached a stable temperature under normal operating conditions. The minimum permissible insulation resistance usually specified is 10 megohms (Ref. S2).

This test is not used between heater and cathode.

(f) **Emission**—The purpose of the emission test is to ensure that the cathode emission is adequate to provide the peak and average space currents for the particular application of the type by a margin which has been found to be satisfactory for good life and performance.

Emission is normally tested by applying a suitable direct positive voltage to all grids connected together with the plate, and measuring the total cathode current.

Because of the very high value of the emission current normally drawn from the cathode, the resulting excessive dissipation of the inner grids and the gas produced as a result of this dissipation and also as a result of ion bombardment of the cathode, the emission test is a damaging test and should be performed as seldom as possible and then always very carefully.

In order to avoid damage to the cathode by this test, the applied voltage must be sufficiently large to approach current saturation without drawing sufficient current to damage the valve due to excessive dissipation of the inner grids. At the same time the test must be of sufficient duration to enable the stability of the emission to be indicated without being so long as to give risk of poisoning the emission. A safe value generally accepted for the duration of the emission test is 3 seconds. During this period the emission should not fall below a value recommended by the valve manufacturer. In general, emission is a minimum reading. As most of the cathode current goes to the No. 1 grid, which is usually wound with very fine wire, and treated lightly during manufacture, the applied voltage must be restricted to a value such that the emission current drawn does not result in damage to the valve. The voltages normally used in manufacture are listed below.

Emission testing with applied alternating voltage is also used, but in this case the test becomes one intermediate between a peak emission test and a high current transconductance test. In practice, there is no exact and simple correlation between a.c. and d.c. emission tests due to the fact that the a.c. emission current depends in part on the emission capability of the valve as well as on its geometry. Experience has shown that mains frequency a.c. emission tests tend to be unreliable owing to the fact that the emission " gets a rest " between cycles and, in a practical case, the rating of peak to average emission current drawn cannot be made sufficiently high to be effective.

Voltages given below are based on JAN-1A (Ref. S2) ; values of voltages and minimum emission currents are given by Ref. 65.

Signal diodes are normally tested for emission with an applied direct voltage of 10 volts, except that 20 volts are normally applied to type 6H6.

Power rectifiers are normally tested with applied voltages as listed below (suffixes of valve types have been omitted) :
20 volts—1V, 12A7, 32L7.
25 volts—84/6Z4, 70L7.
30 volts—5V4, 6ZY5, 7Y4, 12Z3, 25A7, 25Z5, 25Z6, 35Z3, 35Z4, 35Z5, 45Z3, 45Z5, 50Y6, 83V, 117N7, 117Z4, 117Z6.
50 volts—5Z4, 6W5, 6X5, 7Z4, 28Z5.
75 volts—5R4, 5T4, 5U4, 5W4, 5X3, 5X4, 5Y3, 5Y4, 5Z3.

Amplifier valves are normally tested for emission with an applied direct voltage of 30 volts. Some of the exceptions are listed below :
10 volts—1AB5, 6AC7, 6AG5, 7E5, 7F8, 7G8, 7V7, 7W7, 26A7.
15 volts—6BE6.
20 volts—1D8, 1J6, 2A3, 3A8, 6AB7, 6AG7, 6SD7, 6SQ7, 6SH7, 7G7, 7H7, 7J7, 7L7, 7Q7, 7R7, 7S7, 19, 28D7, 35L6, 70L7.
25 volts—117N7.
50 volts—6A6, 6B5, 6L6, 6N6, 6N7, 12A5, 24A, 53, 59, 79.

All the voltages listed above are subject to variation by different valve manufacturers.

(g) **Direct interelectrode capacitances**—The following information is based on recognised engineering practice by the manufacturers of American-type valves, and is in line with the I.R.E. Standard (Ref. S1, S12), the R.M.A.-NEMA Standard (Ref. S8) and with JAN-1A (Ref. S2).

The capacitances which are measured are direct interelectrode capacitances, and not the total (self) capacitances which are the sum of two or more direct capacitances. The measured value of inter-electrode capacitance of a valve is dependent upon the valve shield or, in the absence of a shield, upon the geometry of the external environment. It is therefore necessary for the test to be made under strictly specified conditions of valve shielding and of electrode and internal valve screen connections.

Published values of interelectrode capacitances are stated either for the condition where the valve is shielded with a specified standard valve shield (see below) or is unshielded. Interelectrode capacitances are normally measured with the cathode cold and with no direct voltage applied to the electrodes. The base pins and leads are shielded from each other and from other elements of the valve so that they and their connections do not form part of the capacitance being measured. All external metal parts integral with the valve should be connected to the cathode ; such parts include lock-in valve bases, metal base shells, and pins with no connection. When capacitance measurements are made on indirectly-heated valves the heater should be connected to the cathode unless in special cases the measurement is between the cathode only and other elements, or the heater and other elements. For valves having elements other than a control grid, a plate, and a cathode, the additional elements of the active section including internal shields should be connected to the filament or cathode by the shortest possible connections. For a multiple-unit valve structure, all elements of the other section(s) should be earthed except when reading inter-section coupling capacitances.

The test sockets should be Standard Capacitance Sockets as specified by R.M.A.-NEMA (Fig. 3.4A). Valves with top caps should be tested with the R.M.A.-NEMA Standard Cap Connectors (Fig. 3.4B).

The connections to be made to the electrodes while testing for interelectrode capacitances are given below :

Input capacitance is tested by measuring the capacitance between grid and cathode, the latter being connected to heater, screen and shields ; the plate is earthed.

Output capacitance is tested by measuring the capacitance between plate and cathode, the latter being connected to heater, screen and shields ; the grid is earthed.

Capacitance from grid to plate for all types of valves is measured with all other electrodes earthed.

In multiple unit valves, the capacitance between the grid of one section and the plate of the other is measured with all other electrodes earthed ; similarly from one plate to the other.

The input capacitance of a diode is measured between its plate and cathode, the latter being connected to heater and shields ; other sections are earthed.

The capacitance between diode-plate and grid or plate of other sections is measured with all other electrodes earthed.

In a converter, the r-f input capacitance is measured between the signal grid and all other electrodes connected together.

The mixer output capacitance is measured between the mixer plate and all other electrodes connected together.

The capacitance from oscillator grid to oscillator plate is measured with all other electrodes earthed.

The oscillator input capacitance is measured between oscillator grid and cathode, the latter being connected to heater and shields ; the oscillator plate and all electrodes of the other section being earthed.

The oscillator output capacitance is measured between oscillator plate and cathode, the latter being connected to heater and shields ; the oscillator grid and all electrodes of the other section being earthed.

The capacitance between oscillator grid and signal grid, or oscillator plate and signal grid, is measured with all other electrodes earthed.

In converters in which there is usually a r-f voltage between cathode and earth (e.g., 6BE6), the oscillator output capacitance is measured between cathode and heater, the latter being connected to screen and shields ; the oscillator grid being earthed.

The oscillator input capacitance is measured between oscillator grid and all other electrodes connected together. The capacitance between oscillator grid and cathode is measured with all other electrodes earthed.

Standard sockets, cap connectors and shields for use in the measurement of valve capacitances (R.M.A.-NEMA, Ref. S8).

(1) **Sockets**

The construction and shielding of capacitance sockets and leads shall be such that when the holes for the insertion of the base pins are covered with a grounded, flat metal plate, the capacitance between any one socket terminal and all other socket terminals tied together does not exceed 0.000 10 $\mu\mu$F for receiving valves.

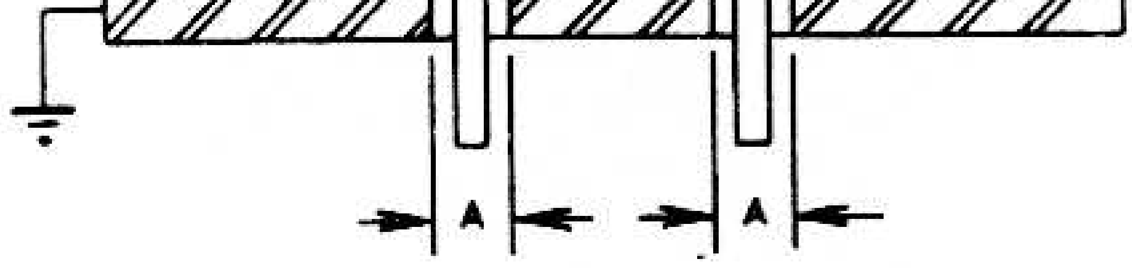

Fig. 3.4*A.* *RMA-NEMA Standard Capacitance Sockets* (*Ref.* *S*8).

The hole for the accommodation of the locating lug of octal and lock-in bases shall be less than 0.500 inch diameter.

The diameter of holes for the insertion of the base pins (see Fig. 3.4A) shall be limited to the values shown in Table 1. The socket face plate shall be flat and shall have a minimum diameter as shown in Table 1. Any structure above the face plate shall have negligible effect on the capacitance being measured.

A thin insulating film may be permanently attached to the face plates of capacitance sockets to provide insulation for ungrounded shielding members.

The socket shall be so constructed that the base of the valve under test will seat on the face plate.

Table 1.

Base Designation	**Max. diameter (A)***	**Max. diameter (B)***
Standard 4, 5, 6 or 7-pin	0.250 in.	3 in.
Octal	0.175 in.	3 in.
Lock-in	0.093 in.	3 in.
7-pin miniature	0.075 in.	$2\frac{1}{2}$ in.
9-pin miniature	0.075 in.	$2\frac{3}{4}$ in.

*see Fig. 3.4A.

(2) **Cap connectors.**

Standard Cap Connectors shall be made as shown in Fig. 3.4B. A thin insulating film may be placed on surface X in Fig. 3.4B. Dimensions in inches shall be as tabulated below.

Designation	A	B	C
Medium	$\frac{21}{32} \pm \frac{1}{64}$	0.556	0.850
Small	$\frac{29}{64} \pm \frac{1}{64}$	0.352	0.750
Miniature	$\frac{21}{64} \pm \frac{1}{64}$	0.242	0.750

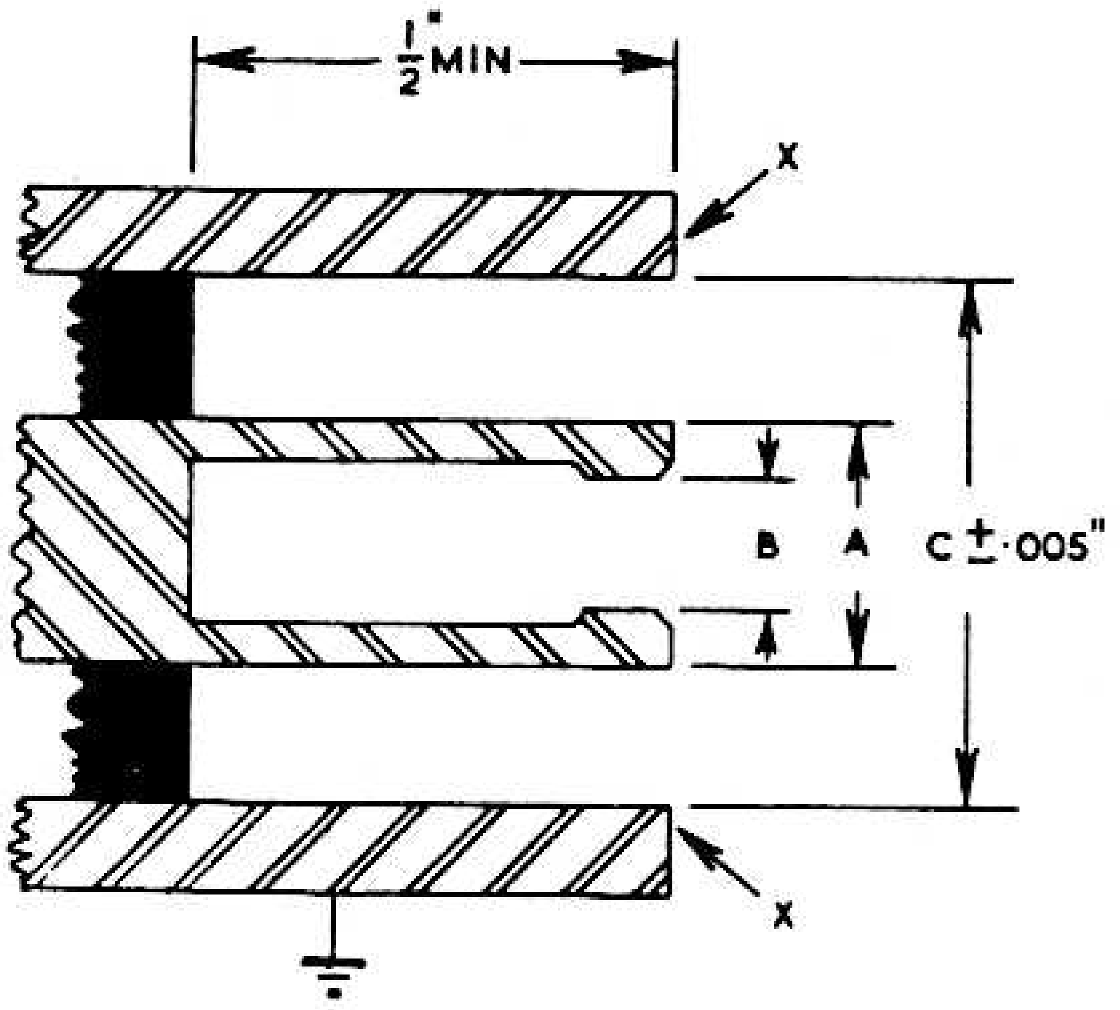

Fig. 3.4B. RMA-NEMA Standard Cap Connectors for use in measurement of valve capacitances (Ref. S8).

(3) **Shields.**

Standard shields are shown in Fig. 3.4C. It is recommended that these shields be used as indicated below, or as specified by the valve manufacturer.

Shield No.		Max. seated height with top cap	without top cap
308	GT glass types with T9 bulbs*	3	$2\frac{7}{8}$ in.
309	G glass types with T9 bulbs*	$3\frac{3}{4}$	$3\frac{9}{16}$ in.
311	G glass types with ST12 bulbs*	$4\frac{5}{16}$	$3\frac{31}{32}$ in
312	G glass types with ST14 bulbs* G glass types with ST16 bulbs*	$4\frac{13}{32}$ $5\frac{1}{8}$	$4\frac{1}{16}$ in. $4\frac{3}{4}$ in.
315	Miniature types with T6½ bulbs*	—	$2\frac{3}{8}$ in.
316	Miniature types with T5½ bulbs*	—	$2\frac{3}{8}$ in.

(4) **Methods of measuring inter-electrode capacitances** are described in the I.R.E. Standard (Ref. S12). The R.M.A.-NEMA Standard (Ref. S8) states that the r-f bridge method (Refs. 77, S8, S12) and the transmission method (Refs. S8, S12) shall be the standard methods of measuring interelectrode capacitances ; both methods are described. These measurements are normally made only in valve laboratories.

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*The maximum outside diameters of these bulbs are : T9 1-3/16 in. ; ST12 1-9/16 in. ; ST14 1-13/16 in. ; ST16 2-1/16 in. ; T5½ 3/4 in. ; T6½ 7/8 in.

RMA-NEMA STANDARD SHIELDS FOR USE IN MEASUREMENT OF VALVE CAPACITANCES (Ref. S8)

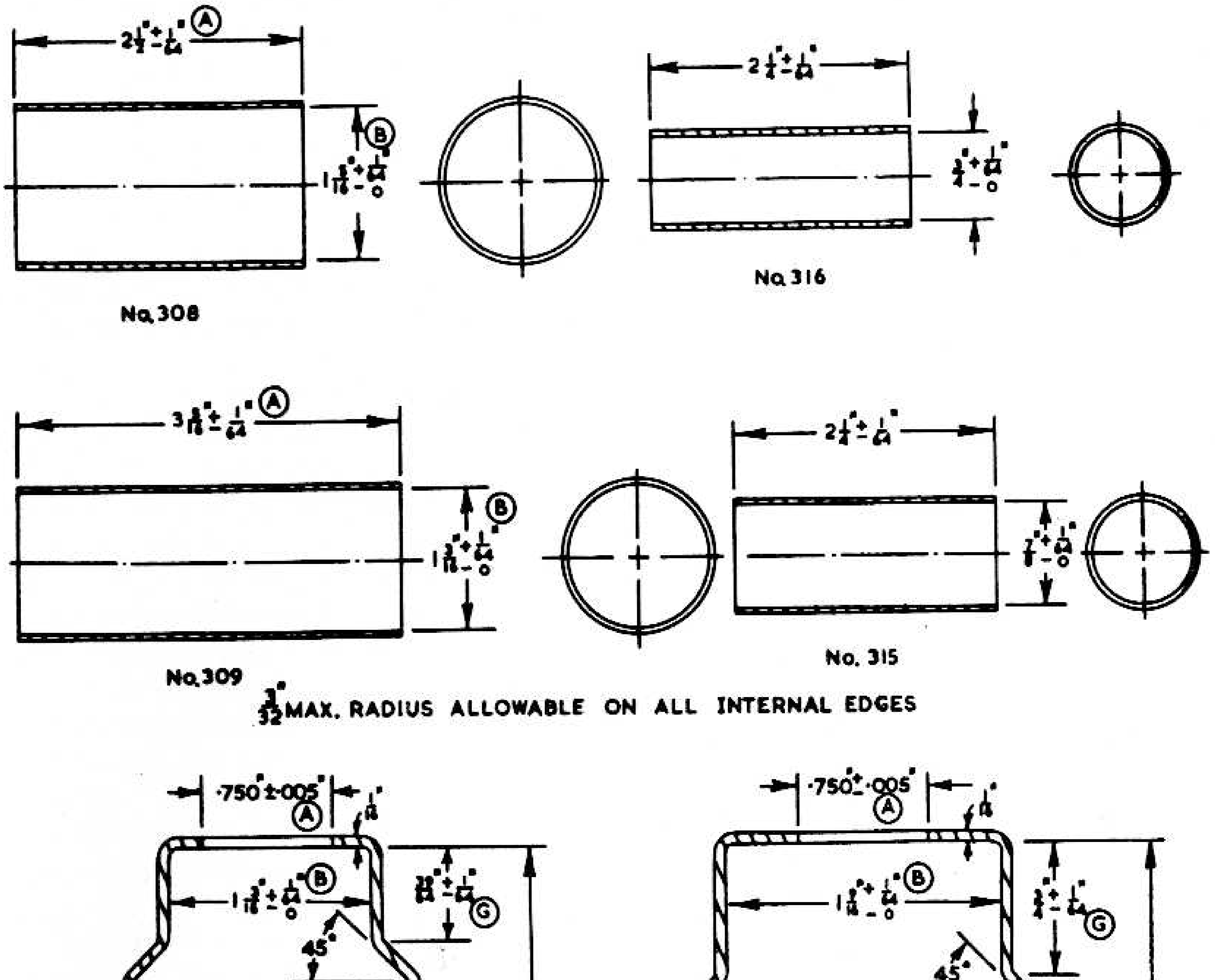

FIG. 3.4C

The significance of interelectrode capacitances and their measurement are covered by many text books and some articles including Refs. 3, 4, 5, 8, 9, 10, 11, 12, 13, 16, 18, 21, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 74, 75, 76, 77.

