ELECTRONIC DEVICES

ELECTRONICS

By

F. G. SPREADBURY, A.M.Inst.B.E.

An authoritative and up-to-date book dealing with the science and applications of the electron The author explains the facts in a most logical manner, and gives a clear and competent understanding of the nature of Electronics and the purposes to which it can be applied. The book is of essential value and importance to all radio and electrical engineers and technicians.

PITMAN

ELECTRONIC DEVICES

BY

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PREFACE

THERE is to-day an enormous demand for electronic devices. Their application in the factory, shop, office—and even the home —is ever increasing. Yet their principles and functions are not widely realized. In the course of his normal day a man may switch on his radio receiver, his television set, his fluorescent lighting, and still look upon electronics as a laboratory art.

Atomic energy is now front-page news. To-morrow it may well be a recognized source of power supply. The atomic nature of electricity was conceived in the early 1800's but, although the fact that electricity could be conducted through a gas or partial vacuum was definitely established, it was not until 1870 that the presence of free electrons was even suspected. To gain some idea of electronic progress during the last few years we must remember that the heart of the atom-smashing Betatron, that mass of iron, glass and copper weighing 130 tons, is a vacuum tube provided with an electron gun, also that the Cyclatron, another machine used in the production of atomic energy, employs high voltage electronic technique to kick the protons forward.

An even more recent application, the so-called "Electronic Brain," known in the U.S.A. as "Eniac," employs 18,000 valves and can handle about a million calculations an hour worked out to ten figures of decimals. A British apparatus (the "Ace") now being evolved at an estimated cost of £100,000 to £125,000 will ultimately have a memory storage, will be able to multiply two ten-figure numbers in two-thousandths of a second, and will be capable of dealing with simultaneous equations with one hundred unknowns.

We know that the passage of electrons through a gas or vapour is accompanied by an interchange of energy. Furthermore, this interchange may result in the production of mechanical, electrical, or light energy. Thus an electronic device may be justly regarded as the most versatile modifier of electrical energy so far available.

The main object of this book is to summarize some of the electronic devices available at the present time. Two types of reader have been borne in mind: the student, and the electrical engineer not primarily concerned with electronics. In other words, an attempt has been made to fill the gap between elementary theory and technical specialization.

H. A. MILLER.

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CHAPTER I

INTRODUCTION

ELECTRONICS is concerned with the conduction of electricity through gases, vapours, or partial vacua. It is by no means a new discovery. Luminous discharges in partially exhausted glass bulbs were observed by Nollet during his "electric egg" experiments of 1750. The utilization of electronic principles, however, has developed so rapidly during the last decade or so that the production of electronic devices can now be regarded as a large and highly specialized industry.

Electronic Device. An electronic device may be defined as an apparatus that depends for its action upon the emission of free electrons from the cathode. This may be brought about by the application of heat, light, or electric fields. It may be facilitated by coating the cathode with an alkali earth oxide. It may be controlled by the influence of another electrode or a magnetic or an electrostatic field.

An electron stream is itself invisible, although its effect may become apparent in a gas- or vapour-filled device by a luminous glow.

Of the electron itself comparatively little is known. Its mass is now generally accepted to be $0 \cdot 911 \times 10^{-27}$g, its charge $4 \cdot 803 \times 10^{-10}$ e.s.u., and its diameter about 2×10^{-13} cm. Electrons are present in each atom of matter and are normally held in position by balance of the attractive forces.

In the case of crystalline solids, such as metals, the atoms may be maintained in lattice formation. Under the influence of heat energy or electric or magnetic force, however, free electrons can be set in motion. This is the necessary condition for electronic emission.

Emission. Emission may principally be obtained (1) thermionically, (2) photo-electrically, (3) by bombardment (secondary emission), and (4) by ionization (in the case of gases and vapours).