The special low range capacitance bridge circuit used in the inter-electrode capacitance meter of Ref. 3 is capable of measuring directly the capacitances, with a range from

0.0001 to 2 $\mu\mu$F, between any two electrodes of a valve with all the other electrodes earthed, at a frequency of 400 Kc/s.

Capacitances above 2 $\mu\mu$F are usually measured on a simple capacitance bridge at 1000 c/s. Commercial bridges having a logarithmic scale are available for this purpose, reading from 0 to 30 $\mu\mu$F. However, audio-frequency bridges are out of the question for very low capacitances, because the insulation resistance between electrodes may be lower than the reactance of a 0.0001 $\mu\mu$F capacitance. Even at 1000 Kc/s the reactance of this value of capacitance is 1500 megohms.

The capacitance measured with an audio-frequency capacitance bridge is frequently higher than that measured with a capacitance bridge operating at radio frequency. This effect is associated with the presence of resistive films on the insulators supporting the valve electrodes. Such films may be caused by deposition of getter or by the evaporation of metal from the cathode either during the manufacture or during the life of the valve. The value of the resistance may be as high as 1000 megohms or more, but is capable of modifying the measured value of the capacitance and prevents the prediction of the performance of the valve at frequencies higher than that of the measurement (Ref. 23).

The actual capacitance of a valve depends on its operating conditions and the impedances in the electrode circuits. For purposes of specification testing the valve is tested with the cathode cold and without any voltages applied to the electrodes. In any particular case under specified operating conditions the interelectrode capacitances will differ from the static capacitances measured in this way. For further information see Chapter 2 Sect. 8(iii) and the references there listed.

(iii) Specific diode characteristics

(a) Rectification test. Power diodes—The rectification test is an operation test as a rectifier at the maximum ratings for applied r.m.s. voltage with condenser input filter, and with the maximum rated values of average and peak currents. The basic circuit is shown in Fig. 3.5 in which T_1 is the plate transformer and T_2 is the filament transformer. The average current is measured with the d.c. milliammeter, while the voltage across R_L may either be calculated from the resistance and current or may be measured by the direct voltmeter V. The condenser C_L should be an impregnated paper type.

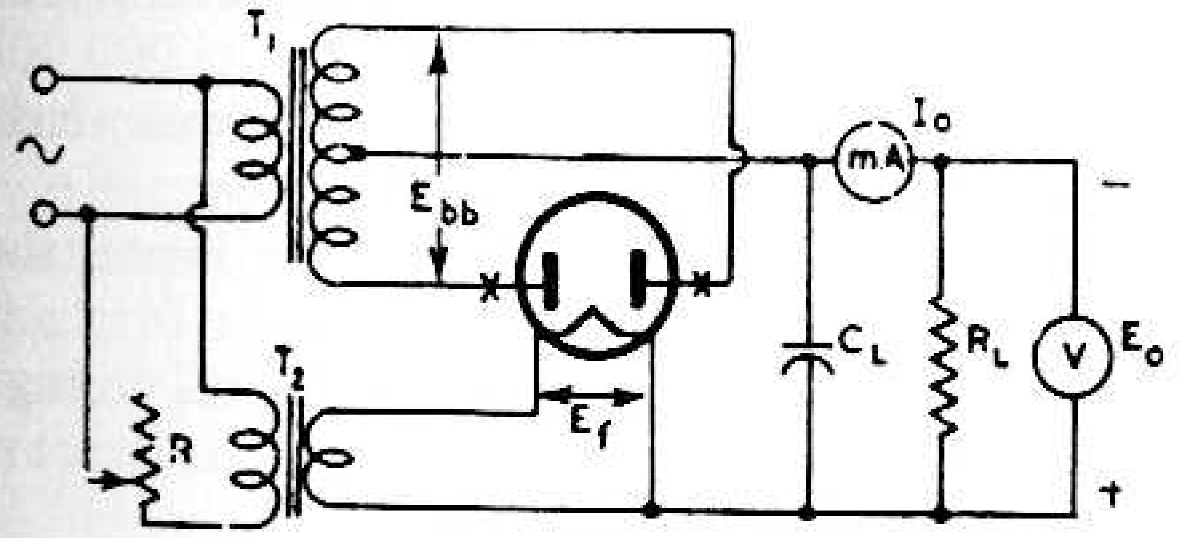

FIG. 3.5

Fig. 3.5. Rectification test.

The plate supply impedance is that of transformer T_1 which should be one having good regulation and low winding resistance.

In a transformer the plate supply impedance per plate is given approximately by

$$R_S \approx N^2 R_{pri} + R_{sec} \qquad (1)$$

where N = voltage ratio of transformer at no load (primary to half secondary in the case of full-wave rectification)

$$= \frac{\text{(half) secondary voltage}}{\text{primary voltage}} \text{ at no load}$$

R_{pri} = resistance of primary winding in ohms

and R_{sec} = resistance of secondary winding in ohms (or half-secondary in the case of full-wave rectification).

If the transformer plate supply impedance per plate is less than the required value, two equal resistances should be added at points XX in Fig. 3.5 to make up the deficiency. If the transformer plate supply impedance per plate is greater than the required value, the test will not be so severe since it will reduce the peak plate current and also reduce the output voltage or current.

In view of this limitation, a rectification test which may be used and which should be satisfactory for all practical purposes is to make use of the maximum published conditions with a condenser input filter. These conditions include the maximum r.m.s. applied voltage, the maximum d.c. load current, the minimum plate supply impedance per plate and the maximum filter capacitance for these conditions, if published. In cases where the latter information is not available, it is usually safe to test with the maximum value of filter capacitance used in the published curves or typical operation data, provided that the plate supply impedance per plate is equal to the minimum rated value or to the value used for the curves or typical operation data, whichever is the greater. In all cases it is essential that the maximum peak plate current rating per plate be not exceeded.

The rectification test may be used for the purpose of checking the output voltage and so determining end of life. The circuit constants for the rectification test may be obtained by the following procedure. The value of R_L is given by E_0/I_0 where E_0 and I_0 are the direct voltage and current respectively across the load resistance under maximum ratings. The value of E_0 is obtainable from the usual operational curves published by valve manufacturers, and is the direct voltage for the maximum r.m.s. applied voltage at the maximum value of load current (I_0). If curves are published for more than one value of filter capacitance, the curve corresponding to the highest capacitance should be selected. The rectification test should be carried out with the value of C_L equal to that used for the derivation of E_0, while the total effective plate supply impedance per plate should be as specified above. Under these conditions an average new valve should give a voltage E_0 and a current I_0 approximately equal to the published values, and individual valves will have values either higher or lower than the average as permitted by the manufacturing tolerances. The end-of-life point is commonly taken as 80 per cent. of the value obtained with a valve having bogie characteristics (R.M.A., Ref. S7).

The rectification test may be carried out either with full-wave rectification as in Fig. 3.5 or with half-wave rectification, each unit being tested separately with half the total average load current. The test is usually performed by inserting a cold valve and waiting until it has attained normal temperature.

In all cases, rectifier valves are required to operate satisfactorily in the rectification test without arcing or sputtering.

Where valve failure has been due to arcing or sputtering, the conditions under which this occurred may be reproduced for the purposes of testing either by

(1) allowing the valve to heat up to normal temperature from cold, the heater and plate supply voltages being applied simultaneously, or

(2) operating the valve at normal temperatures with heater and plate voltages applied, and then " keying " the plate voltage.

(b) Sputter and arcing

Sputter and arcing are closely akin. When an indirectly-heated close-spaced rectifier is warming up with plate voltage applied, there is no space charge and the electrostatic field gradient at any sharp peaks on the cathode surface may be high enough to vapourize the coating material and lead to the formation of an arc. Even when there are no sharp points on either cathode or plate, a discharge of gas leading to an arc may occur when there is no space charge, and the peak current required is greater than the available emission. Sputter does not usually occur with directly-heated rectifiers.

Signal diodes may be tested in a rectification test as an alternative or addition to the emission test. Diodes in diode-amplifier valves may be tested as half-wave rectifiers with $R_L=0.25$ megohm, $C_L=2\,\mu$F and an applied voltage of 50 volts r.m.s.

(c) **Back emission**—Back emission is emission from the plate to the cathode during the half-cycle when the cathode is positive with respect to the plate. Any appreciable amount of back emission results in severe bombardment of the cathode and ultimate plate-to-cathode arcing. Back emission may be tested by the circuit of Fig. 3.6. Switch S_1 is normally closed, and is only opened momentarily while taking a reading. The combined effect of contact potentials and initial electron velocities in the 6X5 and 6H6 rectifiers is to cause a residual current of perhaps 400 μA to pass through the back emission meter while S_1 is closed. The back emission current is then taken as the increase in the meter reading when S_1 is opened.

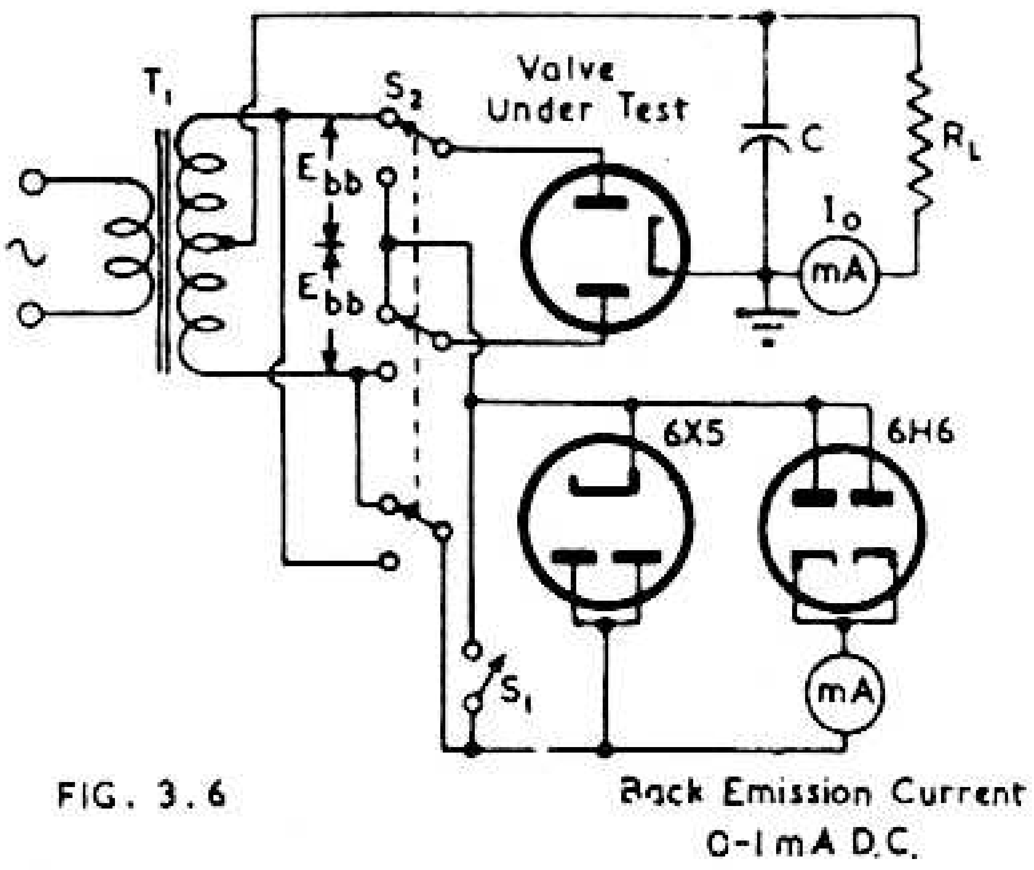

FIG. 3.6

Fig. 3.6. *Back emission test.*

(d) **Zero signal or standing diode current**—This is usually read by measuring the current through, say, 0.25 megohm connected between diode plate and cathode with no signal applied ; the standing diode current is likely to vary during life. It should be noted that the diode direct plate voltage required to make the plate current just zero should never be positive if loss of detector sensitivity at very low signal levels is to be avoided.

(iv) Specific triode, pentode and beam tetrode characteristics

(A) Reverse grid current

Reverse grid current is the sum of gas current, leakage current and grid (primary) emission current. The test is normally carried out after pre-heating—see Sect. 3(i) above—since this is the condition which obtains under normal operation in equipment. Reverse grid current is measured by inserting a microammeter* in the grid circuit in series with a resistor, with maximum plate and screen voltages and dissipations and maximum cathode current. The circuit used is shown in Fig. 3.1 in which the microammeter is protected by a shorting key which is only opened when the reading is to be taken. The maximum value of the grid circuit resistance during the test as specified by JAN-1A should not exceed 100 000 ohms, although values up to 500 000 ohms are commonly used. The reading is normally taken after the reverse grid current has reached a steady value.

Alternatively, a suitable value of grid resistor (R_c) is connected in the grid circuit, with a switch for short-circuiting the resistor when desired. With the switch closed, the grid and plate voltages are adjusted to the desired values and the plate current is read. The switch is then opened and the grid bias readjusted so that the plate current returns to its former value The reverse grid current may be computed from

$$I_c = \Delta E_c / R_c \qquad (2)$$

where ΔE_c = change in grid voltage to maintain constant plate current.
When the mutual conductance is known (or as an approximation using the nominal value) the reverse grid current may be computed from

$$\text{Grid current in microamperes} = 1000\ \Delta I_b / g_m R_c$$

where ΔI_b = change in plate current in milliamps.
g_m = mutual conductance in micromhos
and R_c = resistance of grid resistor in megohms.

Typical values of maximum reverse grid current in new valves, based on American JAN-1A Specifications (Ref. S2).

These values apply to types commonly used in radio receivers. They are only useful as a general guide, since commercial valves may be tested to slightly different specifications

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*Alternatively, an electronic microammeter may be used, incorporating a less sensitive indicating instrument. One possible form uses a 6SN7-GT twin triode, cathode coupled ; the maximum resistance in the grid circuit is 50 000 ohms for a 0-3 μA range. This arrangement has the advantage that the instrument can be made self-protecting so that the indicating meter is not damaged by excessive gas current.

High-mu triode ($\mu \nless 65$)	0.5 to 0.6 μA
Medium-mu triode	1.0 to 2.0 μA
Twin triode—medium mu	1.0 to 1.5 μA each section
high mu ($\mu > 65$)	0.5 to 1.0 μA each section
R-F pentode	
sharp cut-off (generally)	0.5 to 1.0 μA*
remote cut-off	1.0 to 2.0 μA
Power output	2.0 to 4.0 μA
Converter	1.0 to 2.0 μA

*Exceptions are : 6AK5 & 713A 0.1 μA, 6AS6 0.2 μA, 6AJ5 0.25 μA, 1231 & 7G7/1232 1.5 μA.

These reverse grid currents apply rigidly only when measured under the specified electrode conditions (for values see Ref. 65, Sec. 14). These are, in general, identical with the published typical operating condition or, if there is more than one, at the typical operating condition having the greatest plate dissipation.

The maximum value of grid current which may be used in any particular application without seriously affecting the performance, is dependent upon the actual value of grid circuit resistance—see Sect. 1(v)d.

(a) **Gas current (ionization current)**—Gas current cannot be readily measured directly†. It may be determined approximately by measuring the total reverse grid current under conditions of maximum dissipation (see above), and then subtracting the hot leakage current and grid emission current under the same conditions.

(b) **Cold and hot leakage**—Leakage currents may be measured with a voltage applied between the grid and each electrode in turn, with the other electrodes floating. Measurements may be made either with the valve cold (" cold leakage "), or immediately after the filament (or heater) has been switched off after testing for reverse grid current (" hot leakage "). The grid to cathode hot leakage current, with the grid biased as for the negative grid current test, may be too small to measure on the microammeter ; in this case it may be regarded as zero in deriving the gas current. If any grid emission is present, the procedure will be as indicated in (c) below.

(c) **Grid (primary) emission**—Grid primary emission current may be derived by operating the valve under maximum rated voltages and dissipations for, say, 5 minutes, or until the characteristics have reached stable values, then by increasing the grid bias to the point of plate current cut-off without any other change in electrode voltages, and by measuring the negative grid current at this point. This negative grid current is then the sum of hot leakage and grid emission currents. There is no simple method of distinguishing between real grid emission current and those hot leakage currents which fall during the first few seconds as the valve cools. However, it is generally possible to distinguish hot leakage and grid emission by plotting the cooling curve of the reverse grid current versus time characteristic (this test cannot be applied to valves of the pentagrid type).

Grid current characteristics are described in Chapter 2 Sect. 2(iii).

(d) **Grid secondary emission**—The amount of secondary emission from the grid of a valve cannot be measured directly. Valves of the same type, however, may be compared as to the relative amount of secondary emission present by plotting, or tracing on a C.R.O., the positive grid characteristic. If the amount of secondary grid emission is sufficient for the characteristic to cut the axis, blocking may occur—see Sect. 3(iv)N.

(B) Grid current commencement voltage

The circuit of Fig. 3.1 is used except that the polarity of the grid microammeter is reversed. The grid voltage is then measured for which the grid current is positive and of the smallest value discernible on the microammeter (e.g., 0.2 μA).

(C) Positive grid curren

This test applies usually to zero biased r-f pentodes, particularly filament types, to ensure that conduction does not occur during service when low screen voltages are used. The test is normally performed under low screen voltage conditions, with other

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†Gas current may be measured by the method which converts the desired ion current to an alternating current by modulation of the ionizing electron stream while leaving undesired stray currents (e.g., leakage) unmodulated. See Ref. 40.