In thermionic emission the metal is heated in order that electrons may be more readily released. Electrons are emitted photo-electrically from certain metals by transfer of energy to electrons as a result of the application of light. Bombardment of a metal surface by free electrons or ions will, provided that the energy transfer is sufficient, result in secondary emission. The removal of electrons from molecules of gas is known as "ionization."

CHAPTER II

THERMIONIC VACUUM VALVES

THE application of thermionic vacuum valves to wireless transmission and reception needs no introduction. Nevertheless, there are a great many industrial devices in which they are indispensable. In some ways the thermionic valve may be regarded as the basis of electronics.

Classification. Vacuum valves are classified primarily according to the number of electrode elements they contain. Essentially, two elements at least—a cathode and an anode—must be provided. A valve containing only these two is termed a "diode," and is used as a rectifier of alternating currents.

A valve containing a cathode and an anode with a third electrode (the "grid") between them is called a "triode"; this may be used for a number of purposes, including amplification, modulation, oscillation, frequency conversion, and controlled rectification.

By inserting a further grid (the "screen grid") between the anode and the grid, the tendency in the triode of the anode-cathode circuit to react upon the grid-cathode circuit is prevented. The valve, containing four electrodes, is then termed a "tetrode." It is mainly used for amplification of voltage changes, since it is extremely sensitive to changes in voltage applied to the grid.

The "pentode," a very popular valve in radio receivers, has five electrodes. In other words, it is a tetrode with an extra grid interspersed between the screen grid and the anode. The function of the additional grid is to suppress the effect of undesired secondary emission from the anode. Both voltage and power may be amplified to a considerable extent by the pentode.

Combinations of the four valves mentioned above are often contained in a single glass envelope for use in superheterodyne receivers. The heptode, a seven-electrode valve containing five grids, is used for mixing the incoming signal current with the local oscillator current. Another example, the duo-diode-pentode, is really a combination of two diodes and a pentode operating from a common cathode.

All thermionic valves are based on the principle that electrons emitted from the cathode may be controlled and collected by other electrodes mounted in the same evacuated envelope. A particular feature of these devices is their ability to control instantly, and with a minimum of energy, the flight of millions of electrons. They are, thus, capable of operating efficiently and accurately at frequencies greatly in excess of those attainable with rotating machines.

Functions. The motion of electrons can be accelerated by the application of heat energy. When metal becomes red hot electrons may acquire enough speed to break away from the surface; this is the function of the thermionic cathode.

Two methods of heating the cathode are available. If the cathode consists of a filament, it is known as a "directly heated" cathode. If, on the other hand, the cathode is a metal sleeve enclosing a filament, it is called an "indirectly heated" cathode.

Directly heated cathodes require little power for successful operation. For this reason they are used in most types of portable apparatus in which it is desirable that the current drain on the batteries should be as small as possible.

Indirectly heated cathodes are well adapted for operation from A.C. mains. Because of the electrical separation of the heater from the cathode, valves containing this type of cathode have certain advantages over the directly heated type. They provide more flexibility, they are far less likely to transmit hum from A.C. mains, and closer spacing between the electrodes is possible.

When the cathode is heated, the electrons released from it are attracted by any metal to which a positive potential is applied. In a diode, it is the anode that draws the electrons, the positive potential being supplied from an external source. The resulting flow of electrons gives rise to the "plate" current.

If a negative, instead of a positive potential, is applied to the anode, no plate current will flow and the valve will then permit electrons to flow in one direction, from cathode to anode, only. Thus, alternating voltage applied to the valve will be "rectified," and the valve is functioning as a "half-wave rectifier," since current flows during only one half of the alternating current cycle. By fitting two anodes in place of one, the current can be caused to flow during both halves of the cycle: the valve is then a "full-wave rectifier."

Owing to the fact that some of the electrons emitted by the thermionic cathode fail to reach the anode, a "space-charge" is formed. This has a repelling action on the other electrons leaving the cathode. It may be reduced by applying increased plate voltage, until a definite limit is reached, beyond which the plate current is not appreciably altered by additional plate voltage. This value of maximum current is known as either "saturation" or "emission" current.