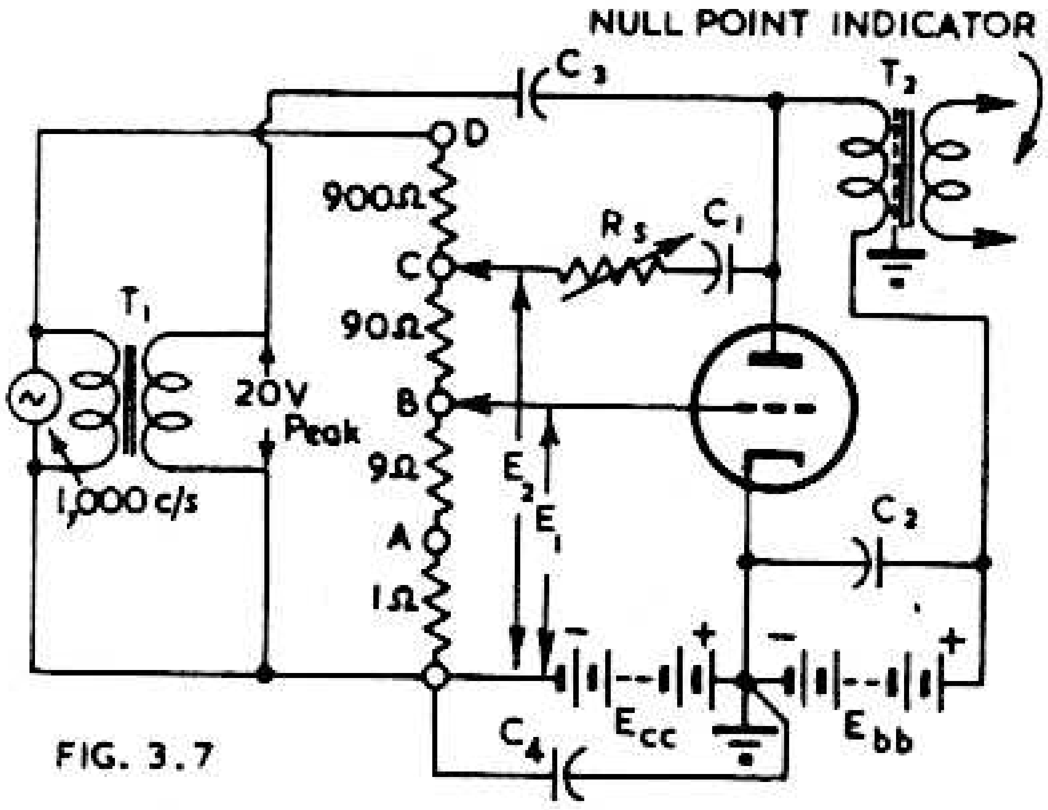

FIG. 3.7

Fig. 3.7. Dynamic voltage-ratio method of measuring mutual conductance (or transconductance).

electrode conditions normal. It is a matter of experience that the grid current commencement voltage moves in a negative direction in some filament type pentodes as the screen voltage is reduced.

(D) **Positive voltage electrode currents**

The currents of the positive electrodes may be measured at the electrode voltages specified under typical (or any other) operating conditions, by using the circuit of Fig. 3.1. The valve may be damaged if it is operated, even momentarily, at electrode currents and dissipations in excess of the maximum ratings.

The electrode currents may tend to drift, particularly when the valve is operated at other than the cathode current at which it has been stabilized. If a series of curves is to be plotted, it is desirable to check one of the earlier readings at intervals during the test, to see whether the valve has drifted.

(E) **Transconductance or mutual conductance***

Transconductance may be determined from the slope of a characteristic which has been plotted carefully. An approximation to the grid-plate transconductance, which generally errs on the high side, is to measure the plate current at equal grid-voltage increments on either side of the desired voltage, and to calculate the slope—see Chapter 2 Sect. 2(ii).

Grid-plate transconductance and mutual conductance may be measured by many methods, but the most satisfactory and most generally used laboratory method is the dynamic voltage ratio method developed by Tuttle (Ref. 2).

A simple adaptation which is satisfactory for all practical purposes is described below. In Fig. 3.7 a 1000 c/s generator is connected to a voltage divider and voltages E_2 and E_1 are applied to the plate (through R_s and C_1) and grid respectively of the valve under test. Resistor R_s is then adjusted to give a null point on the indicator. Condenser C_3 is provided to balance out reactive currents arising from stray capacitances ; the secondary of transformer T_1 should be connected in the direction which allows capacitive balancing.

At balance, the value of mutual conductance is given by

$$g_m = \frac{E_2}{E_1} \cdot \frac{1}{R_s}. \qquad (3)$$

One convenient form is shown in Fig. 3.7 where E_1 and E_2 are adjustable in steps of 10, while R_s is variable from 5000 minimum to 100 000 ohms maximum.

Range	**Grid tap**	**Plate tap**	E_2/E_1	R_s **min.** ohms	R_s **max.** ohms
1-10 μmhos	C	B	1/10	10 000	100 000
10-100	B	B	1	10 000	100 000
100-1000	B	C	10	10 000	100 000
1000-20 000	A	C	100	5 000	100 000

Values of the other components may be :

C_1=0.5 μF, C_2=1 μF, both 400 V working
C_3=one gang condenser section
T_1=step up transformer, 1 : 2 turns ratio
T_2=electrostatically shielded output transformer, with primary resistance not greater than 50 ohms.

The reactances have been selected to give an error in mutual conductance not greater than 1 per cent. in each case.

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*For definitions, see Chapter 2 Sect. 1.

Pentodes may be tested if a suitable screen supply is added to Fig. 3.7.

Further information on methods of measuring mutual or transconductance is given by Refs. 2, 15, 16, 17, 18, 21, 22, 59, 78, 79, 80, 81, 82, 83, 84, S12.

(F) **Amplification factor**

The amplification factor is usually tested by some form of bridge circuit as in Fig. 3.8. This is suitable for measurements of μ up to 1000. Suggested values of components are :

$R_1 = 10$ ohms, $R_2 = 90$ ohms, $R_3 = 900$ ohms, $R_4 = 10\,000$ ohms max., $L_1 = 5$ henrys min., $L_2 = 20$ henrys min. at max. plate current. $C_1 = 0.5$ μF, $C_2 = 0.5$ μF, C_3 may be two paralleled sections of a gang condenser.

Choke L_1 should be of very low resistance, so that the voltage drop caused by any reverse or positive grid current does not affect the point of operation. Transformer T_1 should be electrostatically shielded.

The amplification factor is given by

$$\mu = \frac{R_4}{R}$$

where R = effective total grid resistance in grid arm of voltage divider (i.e., either R_1 or $R_1 + R_2$ or $R_1 + R_2 + R_3$).

With R_4 adjustable from 1000 to 10 000 ohms, position 1 of S_1 will give a range of μ from 100 to 1000, position 2 from 10 to 100, and position 3 from 1 to 10. A satisfactory value of signal voltage is about 10 volts peak. Too high a value will result in operation over a non-linear portion of the characteristic, while also introducing the possibility of positive grid current with some types of valves operated at low grid bias.

Capacitance currents may be balanced out by adjusting the value of C_3 and by moving switch S_2 to the position giving capacitance balance.

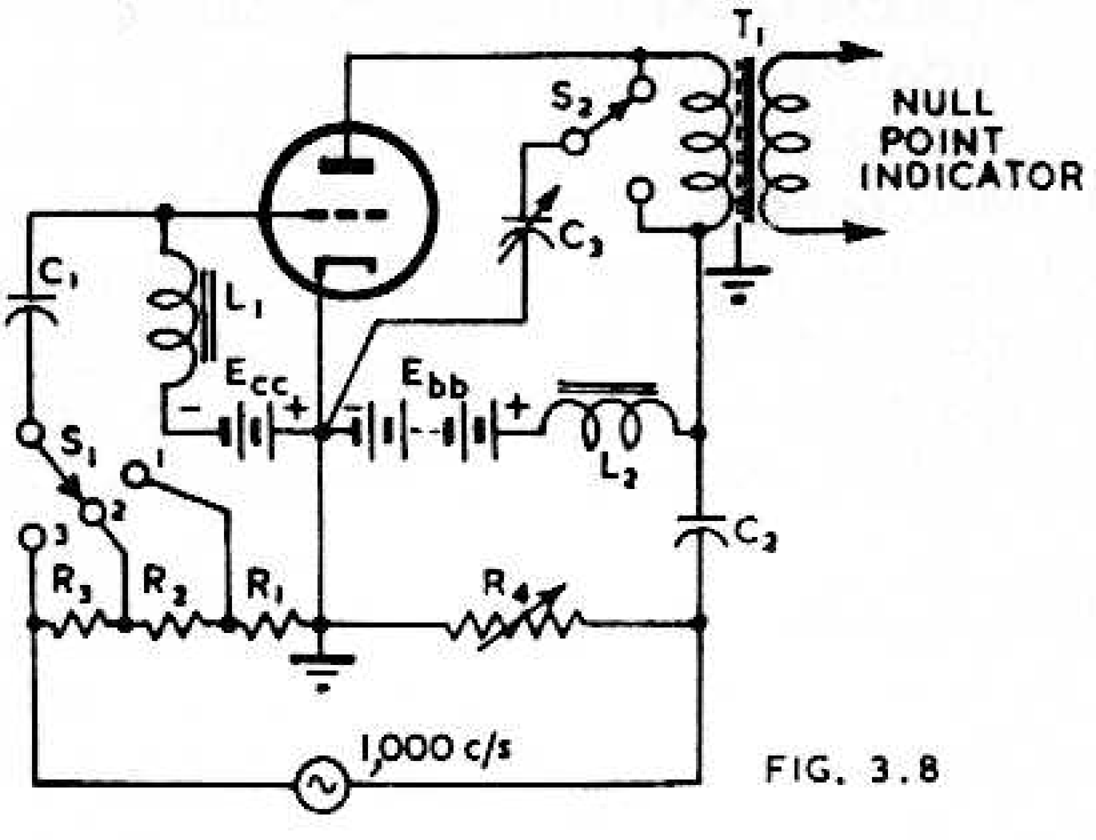

FIG. 3.8

Fig. 3.8. *Bridge test for measuring amplification factor.*

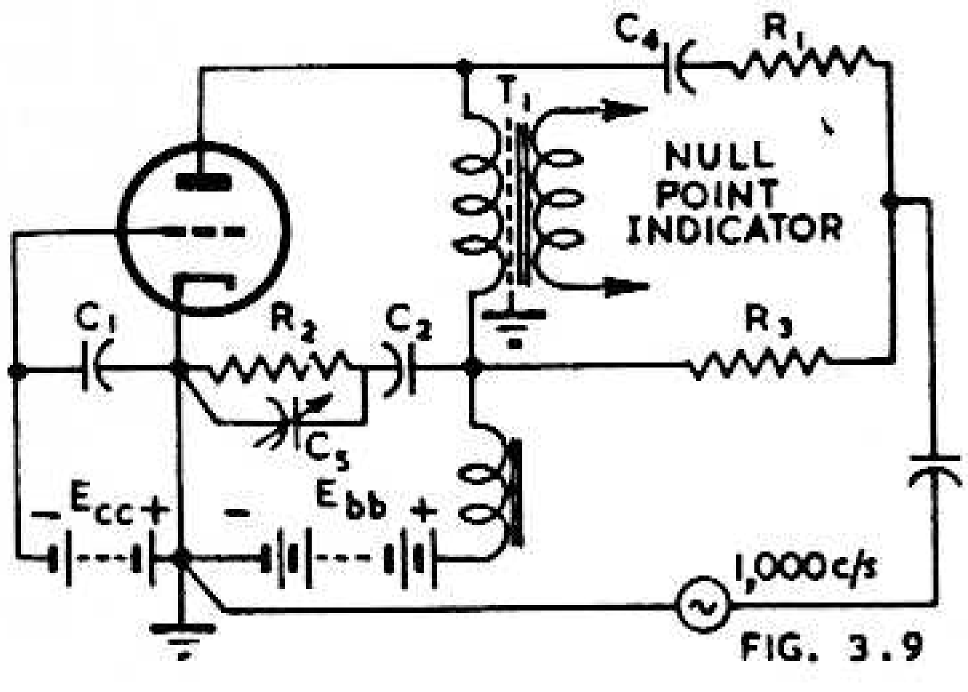

FIG. 3.9

Fig. 3.9. *Method of testing for plate resistance.*

The amplification factor test of Fig. 3.8 may be used for pentodes with the addition of a suitable screen supply. For values of amplification factor over 1000 a higher ratio of the plate and grid arms of the bridge is required, that is R_4/R. This will result in some loss in accuracy at the higher values of μ due to capacitance effects.

References to measurement of mu factor and amplification factor : Refs. 2, 15, 16, 17, 18, 21, 22, 78, 79, 80, 81, 82, 84, S12.

(G) **Plate resistance**

Plate resistance may be measured conveniently by the dynamic voltage ratio method developed by Tuttle (Ref. 2) and an adaptation is shown in Fig. 3.9. The value of plate resistance is given by

$$r_p = \frac{R_1 R_2}{R_3} \qquad (4)$$

where R_1, R_2 and R_3 may have any convenient values of resistance.

One possible combination of resistances is :

Range of r_p	R_1 (fixed) ohms	R_2 (fixed) ohms	R_3 (variable) ohms
1000 to 10 000 ohms	10 000	1000	10 000 to 1000
10 000 to 100 000 ohms	100 000	1000	10 000 to 1000
0.1 to 1.0 megohm	100 000	10 000	10 000 to 1000
1 to 10 megohms*	100 000	100 000	10 000 to 1000

*On this range the accuracy is poor.

This circuit may be used for pentodes with the addition of a screen supply. Under these conditions C_2 should have a minimum capacitance of 1 μF and C_4 a minimum capacitance of 0.1 μF (paper dielectric, 400 V working) for a maximum error of 1% in each case, while choke L_1 should have an inductance of at least 12.5 henrys for a maximum error of 1% (except on the maximum range), for a frequency of 1000 c/s.

On the maximum range, the inductance of L_1 must be at least 125 henrys for a maximum error of 1 per cent., but the plate current through L_1 will normally be only a few milliamperes on this range. Thus two separate chokes will be required if the maximum range is to be used. Transformer T_1 should be electrostatically shielded, and its primary should have a resistance less than 50 ohms. Condenser C_3 is merely a blocking condenser of any convenient value, connected in series with the 1000 c/s source ; it does not affect the readings.

Condenser C_5 is for the purpose of balancing out capacitance currents ; it may be a single section of a gang condenser.

The combination of mutual conductance, amplification factor and plate resistance into a single unit introduces serious design difficulties and necessitates difficult compromises. A more elaborate combined bridge using Tuttle's method has been marketed by the General Radio Company and the theory is published in Ref. 2.

Plate resistance may also be measured by the well known bridge circuit (e.g., see Refs. 8, 9, 18, 21, 22, S12). The quadrature current may be balanced out by a small capacitor in the arm of the bridge adjacent to the arm containing the unknown.

References to the measurement of plate resistance : Refs. 2, 15, 16, 17, 18, 21, 22, 33, 78, 79, 80, 81, 82, 84.

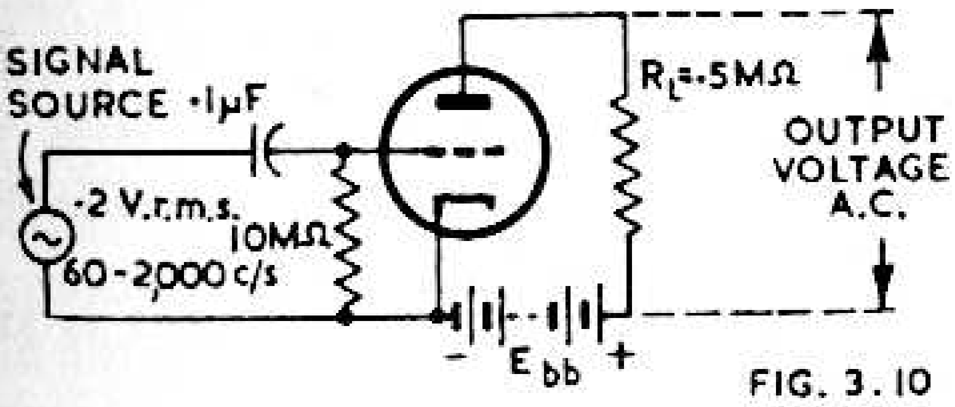

FIG. 3.10

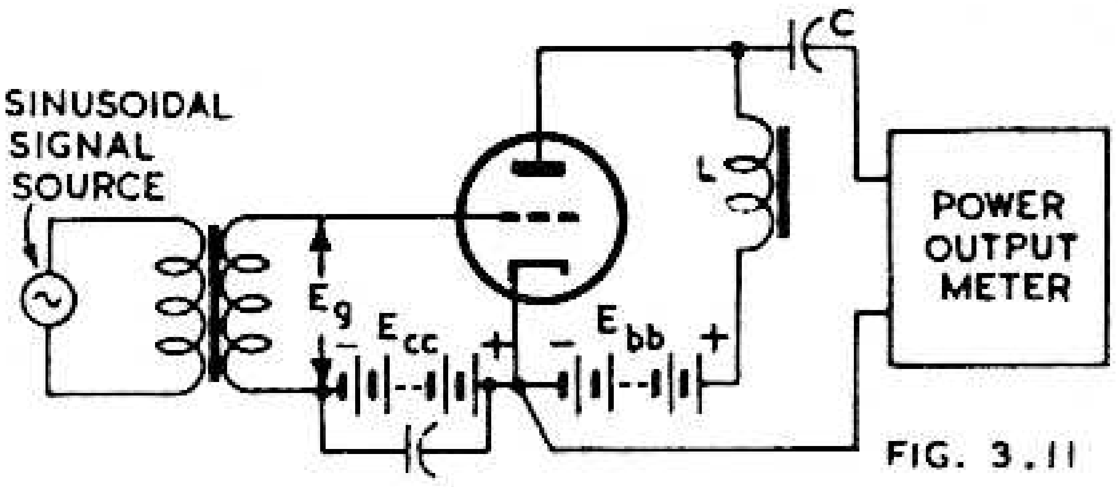

FIG. 3.11

Fig. 3.10. *Method of testing for a.c. amplification (after RMA).*

Fig. 3.11. *Method for testing for power output.*

(H) A.C. amplification

The standard R.M.A. test for a.c. amplification (Ref. S7) is shown in Fig. 3.10. This is applied to audio frequency voltage amplifier pentodes, and to a-f voltage amplifier high-mu triodes. This is a resistance-coupled amplifier test normally performed at zero bias with a 10 megohm grid resistor. The internal impedance of the signal source should not exceed 2500 ohms. The test is made at rated heater or filament voltage and normally with a plate load resistor of 0.5 megohm, and an appropriately by-passed screen resistor in the case of a pentode. In performing this test, it is important to specify whether the output voltage is to be read across the plate load resistor alone (as in the R.M.A. test of Fig. 3.10) or across a capacitively-coupled following grid resistor of specified value. It is also important, if accurate results are to be obtained, that the valve voltmeter used be true r.m.s. reading—that is, one having a square-law characteristic.