With the triode, the plate current is controlled by the grid potential. A negatively charged grid opposes the flow of the electrons to the plate. If, therefore, the voltage of the grid is made to vary in accordance with some external influence, e.g. a wireless signal, the plate current of the valve will correspondingly alter. Quite a small voltage applied to the grid is capable of controlling a large amount of plate current.

Each electrode of the triode can be considered as one plate of a condenser, resulting in capacitance between grid and anode, anode and cathode, and grid and cathode. Of these "inter-electrode" capacitances, that between grid and anode is generally the most important, since it may result in coupling between the input circuit (the circuit between grid and cathode) and the output circuit (the circuit between anode and cathode). Its effect may be considerably reduced by an additional electrode between grid and anode. in other words by the use of a tetrode or four-electrode valve.

The function of a further grid, the "suppressor," in the pentode, has already been mentioned.

Speech or music may be transmitted by radiating a radio-frequency wave, of which the amplitude varies according to the audio-frequency signal being emitted. In other words, the radio-frequency wave is "modulated" by the audio-frequency wave.

As a radio receiver is required to reproduce the original audio-frequency modulating wave from the modulated radio-frequency wave, the signal must first be "detected." The principle of this is the partial, or complete elimination of alternate half-cycles of the radio-frequency wave. This can be achieved by either a diode detector, a grid-bias detector, or a grid-leak detector.

The diode method produces the least distortion, but has the disadvantages that it does not amplify the signal, and that it reduces selectivity by drawing current from the input circuit. The grid-leak detector amplifies the signal, but still draws current from the input circuit. The so-called "grid-bias" circuit, in which the grid is biased negatively, amplifies the signal and does not draw current from the input circuit.

After detection, the signal must be amplified. There are a number of ways in which valve amplification can be carried out. Four main classes of amplification were standardized by definitions issued by the American Institute of Radio Engineers.

A Class A amplifier is one in which the grid-bias and alternating grid voltages are such that plate current in a specific valve flows at all times. In Class A voltage amplification a valve is used to reproduce voltage variations across an impedance or a resistance in the plate circuit. In Class A power amplification the valve is used in the output stage of a receiver to supply power to the loudspeaker.

A Class AB amplifier is an amplifier in which the grid-bias and alternating grid voltages are such that the plate current in a specific valve flows for appreciably more than half, but less than the entire electrical cycle. Class AB power amplification employs two valves, connected in push-pull with a high negative bias.

In a Class B amplifier the grid bias is approximately equal to the cut-off value, so that the plate current is zero when no exciting grid voltage is applied, and so that plate current in a specific valve flows for roughly one-half of each cycle when an alternating grid voltage is applied. For Class B power amplification two valves in push-pull are biased in such a way that the plate current is practically zero when no signal voltage is applied to the grids.

A Class C amplifier is one in which the grid bias is approximately greater than the cut-off value, so that the plate current in each valve is zero when no alternating grid voltage is applied, and so that plate current flows in a specific valve for appreciably less than one-half of each cycle when an alternating grid voltage is applied.

To denote that grid current does not flow during any part of the input cycle, the suffix 1 may be added to the letter or letters of the class identification. The suffix 2 may be used to denote that grid current flows during some part of the cycle.

Construction. Small hard vacuum valves are exhausted on a rotating pump system. This may consist of a turntable with either a separate connexion to a backing pump for each valve or with one sliding joint with a number of backing pumps in parallel. Modern rotating vacuum pump systems are arranged to process as many as sixty-four valves at the same time.

Each valve is connected to the pumping system by a glass tube sealed into the pinch; usually, thick-walled pure rubber pressure tubing provided with steel clamps is used to join the glass tube to the actual pump inlet.

After exhaustion, the valves, fitted with electrode assemblies, are passed slowly through an oven at about 450°C. This removes all water vapour. The valves are then automatically encircled by eddy current heater coils and the electrodes are de-gassed by a heating period of from a half to one and a half minutes, according to the size of the anodes.

The next process consists of heating the valve filament or cathode heater. Usually, the electrical connexion for this purpose is made by the action of the turntable. This filament heating serves to decompose the barium and strontium carbonates. While the filaments are still hot, the eddy current heating is resumed. It is important to note that the cathode and other electrodes must be heated simultaneously, otherwise there may be an interchange of gas between them.

Fig. 1. Osram PX4 Valve
(*General Electric Co. Ltd*)

Gettering is then carried out under the conditions of low pressure. The action of flashing a barium pellet by eddy current heating still further reduces the gas pressure in the valve. The valves are then sealed off the pumping system and are ready for cathode activation.

To form an oxide-coated cathode, which is required for highest emission, the cathode is heated and, with the other electrodes strapped together, a current of about 100 mA (dependent on the type of valve, and on the positive potential applied) is drawn to them. This causes an electrolytic action in the cathode coating, and free barium is formed on the cathode surface.

The process described applies to valves with anode dissipations of up to about 10 watts. Larger valves, particularly transmitter valves, are generally pumped singly, and require longer periods of baking and heating.

* **Commercial Thermionic Vacuum Valves.** The Osram valves described below are representative of some of the modern types available at the present time.

Type PX4 (Power Amplifying Triode). This is a directly heated power triode for the output stage of receivers and amplifiers where a considerable undistorted power output is required with an anode voltage up to 300. For this purpose, the valve has exceptionally good characteristics, and is particularly suitable for operating moving-coil speakers at considerable volume without

* *By courtesy of the General Electric Co. Ltd.*

TYPE PX4

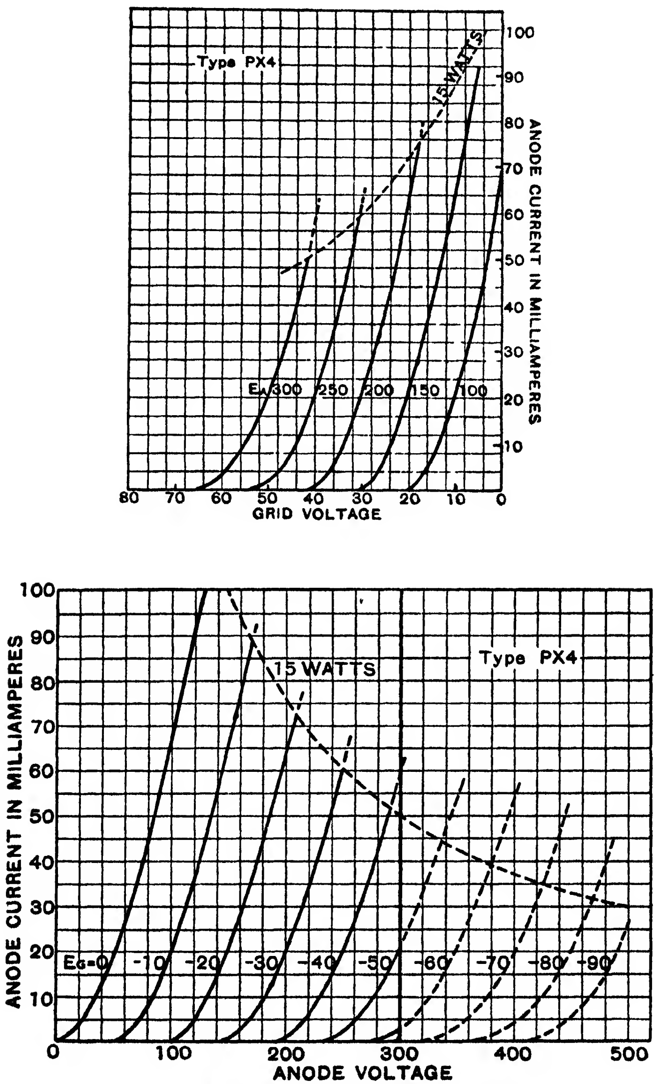


FIG. 2. CHARACTERISTIC CURVES OF AVERAGE VALVE

(*General Electric Co. Ltd.*)

distortion. The filament is of the robust oxide-coated type, and may be heated from A.C. through a suitable step-down transformer.