(I) Power output

Power output from the plate may be measured under the conditions indicated in Fig. 3.11. The peak value of the sinusoidal voltage E_g applied to the grid is normally equal to the bias voltage E_{cc}, unless otherwise specified. The signal frequency is preferably either 400 or 1000 c/s, in order to reduce the size of L and C. The impedance of the choke L at the signal frequency should be at least, say, 7 times the impedance of the load, while the reactance of C should be less than, say, one seventh of the load impedance.

The power output meter for approximate and routine testing may be of the rectifier/d.c. meter type. In this case the load resistance will be incorporated in the power output meter as drawn in Fig. 3.11.

For accurate measurements, however, it is essential to measure either the true r.m.s. voltage across, or the current through, a load resistor of specified value and unity power factor. Generally the latter measurement is the more convenient as the current through the load may be measured by means of a thermo-couple ammeter.

The power output of a Class B amplifier may be measured either with push-pull operation or on each section separately. In the latter case the load resistance is one quarter that of the plate-to-plate value for push-pull operation, and the unit not under test is tied to the cathode. The power output from one section, owing to shifting of the loadline, is greater than half the power output with push-pull operation (Ref. 58), but the relationship must be established experimentally in each case. Alternatively, a resistive load may be connected directly in the plate circuit to give a closer approach to normal push-pull operation. The value of the resistance is arranged to be one quarter of the plate-to-plate load resistance with push-pull operation, and the plate supply voltage equal to the specified plate voltage for normal push-pull operation. Under these conditions the power output is given by (Ref. 58):

$$P_o \approx 2.47\,(I_b - 0.25 I_{bo})^2 R_L \tag{4a}$$

where P_o = power output from one section, in watts

I_b = direct plate current in amperes, as measured by a d.c. meter

I_{bo} = plate current with no signal, in amperes,

R_L = load resistance per section, in ohms.

The value of I_{bo} may be taken, with sufficient accuracy for many purposes, as the published value.

In all cases with Class B amplifiers the specified value of input voltage is applied to the grid circuit in series with a specified value of resistance. The plate voltage source should have good voltage stability, an electronic voltage regulator being satisfactory. If a plate source impedance is specified, a series resistor of the appropriate value must be inserted in the plate supply circuit.

The relevance of a particular output measured under specified conditions is significant only in relation to the distortion present under those conditions.

(J) Distortion

Distortion in the power output test may be measured by one of several suitable methods, provided that the signal source is truly sinusoidal. The effect of harmonics from the signal source may be reduced by connecting a low-pass filter between the signal source and the grid.

The distortion may be measured by a harmonic analyser, of which several types have been described in the literature. When merely the value of the total harmonic distortion is desired, as in determining the undistorted output, those analysers which measure the root-mean-square value of all harmonics present are preferable to those which measure the separate harmonics.

The method of Suits (Ref. 85) is a particularly good example of the type of analyser which measures the harmonics separately. The Suits method requires only the simplest apparatus, and where laboratory facilities are limited this advantage may outweigh the disadvantages involved in the computation of the total harmonic distortion.

The Belfils analyser (Refs. 86, 87) utilizes an alternating-current Wheatstone-bridge balance for the suppression of the fundamental, and is particularly useful for direct measurement of the total harmonic distortion. For maximum convenience, the frequency of the audio-frequency source should be very stable. This instrument can be operated so that it is direct reading, by maintaining a constant input voltage.

In the McCurdy-Blye analyser (Ref. 88), low- and high-pass filters are used to separate the harmonics from the fundamental. This instrument is superior to the Belfils type in that the frequency of the source may vary somewhat without necessitating readjustment.

A differential analyser especially designed for power-output work has been described by Ballantine and Cobb (Ref. 89).

If an iron-cored choke is employed for shunt feed in the plate circuit (Fig. 3.11), care should be exercised in its selection or design to avoid the generation of harmonics in it due to the non-linear and hysteretic behaviour of the iron.

For measurement of distortion see Chapter 14 Sects. 2, 3 ; Chapter 37 Sect. 3.

(K) Microphony

There is no published standard test for microphony outside of Service or manufacturers' specifications. However an indication of the microphony of valves may be obtained using the same conditions as the R.M.A. standard audio frequency noise test (see below). It is reasonable to adjust the amplifier gain to be of the same order as the gain of the subsequent portion of the amplifier in which the valve is to operate. Nevertheless, valves unless specifically designed for low-level high-gain pre-amplifier use, should not be expected to be non-microphonic and free from noise at low levels when tested under such conditions.

In radio receiver factories the valves are usually tested in the chassis in which they are to operate, the set being tuned to a signal generator with internal modulation, and the volume control set at maximum. Any microphonic sounds which quickly die away are not considered as cause for removal of the valve, but a sustained howl is so considered. Such a valve may not be microphonic in another position in the chassis or in another model of receiver. Actions to be taken to reduce microphony have been described in Chapter 35 Sect. 3(iv). Notwithstanding the considerations above, all valves cannot be expected to be non-microphonic when placed directly in the acoustic field of, and close to, the loudspeaker in a receiver, particularly in small cabinets.

Ref. S2.

(L) Audio frequency noise

The R.M.A. standard for audio frequency noise test is with normal voltages applied to all electrodes, and the plate of the valve under test is coupled to the input of an amplifier with a frequency range of 100 to 2000 c/s (±5 db of response at 400 c/s). A dynamic loudspeaker with a rating of at least 2.5 watts is connected to the output of the amplifier. The minimum external grid resistance is 100 000 ohms. The gain of the amplifier and the plate load resistance of the valve under test are to be as specified. The valve under test may be tapped lightly with a felt or cork mallet weighing not over ½ ounce. Any objectionable noise heard in the loudspeaker, is cause for rejection (Ref. S7). See also Ref. S2.

(M) Radio frequency noise

The R.M.A. standard test for radio frequency noise is for normal voltages applied to all electrodes of the valve under test ; the plate is coupled to the input of a r-f amplifier (of a radio receiver) at a frequency within the range of 50 to 1600 Kc/s. The minimum band-width is to be 5 Kc/s at 10 times signal. The audio frequency response is to be within ±5 db of the response at 400 c/s over the frequency range from 100 to 2000 c/s. A suitable tuned transformer giving a resonant impedance of 50 000 to 200 000 ohms is to be used to couple the valve under test to the amplifier. The external grid circuit impedance of the valve under test is to be from 5000 to 25 000 ohms. Other conditions of test are as for the audio frequency noise test (Ref. S7). See also Ref. S2.

(N) Blocking

Tests on grid blocking are normally applied only to certain types subject to this characteristic. A valve may be tested for blocking by either of two methods. In the first method a high positive grid voltage (say 100 volts) is applied instantaneously with normal electrode voltages and the maximum value of grid resistance. The plate current should return to its initial value on the removal of the applied voltage.

The second method (" cross-over ") is to apply a gradually increasing positive grid voltage with substantially zero grid circuit resistance, and to plot the grid current characteristic for positive values of grid voltage up to the point at which the grid current changes from positive to negative (" cross-over " point). See Chapter 2 Sect. 2(iii).

(O) **Stage gain testing**

A circuit such as that shown in Fig. 3.11A can be used to measure the gain of a r-f pentode operating under typical i-f amplifier conditions. Stage gain testing has the advantage of evaluating at the one time and under operating conditions at the appropriate frequency the effects of all valve characteristics which influence gain, such as mutual conductance, output impedance, input resistance, reverse grid current and even the effect of high screen or plate currents in increasing control grid bias or decreasing screen grid voltages

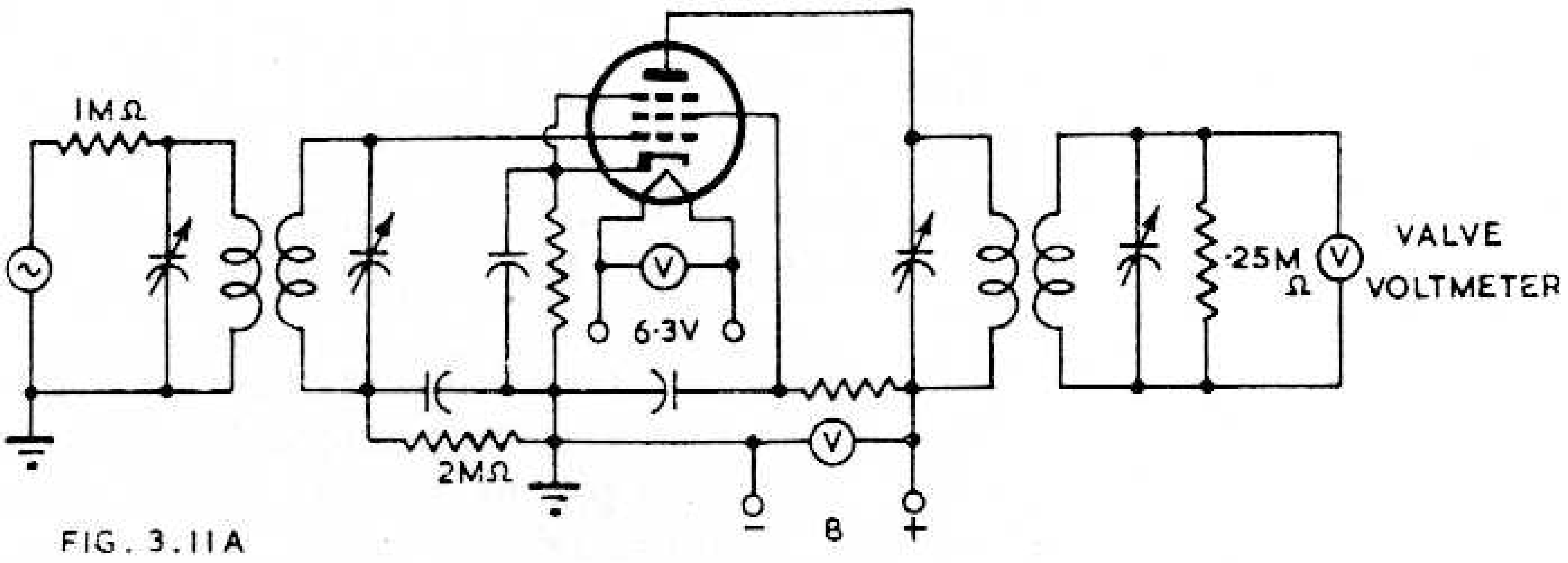

FIG. 3.11A

Fig. 3.11*A*. *Method of testing for i-f stage gain.*

In Fig. 3.11A the input and output circuits are typical high-impedance i-f transformers with secondary tuning of the first and primary tuning of the second, adjustable from the front panel of the tester to allow accurate alignment with varying capacitances in the valves under test. The 1 megohm resistor represents the plate impedance of a preceding converter stage and the 0.25 megohm resistor simulates the impedance of a diode detector. Screen and bias resistors are designed to give the required voltages with a valve of bogie characteristics, and the high impedance in the control grid circuit allows the effect of reverse grid current to be evaluated.

The output meter is calibrated to show stage gain in db for a given input at 455 Kc/s and limits are marked on the scale at a suitable number of db above and below the stage gain of a bogie valve.

(P) **Electrode dissipation**

The dissipation of an electrode is determined by subtracting the power output from that electrode—see Sect. 3(iv)I—from the d.c. power input to that electrode. Where the power output from an electrode is zero, the electrode dissipation is then equal to the d.c. power input.

(v) Specific converter characteristics

(A) Methods of operation including oscillator excitation

A converter valve essentially includes two sections, an oscillator and a mixer, which may be either separate units supplied by independent cathode streams as in a triode-hexode or combined to use a single cathode stream as in the pentagrid types. The characteristics of a converter depend both on the electrode voltages of the mixer and oscillator and on the excitation of the mixer by the oscillator.

For purposes of testing, the oscillator may be either self-excited or driven by an external source of alternating voltage of suitable amplitude ; alternatively a limited range of characteristics may be determined under purely static conditions with direct voltages only applied to the electrodes. In general, the latter is not recommended for routine testing outside of valve factories, owing to the practical difficulties of correlating characteristics with published characteristics obtained under oscillating conditions.

(1) **Oscillator self-excited**

This is the normal method of operation in most radio receivers, and although it has much to commend it as a simultaneous test of both mixer and oscillator sections, the oscillator circuit characteristics require to be specified exactly and closely controlled in order to obtain consistent results. For general service testing, less critical methods are therefore to be preferred. This method of testing, with a self-excited oscillator, requires a completely specified oscillator coil, particularly as regards the resonant impedances presented by the circuit to the valve which, together with the electrode voltages, determine the peak and average plate currents of the various electrodes. In practice, it is usually convenient to standardize the circuit by using a valve having specified characteristics under particular conditions (transconductance, amplification factor, plate current) and adjusting the resonant impedance of the tuned circuit by means of the shunting resistor to give a prescribed grid current.

The oscillator frequency is usually either an audio frequency or 1 Mc/s, the latter being more typical of normal operation

(2) Oscillator driven

This is a fairly commonly used test, because it has less dependence of the mixer on the oscillator characteristics. It suffers from the disadvantage, however, that inasmuch as the driving voltage is applied to the oscillator grid, it does not provide a satisfactory test of oscillator characteristics. With this method of testing, if grid current is regarded as a criterion of oscillator characteristics, the oscillator emission needs to be adequate only to supply the rectified current resulting from the excitation but may be quite inadequate to supply the high peak oscillator plate currents which may occur in normal operation, the values of which depend upon the impedance in the oscillator plate circuit.

For this reason, it is generally more satisfactory in service testing to use the driven method with prescribed excitation to test the mixer characteristics and to test the oscillator by means of either a transconductance test at a high plate current or a prescribed self-excited oscillator circuit test which calls for a reasonably high peak plate current, with rectified grid current as the criterion. In the latter case provided the oscillator circuit characteristics, that is the resonant impedances presented to the valve, are precisely specified the test is not critical as regards grid current.

(3) Static operation

With this method of testing, static voltages are applied to all electrodes and the electrode currents are measured.

(B) Specific characteristics

(a) Reverse signal grid current

This test is performed under the same general conditions as for triodes and pentodes, except that the method of operation may be with the oscillator self-excited, or with the oscillator driven, or with static operation.

(b) Signal grid current commencement

In general this test may be performed as for triodes and pentodes, except that the oscillator may be either self-excited or driven.

(c) Mixer positive voltage electrode currents

These may be measured, in general, as for triodes and pentodes, except that the oscillator may be either self-excited or driven.

(d) Mixer conversion transconductance*

Mixer conversion transconductance is determined from measurements of the magnitude of a beat-frequency component, (f_1-f_2) or (f_1+f_2), of the output current, and the magnitude of the input voltage of frequency f_1 where f_2 is the oscillator frequency. The method of measurement which has been standardized by JAN-1A (Ref. S2) and R.M.A. (Ref. S7), and which uses a driven oscillator, is to apply voltages of identical phase and frequency—usually mains frequency for convenience—to the specified electrodes (that is the signal and oscillator grids) with provision for a phase reversal of 180° of one with respect to the other. The change in direct plate current due to the phase reversal represents the difference-frequency plate-current component.

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*Also referred to as conversion conductance. Mixer conversion transconductance is defined as the quotient of the magnitude of a single beat-frequency component (f_1+f_2) or (f_1-f_2) of the output electrode current by the magnitude of the control-electrode voltage of frequency f_1, under the conditions that all direct electrode voltages and the magnitude of the electrode alternating voltage f_2 remain constant and that no impedances at the frequencies f_1 or f_2 are present in the output circuit, and that the magnitude of the signal voltage f_1 is very small.

This value divided by twice the peak value of the sinusoidal voltage applied to the signal input electrode is taken as the mixer conversion transconductance. Specified voltages are applied to the valve electrodes under specified circuit conditions and the oscillator excitation voltage is adjusted to the specified value or to give the specified oscillator grid current. Other methods of testing are acceptable if correlated with this method.

The relationship may be expressed in the form

$$g_c = \frac{I_{b1} - I_{b2}}{2E_{1m}} \tag{4b}$$

where g_c = conversion conductance in mhos

I_{b1} = plate current for the in-phase condition of signal and oscillator voltages E_1 and E_2 in amperes

I_{b2} = plate current for the out-of-phase condition of E_1 and E_2, in amperes

and E_{1m} = peak value of the signal voltage.

It should be clearly understood that the value of conversion transconductance measured by this method is dependent on the signal grid voltage and on the curvature of the mixer characteristics and consequently only approaches a true " differential " transconductance at the point of operation, as distinct from an average value, if the signal grid voltage amplitude is sufficiently small. In most cases, if the signal grid voltage does not exceed say 25 mV, exact correlation can be obtained for all types. At higher values, up to 100 mV, the error may be acceptable, depending upon the type and the condition of operation.