The characteristics are as follows

Filament voltage	4·0
Filament current	1·0 amp. approx.

	Single Valve, Class A Max.		
Anode voltage	300	250	200
Grid voltage (approx.)	42	32	- 28
Anode current (average)	50 mA	48 mA	25 mA
Anode dissipation (watts)	15	12	5
Bias resistance (ohms) (A.C. filament heating)	850	700	1 200
Load resistance (ohms)	4 000	2 400	4 500
Estimated A.C. power output (watts)	3·5	2·5	1·9

Amplification factor	Measured at anode volts 100 grid volts 0	5
Impedance		830 ohms

The wiring and arrangement of an amplifying circuit employing a Type PX4 valve should be such as to keep the capacity between input and output circuits at as low a value as possible. A grid stopper resistance is necessary to prevent parasitic oscillation; this should be wired close to the valve holder. The total resistance in the grid circuit should never exceed 250 000 ohms.

Automatic bias should always be employed, and it is recommended that separate bias be used for each valve in the case of a push-pull circuit. Where the valves are operated well below the maximum voltage or wattage limit, however, a common bias resistance may be used.

The operating data for two PX4 valves in a Class AB1 push-pull amplifier are—

Anode voltage	300 max.
Anode current, average (per valve) (no signal)	40 mA
Grid voltage (approx. varies from valve to valve)	— 45
Input voltage (grid to grid)	90 peak
Load resistance (anode to anode)	6 000 ohms
Bias resistance (each valve)	1 000 ohms
Power output	10 watts, approx.

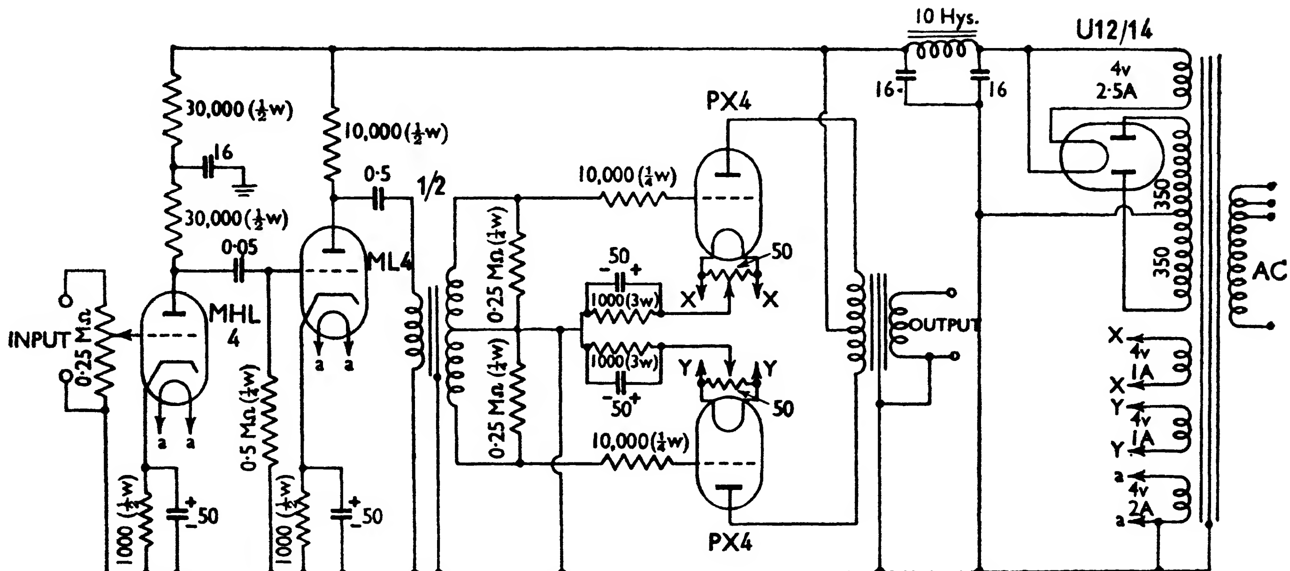


Fig. 3. Two Valves in Class AB1 Push-pull Amplifier Circuit

If used in a radio receiver employing a diode-triode detector valve following the triode section, Type MHD4 should be used in place of Type MHL4 shown as the first stage A.F. amplifier. Input to MHL4 (or MHD4 triode) 0·18 volt, r.m.s. for max. output.

(General Electric Co. Ltd.)

The output transformer should in all cases have low leakage inductance, and be of ratio as below—

$$\frac{\text{Total primary turns}}{\text{Total secondary turns}} = \sqrt{\frac{\text{Anode load}}{\text{Speaker impedance}}}$$

TYPE DA100 (POWER AMPLIFYING TRIODE). This is provided with an oxide-coated dull-emitter filament, and is suitable for use in the output stage of an amplifier. The valve is designed for adequate power output and reliable service and, used under correct conditions, will give exceedingly good working life. It is also suitable for operation in push-pull circuits.

Its characteristics are

Filament voltage		6·0
Filament current		2·7 amp. approx.
Anode voltage		1 000 max.
Grid voltage		— 146 approx.
Anode current (average)		100 mA max.
Anode dissipation		100 watts max.
Amplification factor	Measured at anode volts 1 000 anode dissipation 100 watts	5·5
Impedance		1 410 ohms
Mutual conductance		3·9 mA/volt
Automatic bias resistance with A.C. filament heating		1 490 ohms
Optimum load resistance		6 700 ohms for single valve; 8 000 ohms (anode to anode) in low loading push-pull.

Estimated A.C. power output—

30 watts approx. for single valve, Class A
90 watts approx. in low loading push-pull Class AB1
200 watts approx. Class AB2 (positive grid drive).

Interelectrode capacities—

Grid-anode	16·0 $\mu\mu$F
Anode-filament	9·0 $\mu\mu$F
Grid-filament	15·0 $\mu\mu$F

Under Class A conditions automatic grid bias is strongly

Fig. 4. Type DA100
(General Electric Co. Ltd.)

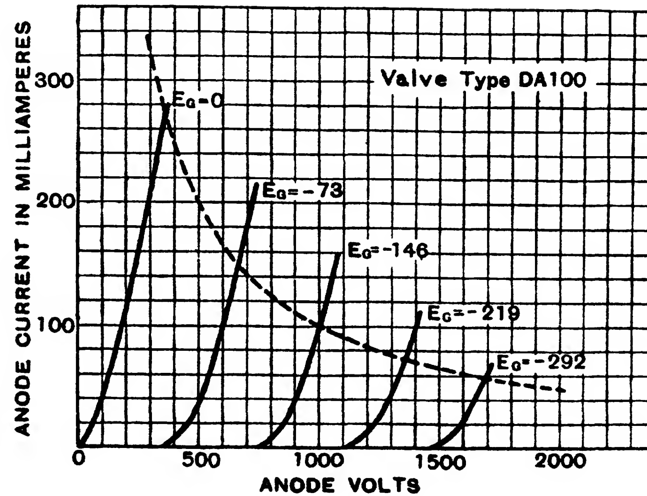


Fig. 5 Characteristic Curves of DA100 (Taken With D.C. Filament Heating)
(General Electric Co. Ltd.)

recommended. A common application of the DA100 valve is the use of two such valves in a push-pull circuit involving low anode load impedance; in this way it is possible to obtain a greatly increased undistorted power output. Provision should be made for ample air circulation to prevent overheating, and care taken to switch off the power supply when any circuit adjustments are made.