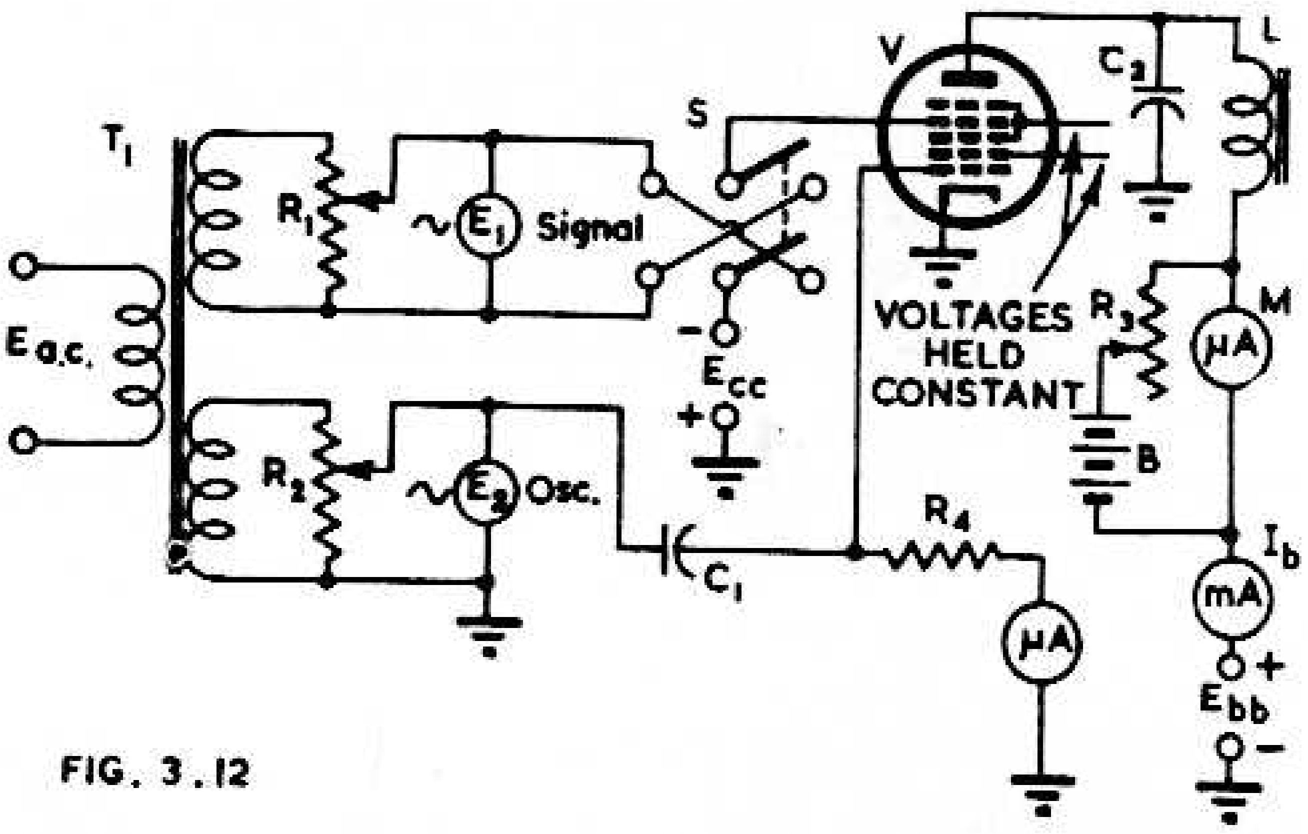

FIG. 3.12

Fig. 3.12. Phase reversal method of measuring conversion transconductance.

The circuit is shown in Fig. 3.12 in which one double-wound transformer, T_1 with two secondary windings provides the signal and oscillator voltages, which are controlled by means of potentiometers R_1 and R_2. A switch S permits phase reversal of the signal voltage. The grid coupling capacitor C_1 and grid resistor R_4 are provided, with a meter to measure oscillator grid current through R_4. In the plate circuit of the valve under test there is a by-pass capacitor C_2 and iron-cored choke L to pass the direct current I_b from the plate voltage source E_{bb}. The increase in plate current is measured by the low resistance microammeter M after the standing current I_{b2} has been " bucked out " by the bucking battery B and rheostat R_3 which should have a minimum resistance at least 100 times that of the microammeter.

In order to obtain exact results, as indicated previously, very small signal voltages are required, which produce only small incremental readings of plate current and demand stabilized electrode voltage sources. In any particular case, the signal voltage may be increased until the error due to the large signal voltage becomes measurable, and tests should then be carried out at a somewhat lower signal voltage.

If a signal voltage of $1/2\sqrt{2}$ volt (0.5 volt peak) is used, the incremental plate current in milliamps then reads conversion transconductance in milliamps per volt. It seems that values of transconductance frequently quoted in published data are obtained using the above-mentioned value of signal voltage, as in many cases the true conversion transconductance under the conditions published differs from this value. As a result, it is frequently difficult to calculate the exact performance of converter stages from published data of the converter used.

The shape of the curve of conversion transconductance plotted against oscillator grid current is very much influenced by the signal voltage used in the tests. The actual operating conversion transconductance in a practical case is a function of the input signal level.

The phase-shift method of testing conversion transconductance is the only **absolute** experimental method of measuring this characteristic, and accurate results can be obtained provided all electrode voltages, including signal and oscillator excitation voltages, are well stabilized, the electrode supply voltages free from hum, the excitation voltages sinusoidal, of low frequency and correct phase and the signal grid voltage sufficiently small.

Side-band method

The side-band method of measuring conversion transconductance is shown by the circuit of Fig. 3.13. The oscillator may be either self-excited at any convenient frequency, say 1 Mc/s as in Fig. 3.13, or may be driven. A signal voltage E_1 at audio frequency (say 1000 c/s) is applied to the control grid. The oscillator is adjusted to give the required grid current through the specified grid resistor R_2. In the plate circuit there is a resonant circuit L_1C_1, tuned to the oscillator frequency and shunted by a resistance R_1, the value of which should be as low as possible and which should not exceed 10 000 ohms.

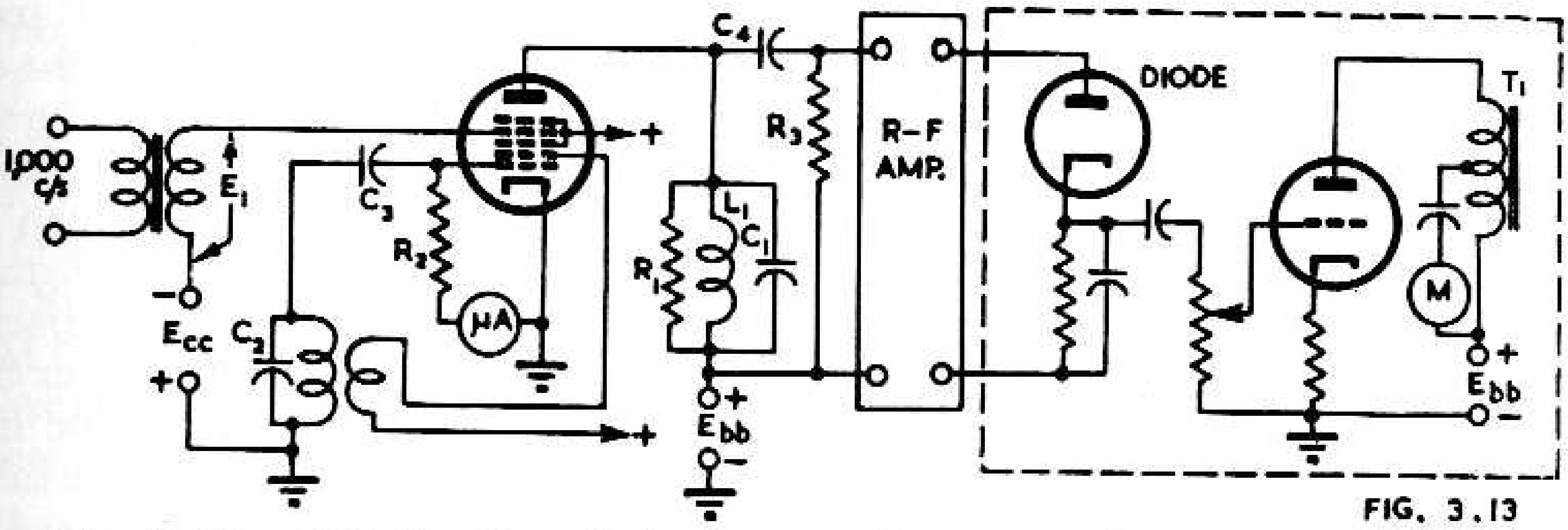

FIG. 3.13

Fig. 3.13. *Side-band method of measuring conversion transconductance.*

The voltage across the resonant circuit comprising the oscillator frequency, the signal frequency and the two resulting sidebands are applied to a radio frequency amplifier followed by a diode detector across whose diode load is connected a valve voltmeter to indicate the amplitude of the audio frequency components. If an r-f amplifier is not used, the region of non-linearity of the diode characteristic results in the calibration of the system being dependent on the voltage developed across the tuned circuit and would thus be unsatisfactory for valves of low conversion conductance. However, the r-f amplifier may be omitted provided the signal applied to the diode is sufficiently high to ensure linear rectification. Where this is not so, the simplified circuit may not be suitable for measurements of low values of conversion conductance.

If the r-f amplifier is omitted, the signal voltage E_1 may be about 0.5 volt peak, and R_1 may be 10 000 ohms.

The tester must be calibrated against the standard phase reversal method and the circuit may be adjusted so that the meter is direct reading.

(e) Mixer plate resistance

This may be measured either with a self-excited or driven oscillator, the value of plate resistance being not affected by the method used. Measurement of plate resistance is performed as for a pentode, except for the excitation of the oscillator.

(f) Mixer transconductance

This may be measured as for a pentode valve, except that the oscillator should be either self-excited or driven.

(g) Oscillator grid current

The oscillator performance of a converter valve depends upon several valve and circuit parameters that are not simply defined.

The oscillator grid current may be used as the criterion of oscillator performance in a self-excited oscillator, operating under specified conditions. The circuit should be designed to draw typical peak and average total space currents. The Boonton Converter Oscillator test circuit is widely used to check oscillator performance, owing to its simplicity of design and ease of adjustment and control and, while not giving an *exact* criterion of oscillator performance, does provide a dynamic test of the usual parameters under conditions that simulate average receiver operation.

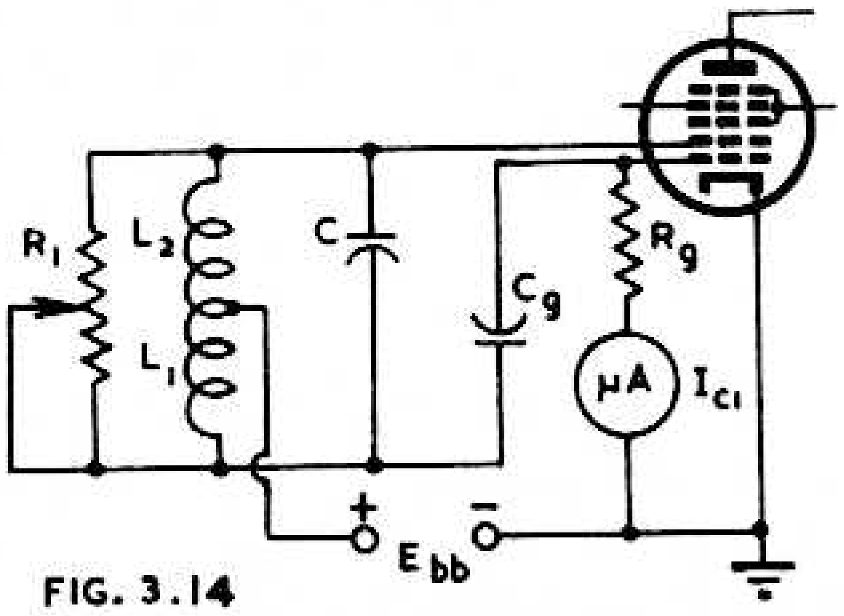

FIG. 3.14

Fig. 3.14. *Self-excited oscillator, using the Hartley circuit, for testing oscillator performance.*

The circuit (Fig. 3.14) is a series-fed Hartley having a fixed feedback ratio and having the tank circuit impedance variable so that the magnitude of oscillation may be adjusted. Normal voltages are applied to all electrodes.

It is necessary to specify the oscillator plate voltage, oscillator plate series resistor (if used), oscillator grid resistor (R_g) the inductance of each section of the coil (L_1, L_2), the mutual inductance between the two sections (M), the capacitance shunted across the whole coil (C), the grid coupling capacitance (C_g), and the resonant impedance of the tuned circuit (R_d). Normally a coil having a higher reactance than the specified value of resonant impedance is used and is shunted by a variable resistance (R_1) to give the specified resonant impedance. Bias is obtained by means of a capacitor and a wire-wound gridleak. The wire-wound grid resistor is used because it has considerably higher impedance to radio frequencies than to direct current. The high radio-frequency impedance diminishes the shunting effect of the gridleak on the tuned circuit. The rectified grid current is read on a microammeter (suitably by-passed) in series with the grid resistor. Before the test oscillator is used, the relationship between the tuned impedance of the tank circuit and the setting of the variable resistor must be determined

The R.M.A. standard (Ref. S7) and JAN-1A (Ref. S2, sheet dated 19 July, 1944) specify the component and coil design values as being : $C=100$ μμF (mica) ; $C_g=200$ μμF (mica) ; $R_1=50\,000$ ohms potentiometer ; $R_g=50\,000$ ohms wire-wound resistor ; $L_1=83$ μH ; $L_2=48$ μH : $M=23.3$ μH ; coil diameter $=1.25$ in. ; winding length $=59/64$ in. ; wire No. 30 a.w.g. enamelled copper ; turns $=83$; tap at 33 turns from anode end. See also Ref. S12.

The constants quoted above have been selected to simulate average circuit conditions in broadcast receivers for composite converters having transconductances less than 1500 μmhos at zero bias. For valves having higher transconductances or for circuits above broadcast frequencies, the circuit with the constants given may not be satisfactory, as spurious oscillations may make it impossible to obtain correlation between test readings and receiver performance.

The ability of a valve to oscillate when the shunt impedance of a tank circuit is low is one criterion of the value of a valve as an oscillator. The oscillation test is made by applying the desired electrode potentials to the valve under test and reading the rectified grid current at some known setting of tank-circuit impedance. A valve that will not oscillate with the tank-circuit impedance below about 9000 ohms is considered to be a weak oscillator. A valve that will oscillate with a tank-circuit impedance as low as 3000 ohms is considered to be a strong oscillator. The minimum tuned impedance at which oscillation will start or cease as indicated by the rectified grid current will depend on the oscillator characteristics of the particular type and will vary from type to type.

(h) Oscillator plate current

The oscillator plate current may be read while the valve is being tested for grid current as a self-excited oscillator, or alternatively at zero grid voltage and specified plate voltage (usually 100 volts).

(i) Oscillator transconductance

The oscillator transconductance is usually measured at zero grid voltage and specified plate voltage (usually 100 volts).

(j) Oscillator amplification factor

The oscillator amplification factor is measured as for any triode, usually with a plate voltage of 100 volts and zero grid voltage.

(k) Oscillator plate resistance

The oscillator plate resistance is measured as for any triode, usually with a plate voltage of 100 volts and zero grid voltage

(l) Signal grid blocking

Signal grid blocking may be treated as for the general case of grid blocking in Sect. 3(iv)N.

(m) Microphony

The general remarks in Sect. 3(iv)K regarding microphony apply also to converters.

(n) R-F noise

Converters may be tested for r-f noise under published electrode voltage and typical receiver circuit conditions, following the relevant recommendations of the R.M.A. r-f noise test—see Sect. 3(iv)M.

(vi) Tests for special characteristics

The following tests are not normally applied to receiving type valves and the undermentioned information is provided to assist designers in obtaining data of these characteristics for particular purposes.

(A) Short-circuit input admittance (y_{11})

At frequencies up to 10 Mc/s it is possible to use conventional bridge methods for the measurement of the four admittances, but at higher frequencies some version of the susceptance-variation or resistance-substitution method is necessary.

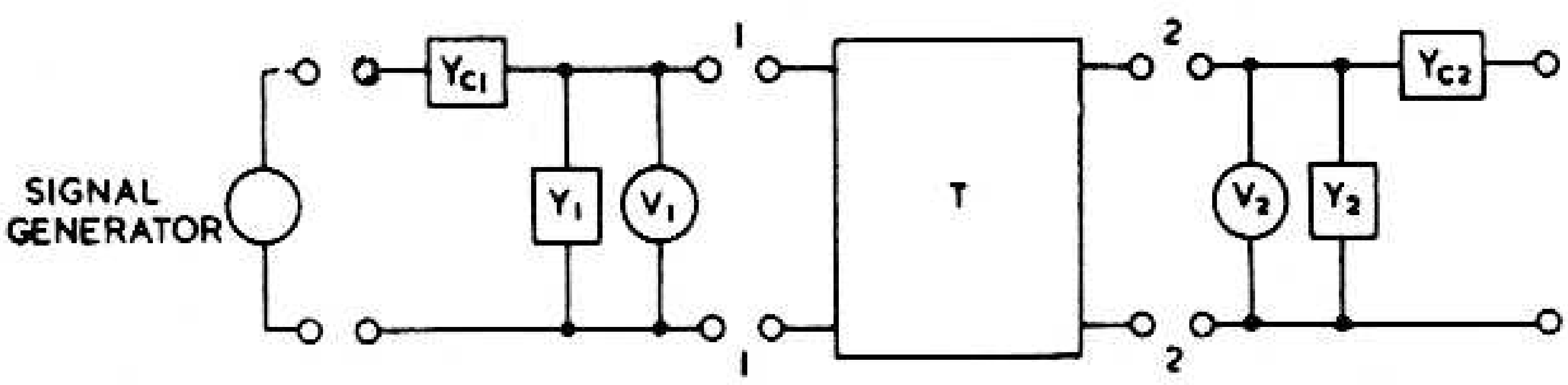

FIG. 3. 15

Fig. 3.15. *Semi-schematic diagram of equipment for measuring admittances by the susceptance-variation method (Ref.* S12).
T is the 4 *terminal transducer to be measured,* Y_1 *and* Y_2 *are calibrated variable-admittance elements which may be of various forms, such as coils or capacitors.* V_1 *and* V_2 *are signal-frequency voltage-measuring devices ; these may be simply crystal or diode voltmeters or heterodyne receivers. Variable admittances* Y_{c1} *and* Y_{c2} *are used for coupling the input or output circuits to the signal oscillators.*

(1) Susceptance-variation method of measurement (Refs. 51, S12)

In this method, the circuit is detuned with either the capacitor or the inductor adjustment to a point giving half the power output observed at resonance. The increment in susceptance, determined from the capacitance calibration curves, is then equal to the circuit conductance. In practice, the mean value obtained by using the half-power points on each side of resonance is used.

Using the circuit of Fig. 3.15 (Ref. S12)—

(a) Short-circuit the output terminals 2-2. This may be done either by detuning Y_2 sufficiently or by placing a suitable by-pass capacitor directly across terminals 2-2.

(b) Excite the input circuit by coupling the signal oscillator loosely through Y_{c1} to Y_1.

(c) Adjust Y_1 for resonance as indicated by a maximum reading of V_1. In order to insure that the coupling to the oscillator is sufficiently small, reduce the coupling until further reduction does not change the setting of Y_1 for resonance. Record the calibrated values of G_1 and B_1 for this setting.