Type DA100 is also suitable for positive grid drive Class B circuits under suitable conditions of operation.

Type DET12 (Carbon Anode). This is also a triode with a thoriated tungsten dull-emitter filament. It is suitable for use at the ultra-high frequencies with a high output and good efficiency; at 200 megacycles, 1·5 metres, two valves in push-pull have an output of 30 watts; at lower frequencies, this output increases rapidly.

Before operating, anode and grid radiators must be attached in order to provide adequate heat radiation and to provide good electrical contact. Condensers for the higher frequencies should be built up by using the metal base plate as one condenser plate and a small metal flag as the other plate, with a thin sheet of mica as dielectric. Condensers tuning the anode circuits should preferably be of the split stator type, in order that the rotor bearings do not carry the large circulating current. For efficient operation as an oscillator below 2·5 metres, and for any oscillation below 1·5 metres, tuned filament chokes are essential.

This valve is frequently used below 120 megacycles in radio-frequency amplifiers (Class A telegraphy). For operation at frequencies above 120 megacycles, wound coils become too small to be practicable, and the tuning systems may consist of resonant lines, frequency variation being obtained by adjustment of the effective length of the lines. Half-wave lines should also be connected in the filament leads in order to earth effectively the active part of the filament. The driver stage consists of a pair of DET12 valves in a push-pull self-oscillator. The amplifier gives a power gain of 2 at 1·5 metres, and ceases to amplify at about 1·2 metres. Control grid bias may be obtained either from a battery or from a grid leak of 10 000 ohms.

Another employment of the valve is in a push-pull oscillator circuit, a resonant line being used in the grid circuit only; it should be slightly less than a quarter wavelength long. The operating conditions in this case at a wavelength of 2·5 metres are set out in the table on page 14.

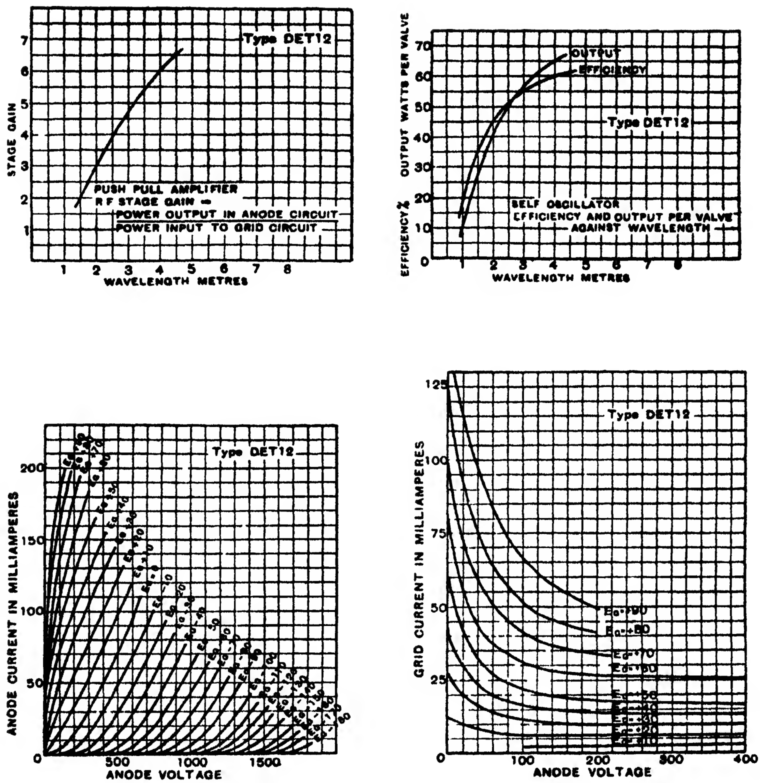
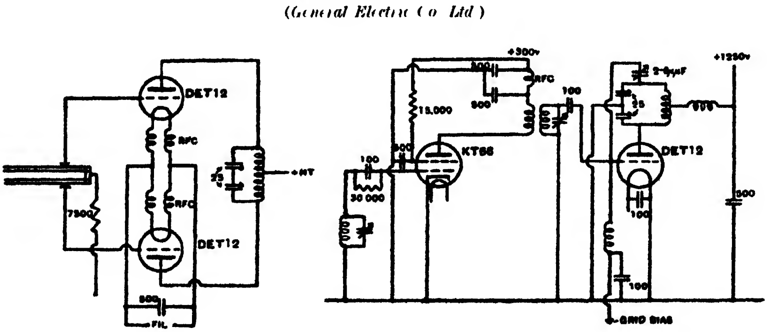