(d) Vary Y_1 on either side of resonance until the voltage V_1 is reduced by a factor $1/\sqrt{2}$. Record the calibrated values of this total variation of Y_1 between half-power points as ΔG_1 and ΔB_1. In order to insure that the oscillator and detector are not loading the circuit, reduce the coupling until further reduction does not change the susceptance variation ΔB_1. The short-circuit input susceptance is then given by the relation

$$B_{11} = -B_1 \tag{5}$$

and the short-circuit input conductance by the relation

$$y_{11} = \tfrac{1}{2}\Delta B_1[(1+2\eta^2)^{\frac{1}{2}} + \eta] - G_1 \tag{6}$$

$$\text{or } y_{11} \approx \tfrac{1}{2}\Delta B_1[1+\eta+\eta^2] - G_1 \tag{7}$$

or even further by the relation

$$y_{11} \approx \tfrac{1}{2}\Delta B_1 - G_1 \tag{8}$$

if η is negligible.

FIG. 3.16

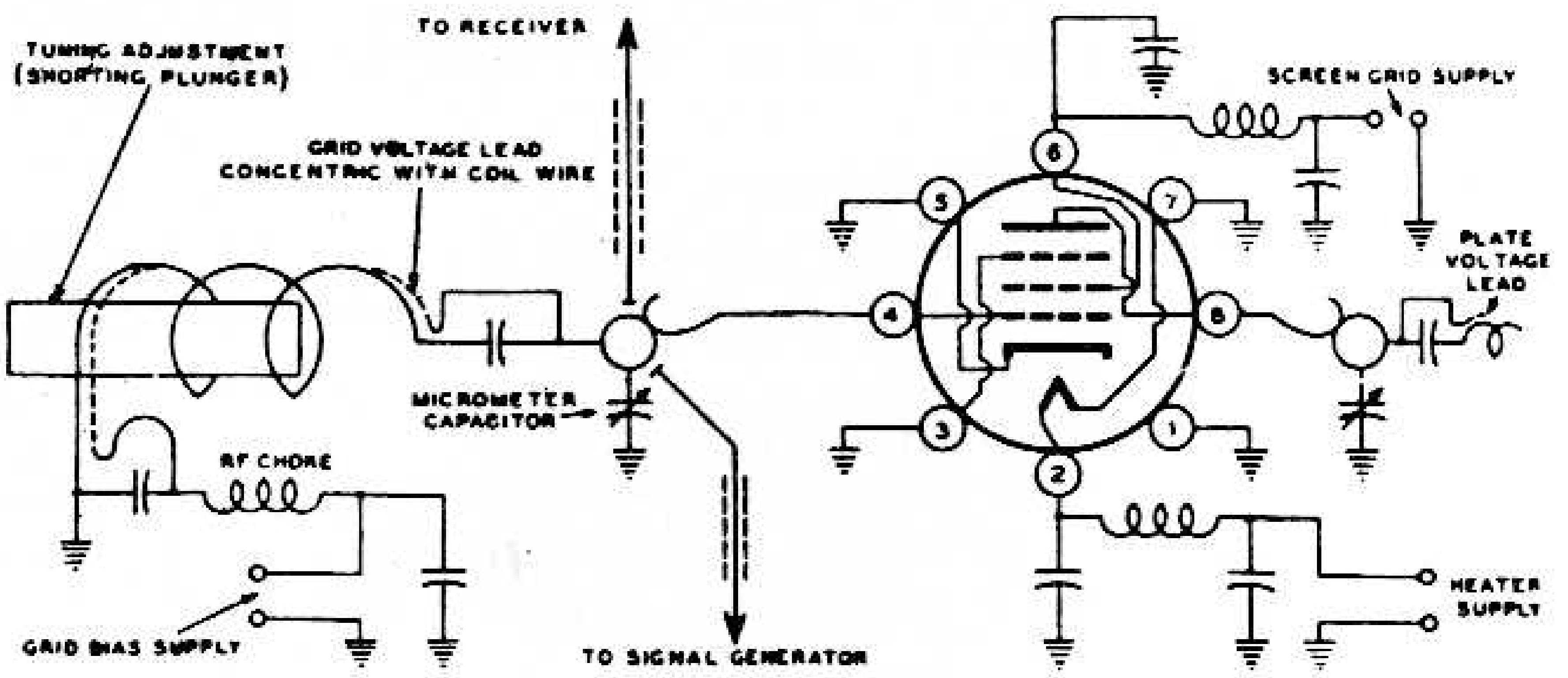

Fig. 3.16. *Circuit diagram of equipment used for measurement of short-circuit input admittance* (*Ref.* 51).

A practical form (Ref. 51) for the frequency range 50 to 150 Mc/s is shown in Figs 3.16 and 3.17. The valve under test is used as a part of a resonant circuit which includes a continuously-variable inductor and a small concentric-cylinder capacitor built on a micrometer head. The high-potential end of the inductor is connected to the high-potential electrode of the micrometer capacitor inside a cylindrical cavity open at the top. Fig. 3.17 also shows the positions of some of the by-pass capacitors used with the octal socket. These are button-type, silver-mica capacitors of approximately 500 $\mu\mu$F capacitance. The socket is of the moulded phenolic type. Terminals 1, 3, 5 and 7 are connected directly to the mounting plate at a point directly below the terminal in each instance. Terminals 2 (heater) and 6 (screen grid) are by-passed to ground, and a lead is brought from each of these terminals through the mounting plate to a small r-f choke and a second by-pass capacitor. Terminal 8 (plate) is by-passed and fitted with a spring contacting the terminal for one of the circuits. Terminal 4 (grid) has only the contact spring. A similar arrangement is used with miniature valves. In this case, the socket is of the wafer type with mica-filled rubber insulation. Terminals 2, 3 and 7 are grounded and terminals 4, 5 and 6 are by-passed to ground. Terminals 1 (grid) and 5 (plate) have contact springs. The by-pass capacitors are closer to the mounting plate than in the case of the octal socket; the capacitors at terminals 4 and 6 overlap the capacitor to terminal 5. A 10 ohm resistor, mounted inside a cylindrical shield to minimize lead inductance, is connected between socket terminal 5 (plate) and the by-pass capacitor. This component was added to suppress a parasitic oscillation observed with certain type 6AK5 valves. The resistor was found to have no

FIG. 3.17

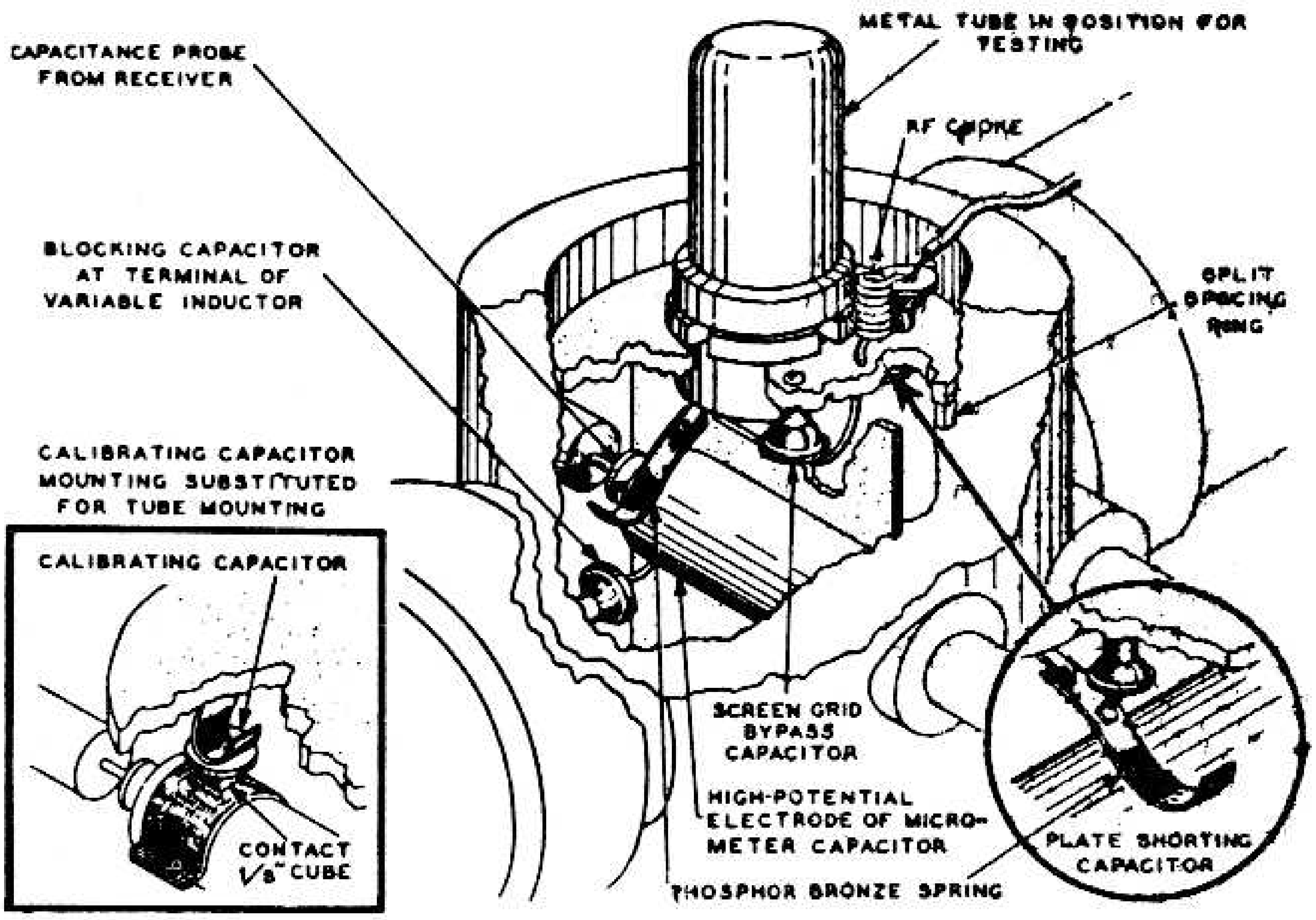

Fig. 3.17. *Physical arrangement of circuit elements of Fig.* 3.16 (*Ref.* 51).

measurable effect on input admittance readings obtained with valves, either of the 6AK5 type or of other types, not subject to the parasitic oscillation.

In order to obtain susceptance values, the circuit must first be calibrated for the capacitance required for resonance at each test frequency. The circuit is calibrated by determining the inductor settings for resonance with each of a number of small, disc-shaped, calibrating capacitors substituted for the valve. The insert in the lower left corner of Fig. 3.17 shows a cutaway view of the cavity with one of the calibrating capacitors in place. The length of the phosphor-bronze contact spring used with the calibrating capacitors is approximately the same as that used with the valve. Thus, the inductance of this lead is accounted for in the calibrating procedure. The reference terminals for the valve are the socket plate and the grid terminal of the socket or, possibly, a point on the grid terminal a little inside the body of the socket. The calculated inductance of the contact spring is 4.5 milli-microhenries per centimeter of length within about ±25 per cent., but the difference in effective lengths of the springs for the socket connection and the calibrating connection is not more than 2 or 3 millimeters.

The range of the micrometer capacitor is sufficient for measurements of the circuit with the calibrating capacitors, with most cold valves, and with some valves under operating conditions. For other cases, adjustment of the inductor is required.

If the conductance being measured is small enough to be measured by the available range of the micrometer capacitor, the susceptance and conductance variations between $1/\sqrt{2}$ voltage points are given by

$\Delta B = \omega \Delta C$

and $\Delta G = 0$

where ω is the angular frequency of measurement and ΔC is the micrometer capacitance variation between the half-power points.

The calibration curves used at each test frequency are :

(1) Capacitance for resonance
(2) Slope of the capacitance curve
(3) Conductance at resonance of the circuit with the calibrating capacitors.

These three quantities are plotted against the inductor adjustment readings. Since the conductance values for the calibrating capacitors themselves are too small to affect the calibration appreciably, the conductance curve corresponds, essentially, to the equipment.

(2) Resistance-substitution method of measurement

The resistance-substitution method applies only to the measurement of the conductive component of the admittance. The susceptive component must be measured by means of a calibrated susceptance element, as for the susceptance-variation method of measurement. Ideally, the resistance-substitution method involves, in the case of a two-terminal admittance, the removal of the electron-tube transducer from the calibrated admittance element and its replacement by a standard pure resistance of such a value that the voltage reading between the two terminals is the same as that obtained with the transducer in place. The calibrated susceptance element must be adjusted to resonance both before and after substitution of the resistance. If the measurement is of y_{11}, the following relations are obtained :

$$B_{11} = -B_1 \tag{9}$$

as in (1) above, and

$$G_{11} = 1/R \tag{10}$$

where R is the standard resistance of a value that satisfies (10).

There are practical difficulties in obtaining standard resistors having negligible reactance at frequencies of the order of 100 Mc/s or higher. Wire-wound resistors are not usable at such frequencies. The most satisfactory types available are the metallized-glass or ceramic-rod resistors of relatively small physical size, having low-inductance terminals and very little distributed capacitance. A further difficulty arises from the fact that such resistors are obtainable only in discrete values of resistance. It would not be practicable to obtain the very large number of resistors needed to match the resistance of any electron-tube transducer. Hence, it is necessary to utilize a transformation property of the admittance-measuring equipment in order to match any arbitrary admittance with some one of a reasonably small set of standard resistors. A suitable resistance-substitution set consists of a transmission line of length l short-circuited at one end, having a characteristic admittance Y_o and a propagation constant γ. If a known admittance Y is placed across the line at a distance x from the short-circuited end, the admittance Y_t at the open end of the line is given by the relation

$$Y_t = Y\left[\frac{\sinh\ \gamma x}{\sinh\ \gamma l}\right]^2 \left[\frac{1}{1+\dfrac{Y \sinh\ \gamma x}{Y_o \sinh\ \gamma l}\sinh\ \gamma\,(l-x)}\right] \tag{11}$$

Conversely, the admittance Y_t is the admittance that would have to be placed at the open end of the line to produce the same effect there as the known admittance Y at the position x. Equation (11) then represents the property of the transmission line of converting admittance Y at position x into admittance Y_t at position l. This expression can be simplified for a low-loss line having a characteristic admittance Y_o large compared with the bridging admittance Y. Thus if $Y_o \gg Y$,

$$\left|\frac{Y}{Y_o}\frac{\sinh\gamma x}{\sinh\gamma l}\sinh\gamma(l-x)\right| \ll 1, \tag{12}$$

and the real part of the propagation constant γ of the line is small,

$$\left[\frac{\sinh\ \gamma x}{\sinh\ \gamma l}\right]^2 \approx \left[\frac{\sinh\ \beta x}{\sinh\ \beta l}\right]^2 \tag{13}$$

where $\beta = 2\pi/\lambda$ Equation (11) then simplifies to

$$Y_t = Y\left[\frac{\sin\ \beta x}{\sin\ \beta l}\right]^2 \tag{14}$$

If Y is a pure conductance of value $1/R$, then Y_t is the pure conductance

$$G_T = \frac{1}{R}\left[\frac{\sin\ \beta x}{\sin\ \beta l}\right]^2 \tag{15}$$

In the measurement of the short-circuit input admittance Y_{11}, a low-loss transmission line of large characteristic admittance is coupled loosely to an oscillator near the short-circuited end. At the open end are a voltage-detecting device and a calibrated capacitor, by means of which B_{11} is obtained from (9). With the unknown transducer across the open end and the capacitor adjusted to obtain resonance, a voltage reading is taken. The transducer is removed and one of the standard resistors placed across the line bridging the two conductors. The position of this resistor along the line is then adjusted and the system is readjusted for resonance with the calibrated capacitor until the voltage, as measured at the end of the line, is the same as before. By (15) we have

$$G_{11}=G_T=\frac{1}{R}\left[\frac{\sin \beta x}{\sin \beta l}\right]^2 \tag{16}$$

where R is the resistance of the standard placed x centimeters from the short-circuited end of the line. It is evident that a resistor must be selected having a resistance value near to but not larger than the reciprocal of G_{11}.

Since the transmission line should have low loss and low characteristic impedance, a coaxial line is desirable. The line will require a longitudinal opening or slot in order to permit one of the standard resistors to bridge the line at an adjustable position to satisfy the required voltage condition. A valve voltmeter is capacitively coupled to the open end of the line across which the electron-tube transducer may be attached. Socket and filter arrangements for wire-lead valves can be attached to this line. Radiation difficulties arising from the longitudinal opening in the line, together with the increasing difficulty in obtaining resistance standards at frequencies much above 300 Mc/s, appear to make this type of measuring equipment impracticable for measurements at higher frequencies on surface-lead valves. Ref. S12.

(B) Short-circuit feedback admittance (y_{12})

Susceptance-variation method of measurement

See (A)1 above for general description.

(a) With the input termination still set at the value for resonance obtained in step (c) in (A) above, excite the output circuit through Y_{C2}. In the event that oscillation difficulties are encountered, detune the output circuit Y_2 or load it until oscillation stops.

(b) Record the voltmeter readings V$_1$ and V$_2$.

The magnitude of the feedback admittance is then given by the relation

$$|y_{12}|=\left|\frac{V_1}{V_2}\right|\frac{\Delta B_1}{2}\left[(1+2\eta^2)^{1/2}+\eta\right] \tag{17}$$

or

$$|y_{12}|\approx\left|\frac{V_1}{V_2}\right|\frac{\Delta B_1}{2}\left[1+\eta+\eta^2\right] \tag{18}$$

or

$$|y_{12}|\approx\frac{\Delta B_1}{2}\left|\frac{V_1}{V_2}\right| \tag{19}$$

where ΔG_1 and ΔB_1 are the values obtained in the preceding measurement of y_{11}.
Ref. S12.

(C) Short-circuit output admittance (y_{22})

The short-circuit output admittance may be measured by following the procedure outlined for the short-circuit input admittance, the signal being coupled through Y_{C2}. If the subscripts 1 and 2 are interchanged, all of the above formulae concerning y_{11} may be used to relate y_{22} to the measured data.

Ref. S12.

(D) Short-circuit forward admittance (y_{21})

The magnitude of the forward admittance may be measured by following the procedure outlined previously for the measurement of the magnitude of y_{12}. If the subscripts 1 and 2 are interchanged, all of the formulae concerning y_{12} may be used to relate y_{21} to the measured data.

Ref S12.

(E) Perveance

(1) Perveance of a diode

The perveance of a diode may be derived by plotting the current against the three-halves power of the voltage, when the slope of the curve will give the value of G. Voltages should be chosen sufficiently high so that such effects as those produced by contact potential and initial electron velocity are unimportant. If this is not possible, a correction voltage ϵ should be added to the diode voltage, where

$$\epsilon=(3/2)I_b r_b-e_b$$

where r_b=anode resistance of diode.

Ref. S12.

(2) Perveance of a triode

The perveance of a triode may be derived as for a diode where the diode anode voltage is taken as the composite controlling voltage

$$e'=\frac{e_c+(e_b/\mu)}{1+(1/\mu)} \tag{20}$$

Multi-grid valves may be considered, with sufficient accuracy for most purposes, as triodes with the screen grid as the anode and the screen grid voltage as the anode voltage.

Low voltage correction—The effects of initial electron velocity and contact potential may be represented by an internal correction voltage ϵ that is added to the composite controlling voltage, where

$$\epsilon=\frac{3I_b\mu}{2g_m(\mu+1)}-\frac{\mu e_c+e_b}{\mu+1} \tag{21}$$

The value of g_m to be used is that obtained with all the electrodes except the cathode and control grid tied together to form an anode which is held at the voltage ordinarily used for the screen grid.

Ref. S12.

(vii) Characteristics by pulse methods—point by point

The characteristics of valves in the region where electrode dissipations or currents exceed safe values may be obtained by pulse methods, in which the valve is allowed to pass current only for short intervals of such duration and recurrence frequency that it is not damaged.

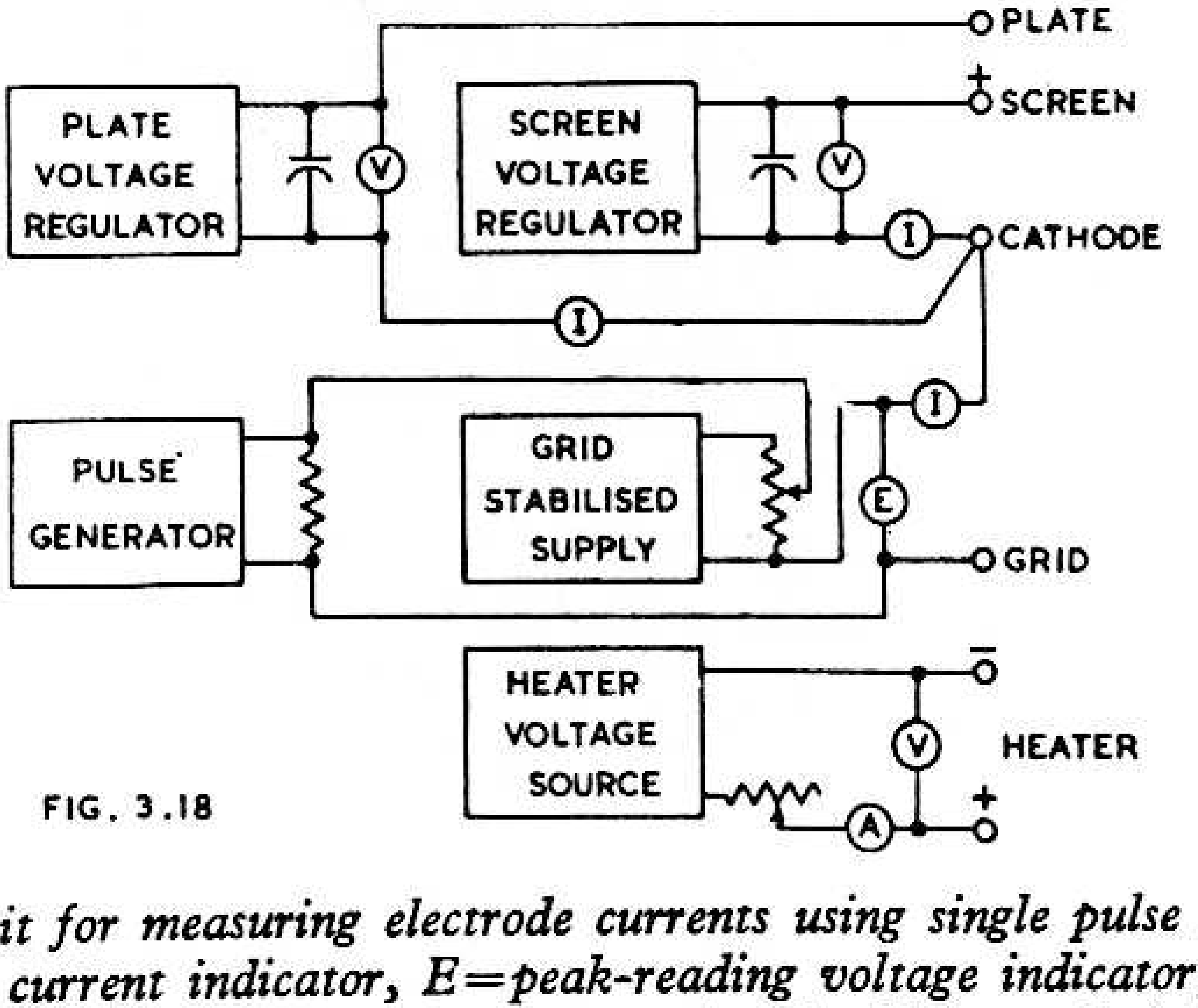

FIG. 3.18

Fig. 3.18. Circuit for measuring electrode currents using single pulse generator method (I=peak-reading current indicator, E=peak-reading voltage indicator, V=moving coil voltmeter). If high accuracy is required, correction should be made for the voltage drop across the current indicators. The regulation of the electrode supplies is not important for point by point testing, provided that the shunt capacitors are sufficiently large.

(a) Single generator method

The valve is operated with the desired screen and plate voltages, but with the grid biased beyond cut-off, in the absence of pulses (Fig. 3.18). If secondary emission effects produce a negative impedance, the pulse generator must be shunted by a non-inductive load resistor of such value as to maintain an overall positive impedance at its terminals.

Refs. 38, S12.

(b) Multiple generator method

With this method, no direct voltages are applied but each electrode has its own pulse generator, all generators having their pulses synchronized. This method is not commonly employed with receiving type valves. Refs. 68, 72, S12.

References to characteristics by pulse methods : Refs. 38, 68, 72, 93, S12.

(c) Pulse generators

Pulse generators are of several types. In the capacitor discharge type a condenser is switched from charge to discharge through the valve under test. If there is no series impedance, the peak voltage applied to the valve is equal to the charging voltage. However, because of the very short duration of the pulse, an accurate current indicator is difficult to design.

Refs. 68, 69, S12.

A rectangular pulse shape is obtainable from a direct supply source in series with a high-vacuum triode (or several in parallel) whose grid is normally biased beyond cut-off. A rectangular control pulse, obtainable from a conventional source, is applied in the grid circuit to permit the triode to conduct only during the duration of the pulse. (Ref. S12). Alternatively an ignitron may be used (Ref. 38).

A half sine-wave, or portion of a half sine-wave, pulse is obtainable from an alternating source with gas triode or other control to provide the desired gap between pulses. Alternatively a d.c. source may be used with a gas triode and *LC* network. Ref. S12.

(d) Peak-reading voltage and current indicators

The input circuit must have a time constant that is large with respect to the time interval between successive pulses. The greatest accuracy is obtained with a rectangular waveform, good accuracy may be obtained from a half sine-wave, while the sharply peaked capacitor discharge method is the least accurate.

A peak-reading voltage indicator may be employed to indicate peak current by using it to measure the peak voltage drop across a non-inductive resistor of known resistance.

One form of indicator is a diode type valve voltmeter with a high resistance load shunted by a large capacitance. The use of this indicator for current-measuring purposes may result in serious errors if the electrode characteristic of the valve under test exhibits any negative slope.

A cathode ray oscillograph may be used directly to measure peak voltage, or peak voltage drop across a non-inductive resistor of known resistance, provided that there is no negative slope in the electrode characteristics. If negative slope is likely to occur, a linear horizontal sweep voltage, synchronised to the pulse generator frequency, may be used to spread out the current trace. In this manner the detection of possible errors is simplified. The vertical deflection corresponding to the maximum horizontal deflection is the one required ; for characteristics having only positive slopes, this vertical deflection will also be the maximum.

Amplifiers may be used provided that they are designed with sufficient bandwidth and sufficiently linear phase-frequency response for the high-frequency components of the pulse. The attenuator should be capacitively balanced, making the ratio of capacitance to resistance of all sections alike.

Reference to peak-reading indicators : Ref. S12.

(viii) Characteristics by curve tracer methods

A characteristic curve may be traced on the screen of a C.R. tube, using a suitable type of pulse generator for one electrode and fixed voltages for the other electrodes. The simplest characteristic for this purpose is the grid voltage versus plate current characteristic, either with zero plate load resistance or with a specified load resistor (" dynamic " characteristic).

A triangular or half sine-wave pulse generator characteristic is satisfactory. The grid is normally biased beyond cut-off, but is swung over the useful range of voltages by the pulse.

The plate voltage versus plate current characteristic may be traced by maintaining the grid (and screen, if any) at constant voltage and by applying the pulse voltage to the plate. This requires a peak voltage of several hundred volts for receiving valves, together with high peak currents. The grid voltage must be maintained constant, the regulation requirements being severe. The regulation requirements of the other electrodes are not important, if large capacitors are used.

A method of showing the two axes for any single characteristic is described in Ref. 73 which makes use of a standard vibrator.

References to curve tracer methods : 37, 39, 69, 70, 71, 72.

Display of valve characteristics

If it is desired to view a family of curves, the voltage of one electrode must be changed in steps for successive pulses. This may be accomplished by means of synchronous contactors (Refs. 34, 35, 36) or by electronic means (Ref. 39). Good regulation (high stability) for the electrode voltage supplies is very important.

See also Refs. 37, 90, 94, 96, S12.

SECTION 4 : ACCEPTANCE TESTING

(i) Relevant characteristics (ii) Valve specifications (iii) Testing procedure.

(i) Relevant characteristics

The relevant characteristics for acceptance testing are those characteristics that are subject to deterioration subsequent to manufacture, it being assumed that the valves have satisfactorily passed the valve manufacturing test specification. These relevant characteristics for acceptance testing may be divided into mechanical and electrical characteristics.

Mechanical characteristics that require checking for faults include loose bases and top caps, dry joints in connections, cracks in envelopes caused by glass strain, damage resulting from inherent strain or careless handling, damage to internal structure resulting in misalignment of electrodes, shorts and open circuits, loss of vacuum, noise and microphony from excessive handling causing damage to the mount and micas.

Electrical characteristics that require checking for faults include gas, a relevant dynamic test, emission and noise.

(ii) Valve specifications

The most widely known of the official specifications are those of the British (K1001) and American (JAN-1A) authorities covering types used in their respective areas.

(iii) Testing procedure

The testing procedure in each case is as laid down in the prescribed specifications. Where, however, valves do not require to be accepted to a prescribed specification, it is satisfactory to adopt the following procedure :

(a) Visually inspect all valves 100 per cent. for mechanical defects.

(b) Test all valves 100 per cent. for shorts and open circuits.

(c) Select at random from all the valves a representative sample (or samples) and test for a suitable dynamic characteristic using established statistical acceptance procedure. The test selected should give a satisfactory indication of the overall performance of the type in its normal application.

References to sampling inspection : Refs. 42, 43, 44.

SECTION 5: SERVICE TESTING AND SERVICE TESTER PRACTICE*

(i) Purpose and scope of service testing and discussion of associated problems.
(ii) Fundamental characteristics which should be tested.
(iii) Types of commercial testers.
(iv) Methods of testing characteristics in commercial service testers
    (a) Shorts testing
    (b) Continuity testing
    (c) Heater to cathode leakage
    (d) Emission testing
    (e) Mutual conductance testing
    (f) Plate conductance testing
    (g) Reverse grid current testing
    (h) Power output testing
    (i) Conversion conductance testing
    (j) Oscillator mutual conductance testing
    (k) Noise testing
    (l) A.C. amplification testing.
(v) A.C. versus d.c. electrode voltages in testers.
(vi) Pre-heating.
(vii) Testing procedure.

(i) Purpose and scope of service testing and discussion of associated problems

Service testing is only carried out on valves which have previously been factory tested and which have also operated satisfactorily in a new receiver. The faults to be expected are those which may occur after manufacture.

Service testing is for the purpose of determining either

(1) whether or not a valve in working condition has reached the point in life when it should be replaced, or (2) whether a valve with unknown history is faulty or not.

The determination of the point of life when a valve should be replaced is a very complex problem. This is a function of the application of the valve and of the standard of performance expected by the user. For example, a valve which still operates reasonably well as a resistance-coupled amplifier may yet give low gain as an r-f amplifier, and a valve which will still operate as an amplifier may fail to oscillate when used in the oscillator position. A receiver with old valves in the r-f and i-f stages may have very much less gain that it would have with new valves, but the effect may not be noticed by the user unless the set is used for the reception of weak signals.

A list of the generally accepted life test end-points is given in Sect. 2(iv)b.

The radio service-man is usually called upon to test a number of valves, frequently the whole valve complement of a receiver, to determine which (if any) is faulty. If one is obviously faulty, for example due to a short-circuit, open-circuit, gas, or extremely low emission, the problem is simple. In other cases it is helpful to test the valves in the original receiver, with a second complement of new valves for comparison, to make certain that the receiver itself is not faulty If the original receiver is not accessible, the valves may be plugged into another receiver (preferably of the same model) for test.

Microphony should be checked in the original receiver. Motor-boating may be due to gas or grid emission, but it may also be caused by a faulty component in the receiver. Distortion is generally due to the power valve, but may also be caused by a defective filter by-pass capacitance in the receiver and in some cases by the signal diode or a defective resistor. Hum is usually caused by heater-to-cathode leakage or breakdown in the valve or a faulty filter capacitor in the circuit.

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*The assistance of A. H Wardale, Member I.R.E. (U.S.A.) and D. H. Connolly, A.S.T.C. is acknowledged.

(ii) Fundamental characteristics which should be tested

The fundamental characteristics which should be capable of being tested in a service tester are

(a) Shorts and continuity.

Testing for short circuits is essential.

Testing for continuity of the electrodes is highly desirable.

(b) Dynamic tests.

The dynamic tests which should be carried out in a service tester are :

Class of valve	**Preferred test**	**Less desirable alternative**
Rectifier (power diode)	Emission	Rectification test
Signal diode	Emission	—
Triode, low mu	Mutual conductance	—
Triode, high mu	A.C. amplification	—
Pentode, r-f	Mutual conductance	—
Pentode, battery a-f	A.C. amplification	—
Pentode, power	Power output	—
Converter	Conversion conductance	Mixer g_m
	Oscillator grid current	Oscillator g_m

See Sect. 3 for methods of testing these characteristics.

The dynamic test should be one in which the peaks and average plate currents approximate to the maximum current in normal operation.

(c) Other tests

Other tests which should be carried out in a service tester are :

Gas (amplifier types only).

Noise (amplifier types only).

Heater to cathode leakage (indirectly-heated types only).

(iii) Types of commercial testers

Commercial service testers are necessarily a compromise. They must be fairly simple to use, flexible with regard to future valve developments, as free as possible from damage to indicating instruments through faulty valves or misuse, speedy in operation and true in their indications.

The possible combinations of characteristics tested are :

Type of valve	**Essential tests**	**Desirable tests**
All	Shorts	Continuity Heater to cathode leakage
Vacuum types	At least one dynamic test	Emission Mutual conductance A.C. amplification Power output
	or for converters	Conversion conductance or Mixer g_m and Oscillator g_m
	together with	Noise Gas

Out of a representative group of 22 modern service testers examined, 17 incorporated some form of mutual conductance test, 7 incorporated an emission test other than for diodes and all 22 incorporated a diode emission test. One provided a plate conductance test. With regard to the remaining tests, 8 incorporated a heater to cathode leakage test, with 7 having a gas test and 7 having a noise test.

It seems to be generally admitted that an emission test alone is not a very satisfactory dynamic test for all amplifying valves. The better types of testers have both mutual conductance and diode emission ; they are deficient in that they do not provide a power output test for power valves, or a.c. amplification for high-mu triodes and a-f pentodes. The method of testing for mutual conductance with a high grid swing is not the equivalent of a power output test. Neither mutual conductance nor emission testing is a satisfactory substitute for a.c. amplification testing of high-mu triodes or a-f pentodes.

It is obvious, therefore, that any ordinary commercial service tester does not give a true indication of the condition of all types of valves, and its readings should be used with discretion.

(iv) Methods of testing characteristics in commercial service testers

(a) Shorts testing

Testing for shorts should be carried out at mains frequency or on d.c., and the voltage applied to the neon lamp circuit should not exceed 110 volts r.m.s. The use of higher voltages results in some good valves being classed as filament-to-grid short circuits.

With a.c. supply, it is usual to design the circuit so that resistances over 0.5 megohm do not indicate as shorts ; this is to avoid capacitance effects. With d.c. supplies there is no similar limitation, but different models vary considerably in their shorts testing sensitivity.

The most satisfactory switching arrangement is one which tests for shorts from any pin to all other pins tied together. The circuit of Fig. 3.4 may be used, except that the cathode need not be heated.

(b) Continuity testing

Continuity testing may be carried out in a manner closely resembling shorts testing, but with the cathode hot. Positive or alternating voltage is applied through the neon lamp to each electrode in turn ; a glow indicates continuity.

The circuit of Fig. 3.4 may be used in a simple service tester, but a more elaborate tester such as the hexaphase (Fig. 3.2) is much more satisfactory for general use.

For further information on continuity testing see Sect. 3(ii)b.

(c) Heater to cathode leakage

The maximum leakage resistance from heater to cathode in new valves varies from 1 or 2 megohms for power valves to 5 megohms for ordinary 6.3 volt 0.3 ampere voltage amplifier valves and even higher for rectifier types having separate heaters and cathodes. A neon lamp will normally glow slightly when used in a shorts tester and applied between heater and cathode. A neon lamp may be de-sensitized either by shunting by a resistor (of the order of 0.1 to 0.5 megohm) or by a mica condenser (a value of 0.01 μF gives a sensitivity of about 5 megohms—this is only useful with a.c. supply).

(d) Emission testing

Of the 7 commercial testers which included emission testing of amplifying valves, 5 used a.c. testing, 1 used half-wave rectified a.c. testing, and 1 used d.c. testing. Owing to the poor regulation obtainable from most service valve testers with d.c. supplies, other than batteries, it is doubtful whether this has any practical advantages over a.c. testing. With a.c. supply, the voltage in most service testers is 30 volts r.m.s. ; this is only a compromise which is far from the optimum for all cases. For laboratory testing of emission see Sect. 3(ii)f.

(e) Mutual conductance testing

Of the 17 commercial testers having a mutual conductance test, 7 used some form of a.c. signal voltage applied to the control grid, and 6 used some grid shift method, the methods used by the other 4 being unknown.

All the American mutual conductance testers examined apply an a.c. signal to the grid, and measure the signal current in the plate circuit ; all but one of these use a mains frequency signal, the exception being one with a 5 Kc/s signal and a tuned signal plate current meter.

In most cases this is not an accurate g_m test for all types of valves because the signal voltage on the grid is fairly high—between 4 and 5 volts r.m.s. in some cases—sufficient to run beyond grid cut-off in one direction and well on to the " flat top " in the other, with short grid-base valves. Even those testers with reduced signal voltages have quite appreciable errors with some types of valves.

On the other hand, all but one of the examined English mutual conductance testers use a grid shift method. This introduces some errors due to plate supply regulation and curvature of the characteristics, but these can be allowed for in the calibration.

(f) Plate conductance testing

This is used by one American tester only as a reasonably close equivalent of the mutual conductance test, the amplification factor being assumed to be constant. Pentodes are triode-connected. A moderately high signal voltage is applied, this being possible with less error than with direct g_m measurement owing to the slight compensating change of μ with plate current.

(g) Reverse grid current testing

Of the post-war testers examined, all those of English design incorporate reverse grid current testing (often referred to as " gas testing ") but this test was incorporated in only two of American design. The usual methods of testing are either by grid current meter or by a shorted grid resistor. For further details see Sect. 3(iv)A.

A valve which passes the reverse grid current test on a service tester may not operate satisfactorily in a receiver. The usable maximum value of negative grid current depends upon the application, the mutual conductance of the valve, the resistance in the grid circuit, the type of bias, the bias voltages, the total dissipation of the valve and its ventilation. The valve may be checked in the actual receiver after running for a period sufficiently long for the valve to reach its stable operating temperature ; it may be tested by variation in the plate current of the valve under test when its grid resistor is shorted.

(h) Power output testing

This is not incorporated into any of the commercial service testers examined, but is the most satisfactory test for all power valves. Triode testing of pentode and beam power valves is quite satisfactory. Methods of testing are described in Sect. 3(iv)I.

(i) Conversion conductance

Only one of the testers examined provided a test for conversion conductance, the method being by phase reversal. For further details see Sect. 3(v)Bd.

A satisfactory alternative is to measure the transconductance of the mixer, this being the method commonly employed.

(j) Oscillator mutual conductance

None of the testers provided a test for oscillator grid current under self-oscillating conditions, although this is the most satisfactory form of test. For details see Sect. 3(v)Bg.

The method commonly employed is to measure the oscillator mutual conductance.

The measurement of oscillator grid current in a suitable receiver is a simple way of checking the oscillator section of a converter.

(k) Noise

The usual form of noise test is to connect the two neon lamp terminals to the aerial and earth terminals of a receiver, during the shorts test. For other forms of noise test see Sect. 3(iv)L and M.

(l) A.C. amplification

This test should be carried out with zero bias and a high value of grid resistor, as described in Sect. 3(iv)H. No test with fixed or self-bias is able to determine how a valve will operate with grid resistor bias.

(v) A.C. versus d.c. electrode voltages in testers

All but four of the commercial testers examined, which made provision for some form of g_m test, used d.c. electrode supplies. The general trend seems to be in the direction of using d.c. supply to all electrodes, and the additional circuit complications appear to be justified.

For comparison between laboratory testing of emission by a.c. or d.c. methods, see Sect. 3(ii)f.

(vi) Pre-heating

When more than one valve is to be tested, a pre-heating socket should be provided to save time. If not incorporated into the tester itself, the pre-heater may be a separate unit with one of each type of socket and a filament voltage switch and transformer. No voltages need normally be applied to the other electrodes except in cases when the valve is initially satisfactory but becomes defective during operation.

(vii) Testing procedure

Always test for shorts before carrying out any other test. When testing for emission, allow ample time for the valve to heat thoroughly before pressing the emission switch ; then press only long enough to give a reading. Do not leave the valve for more than three seconds on the emission test as otherwise the valve may be permanently damaged. The reading may be regarded as satisfactory provided that it is not below the limit and that it does not fall rapidly to the limit in the three second period.

When testing for mutual conductance, the switch may be pressed for any desired length of time, as no damage will be done to the valve provided that the valve is operated within its maximum ratings.

If a valve is gassy, the readings of emission and mutual conductance will be affected (usually increased for a slight amount of gas and decreased by excessive gas). If a valve is both gassy and of low emission, the true fault is " gas ".

If a valve indicates " no emission " while the heater is continuous, the fault may be excessive gas, air in the bulb, cathode coating " poisoned " by gas, or open-circuited cathode. Air in the bulb is indicated by a continuous heater, a cathode not visibly red, and a bulb which gradually becomes warm.

References to service testing : Refs. 55, 56, 57, 60, 61, 62, 63, 64.

SECTION 6 : REFERENCES

1. Benjamin, M., C. W. Cosgrove and G. W. Warren. " Modern receiving valves : design and manufacture " Jour. I.E.E. 80.484 (April 1937) 401.
2. Tuttle, W. N. " Dynamic measurement of electron tube coefficients " Proc. I.R.E. 21.6 (June 1933) 844.
3. Lehany, F. J., and W. S. McGuire. " A radio-frequency interelectrode-capacitance meter " A.W.A. Tec. Rev. 7.3 (April 1947) 271. See also Ref. 5.
4. Pockman, L. T. " The dependence of interelectrode capacitance on shielding " Proc. I.R.E. 32.2 (Feb. 1944) 91.
5. Dobbie, L. G., and R. M. Huey. " A.W.A. interelectrode capacity meter Type R1782 for screen grid valves " A.W.A. Tec. Rev. 2.4 (Oct. 1936) 107.
6. Van der Bijl (book). " The Thermionic Vacuum Tube " (McGraw-Hill Book Co. 1920).
7. Pidduck, F. B. (book). " A Treatise on Electricity " (Cambridge University Press, 1925).
8. Hague, B. (book). " Alternating Current Bridge Methods " (Sir Isaac Pitman & Sons Ltd., London, 5th edit., 1943).
9. Hartshorn, L. (book). " Radio Frequency Measurements by Bridge and Resonance Methods " (Chapman & Hall Ltd., London, 1942).
10. Thomson, J. J. (book). " Elements of Electricity and Magnetism " (Cambridge University Press, 5th edit., 1921).
11. Jeans, J. (book). " The Mathematical Theory of Electricity and Magnetism " (Cambridge University Press, 5th edit., 1943).
12. Smythe, W. R. (book). " Static and Dynamic Electricity " (McGraw-Hill Book Co., 2nd ed. 1950).
13. Maxwell, J. C. (book). " Electricity and Magnetism " (published 1892).
14. Valley, G. E., and H. Wallman (editors). " Vacuum Tube Amplifiers " Radiation Laboratory Series, McGraw-Hill Book Co., 1948.
15. Reich, H. J. (book). " Theory and Applications of Electron Tubes " (McGraw-Hill Book Co., 1939).
16. Chaffee, E. L. (book). " Theory of Thermionic Vacuum Tubes " (McGraw-Hill Book Co., 1933).
17. Scroggie, M. G. (book). " Radio Laboratory Handbook " (Wireless World, London).
18. Terman, F. E. (book). " Measurements in Radio Engineering " (McGraw-Hill Book Co., 1935).
20. Wireless Telegraphy Board Specification K1001 – radio valves.
21. Hund, A. (book). " High Frequency Measurements " (McGraw-Hill Book Co., 1933).
22. Miller, J. M. " A dynamic method for determining the characteristics of three-electrode vacuum tubes " Proc. I.R.E. 6 (June, 1918) 141.
23. James, E. G., and B. L. Humphreys. " Resistive films in valves – effect on interelectrode capacitance " W.E. 26.306 (March 1949) 93.
24. Booth, R. H. (letter). " Triode interelectrode capacitances " W.E. 26.309 (June 1949) 211.
25. Walsh, L. " A direct capacity bridge for vacuum-tube measurements " Proc. I.R.E. 16.4 (April 1928) 482.
26. Wheeler, H. A. " Measurement of vacuum-tube capacities by means of a transformer balance " Proc. I.R.E. 16.4 (April 1928) 476.

27. Hoch, E. T. "A bridge method for the measurement of interelectrode admittance in vacuum tubes" Proc. I.R.E. 16.4 (April 1928) 487.
28. Loughren, A. V., and H. W. Parker. "The measurement of direct interelectrode capacitance of vacuum tubes" Proc. I.R.E. 17.6 (June 1929) 957.
29. Jones, T. I. "The measurement of the grid-anode capacitance of screen-grid valves" Jour. I.E.E. 74.450 (June 1934) 589.
30. Astbury, N. F., and T. I. Jones. "A capacitance attenuator and its application to the measurement of very small capacitances" Jour. Sci. Instr. 13.12 (Dec. 1936) 407.
31. Barco, A. A. "An improved interelectrode capacitance meter" R.C.A. Rev. 6.4 (April 1942) 434.
32. Tillman, J. R., and A. C. Lynch. "Apparatus for the measurement of small three-terminal capacitances" Jour. Sci. Instr. 19.8 (Aug. 1942) 122.
33. Proctor, R. F., and E. G. James. "A radio-frequency and conductance bridge" Jour. I.E.E. 92 Part III. 20 (Dec. 1945) 287.
34. van Suchtelen, H. "Applications of cathode ray tubes: iv—the recording of diagrams" Philips Tec. Rev. 3.11 (Nov. 1938) 339.
35. Douma, Tj., and P. Zijlstra. "Recording the characteristics of transmitting valves" Philips Tec. Rev. 4.2 (Feb. 1939) 56.
36. van der Ven, A. J. H. "Testing amplifier output valves by means of the cathode ray tube" Philips Tec. Rev. 5.3 (March 1940) 61.
37. Millman, J., and S. Moskowitz. "Tracing tube characteristics on a cathode ray oscilloscope" Elect. 14.3 (March 1941) 36.
38. Easton, E. C., and E. L. Chaffee. "Pulse-type tester for high-power tubes" Elect. 20.2 (Feb. 1947) 97.
39. Webking, H. E. "Producing tube curves on an oscilloscope" Elect. 20.11 (Nov. 1947) 128.
40. Herold, E. W. "An improved method of testing for residual gas in electron tubes and vacuum systems" R.C.A. Rev. 10.3 (Sept. 1949) 430.
41. Kauzmann, A. P. "New television amplifier receiving tubes" R.C.A. Rev. 3.3 (Jan. 1939) 271.
42. Dodge, H. F., and H. G. Romig. "Single sampling and double sampling inspection tables" B.S.T.J. Jan. 1941 20.1 (Jan. 1941) 1.
43. Dodge, H. F., and H. G. Romig (book). "Sampling Inspection Tables" (John Wiley & Sons Inc., New York, Chapman & Hall, London, 1944).
44. Keeling, D. B., and L. E. Cisne. "Using double sampling inspection in a manufacturing plant" B.S.T.J. 21.1 (June 1942) 37.
45. Davies, J. A. "Quality control in radio tube manufacture" Proc. I.R.E. 37.5 (May 1949) 548.
46. Harris, J. A. "On the co-ordination of circuit requirements, valve characteristics and electrode design" J. Brit. I.R.E. 9.4 (April 1949) 125.
47. Slonczewski, T. "Transconductance as a criterion of electron tube performance" B.S.T.J. 28.2 (April 1949) 315.
48. British Radio Valve Manufacturers' Association (booklet). "Radio Valve Practice" (August 1948).
49. British Standard Code of Practice BS1106 (Feb. 1943). "The use of radio valves in equipment."
51. Application Note. "Input admittance of receiving tubes" (AN-118, April 15, 1947) Radio Corporation of America.
52. "Tube Handbook" HB3, Radio Corporation of America.
53. "Radio Components Handbook" (1st ed. 1948, Technical Advertising Associates, Cheltenham, Penn., U.S.A.).
55. Hartkopf, R. E. "Simple valve tester—checking insulation, mutual conductance and emission" W.W. 42.12 (Dec. 1946) 386.
56. Everett Edgcumbe Service Valve Tester, W.W. 42.12 (Dec. 1946) 416.
57. "Dynamic mutual conductance tube tester" (Hickok design) Service 16.3 (March 1947) 2.
58. Heacock, D. P. "Power measurement of Class B audio amplifier tubes" R.C.A. Rev. 8.1 (March 1947) 147.
59. Walker, H. S., C. G. Mayo and J. Tomlinson "Portable sub-standard of mutual conductance" B.B.C. Research Dept. Report H.009 (27 Oct. 1938).
60. "A universal tube checker" Radio Craft (Feb. 1944) 292.
61. Dewar, J. A. "Dynamic tube tester" Radio Craft (Nov. 1944) 94.
62. Planer, F. E. "Valve Testing—rapid determination of amplification factor and anode impedance under operating conditions" W.W. 51.6 (June 1945) 20.
63. Simpson. "Dynamic tube tester" Elect. 19.2 (Feb. 1946) 338.
64. "Hickok Tube Tester Models 532C and 532P" Elect. 19.3 (Mar. 1946) 282.
65. Blackburn, J. F. (editor). "Components Handbook" (M.I.T. Radiation Laboratory Series, No. 17, 1st ed. 1949, McGraw-Hill Book Co.).
66. Laws, F. A. (book). "Electrical Measurements" (McGraw-Hill Book Co. 2nd ed. 1938).
67. Appleton, E. V. (book). "Thermionic Vacuum Tubes" (Methuen & Co. Ltd., London).
68. Livingston, O. W. "Oscillographic method of measuring positive-grid characteristics" Proc. I.R.E. 28.6 (June 1940) 267.
69. Kozanowski, H. N., and I. E. Mouromtseff. "Vacuum tube characteristics in the positive grid region by an oscillographic method" Proc. I.R.E. 21.8 (April 1933) 1082.
70. Chaffee, E. L. "Oscillographic study of electron tube characteristics" Proc. I.R.E. 10.6 (Dec. 1922) 440.
71. Schneider, W. A. "Use of an oscillograph for recording vacuum tube characteristics" Proc. I.R.E. 16.5 (May 1928) 674.
72. Chaffee, E. L. "Power tube characteristics" Elect. 11.6 (June 1938) 34.
73. Walker, A. H. B. "Cathode-ray curve tracer" W.W. 50.9 (Sept. 1944) 266.
74. Zepler, E. E. "Triode interelectrode capacitances" W.E. 26.305 (Feb. 1949) 53.
75. Jones, T. I. "The dependence of the inter-electrode capacitances of valves upon the working conditions" Jour. I.E.E. 81 (1937) 658.
76. Humphreys, E. L., and B. G. James. "Interelectrode capacitance of valves—change with operating conditions" W.E. 26.304 (Jan. 1949) 26.
77. Young, C. H. "Measuring interelectrode capacitances" Tele-Tech 6.2 (Feb. 1947) 68.
78. Terman, F. E. "Radio Engineers' Handbook" (McGraw-Hill Book Co., 1943).
79. Dawes, C. L. (book). "A Course in Electrical Engineering" Vol. 2 (McGraw-Hill Book Co. 3rd edit., 1934).
80. Hickman, R., and F. Hunt. "The exact measurement of electron tube coefficients" Rev. Sci. Instr. 6 (Sept. 1935) 268.
81. Eastman, A. V. (book). "Fundamentals of Vacuum Tubes" (McGraw-Hill Book Co. 1937).
82. Albert, A. L. (book). "Fundamental Electronics and Vacuum Tubes" (The Macmillan Co., New York, 1938).

83. Aiken, C. B., and J. F. Bell. " A mutual conductance meter " Comm. 18.9 (Sept. 1938) 19.
84. Millman, J., and S. Seely (book). " Electronics " (McGraw-Hill Book Co. 1941).
85. Suits, C. G. " A thermionic voltmeter method for the harmonic analysis of electrical waves " Proc. I.R.E. 18 (Jan. 1930) 178.
86. Belfils, G. " Mesur du 'residu' des courbes de tension par la methode du pont filtrant " Rev. Gen. d'Elect. 19 (April 1926) 526.
87. Wolff, Irving. " The alternating current bridge as a harmonic analyzer " Jour. Opt. Soc. Amer. 15 (Sept. 1927) 163.
88. McCurdy, R. G., and P. W. Blye. " Electrical wave analyzers for power and telephone systems " Jour. A.I.E.E. 48 (June 1929) 461.
89. Ballantine, S., and H. L. Cobb. " Power output characteristics of the pentode " Proc. I.R.E. 18 (March 1930) 450.
90. " Curve generator for tubes " developed by M. L. Kuder of N.B.S., Elect. 23.7 (July 1950) 144.
91. " Heater-cathode leakage as a source of hum " Elect. 13.2 (Feb. 1940) 48.
92. Zepler, E. E. and S. S. Srivastava " Interelectrode impedances in triodes and pentodes " W.E. 28.332 (May 1951) 146.
93. Wagner, H. M. " Tube characteristic tracer using pulse techniques " Elect. 24.4 (Apr. 1951) 110.

Additional references will be found in the Supplement commencing on page 1475.

Standards Specifications.

S1. Standards on electronics (1938) The Institute of Radio Engineers. U.S.A. See also S12.
S2. Joint Army-Navy Specification JAN-1A (U.S.A.).
S3. Joint Army-Navy Specification JAN-S-28 Sockets, electron tube, miniature.
S4. RMA-NEMA* Standards for electron tube bases caps and terminals (Feb. 1949)—RMA Standard ET-103A.
S5. RMA-NEMA* Dimensional characteristics of electron tubes (Jan. 1949)—RMA Standard ET-105A.
S6. RMA-NEMA-JETEC Standard ET-106A (Feb. 1952) Gauges for electron tube bases.
S7. RMA Standard ET-107 (Dec. 1946) Test methods and procedures for radio receiving tubes.
S8. RMA-NEMA* (Dec. 1947) Standards for measurement of direct interelectrode capacitances—RMA Standard ET-109.
S9. RMA-NEMA* (Feb. 1948) Standard for designation system for receiving tubes—RMA Standard ET-110.
S10. RMA-NEMA* (Feb. 1949) Designation system for electron tube shells—RMA Standard ET-112.
S11. " Tube Ratings "—RMA Standard M8-210 (Jan. 8, 1940).
S12. " Standards on electron tubes : methods of testing 1950 " Proc. I.R.E., Part 1, 38.8 (Aug. 1950) 917 ; Part 2, 38.9 (Sept. 1950) 1079.

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