FIG. 6. CHARACTERISTIC CURVES OF DET12
(General Electric Co. Ltd.)



(*a*) (*b*)

FIG. 7. DET12 VALVE IN (*a*) CLASS C AMPLIFIER. (*b*) PUSH-PULL OSCILLATOR

Anode Voltage	Anode Current 2 valves	Grid Current 2 valves	Watts Output	Anode Efficiency	Anode Dissipation per Valve
	mA	mA			watts
1 100	140	15	65	42%	44·5
800	115	18	38	41%	27
500	110	28	23	42%	11

The operating conditions in a circuit using resonant lines in both anode and grid circuits, suitable for operation between 1·25 and 2 metres, are shown in the table below—

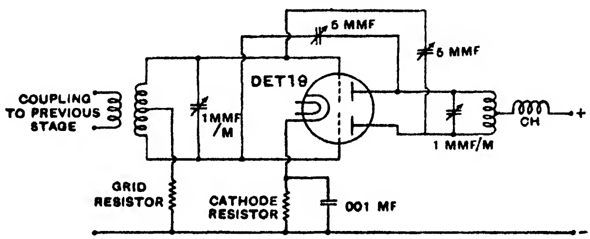
Wavelength metres	Anode Voltage	Anode Current 2 valves	Watts Output 2 valves	Anode Efficiency	Anode Dissipation per Valve	Remarks
		mA			watts	
3·0	1 100	90	45	42%	25·5	Untuned
2·1	1 000	110	38	32%	37·5	filament
1·6	850	115	18	18·5%	40	chokes
2·5	1 000	100	50	50%	25	Tuned
2·1	1 000	110	48	44%	31	filament
1·4	820	100	27	33%	27·5	chokes

A single DET12 may also be used as a self-oscillator in a suitable circuit. Below 2·5 metres the main oscillatory circuit consists of a copper strip tuned by the grid-anode capacitance of the valve in series with the grid blocking condenser. The wavelength of operation is controlled by the length of the strip. For above 2·5 metres a tuned filament system is not essential, quarter-wave chokes being quite satisfactory. Below 1·5 metres, however, oscillation can be obtained only with a tuned filament system, the table of operating conditions of which is given under—

Wave-length metres	Anode Voltage	Anode Current	Grid Leak ohms	Grid Current	Watts Output	Anode Efficiency	Anode Dissi-pation
		mA		mA			watts
4·4	1 250	90	15 000	24	67	60%	46
2·5	1 000	100	7 500	22	50	50%	50
2·0	950	100	7 500	18	43	45%	52
1·5	800	100	7 500	12	28	35%	52
1·1	650	100	2 500	11	13	20%	52
0·9	500	100	2 500	7	7	14%	43

TYPE DET19 (DOUBLE TRIODE). Type DET19 is a low-power transmitting or power amplifying valve consisting of two triodes in one bulb, with the two indirectly heated cathodes connected. It is suitable for use in a push-pull amplifier, oscillator or frequency multiplier, and for use on telephony anode or grid modulation may be employed. Both anodes are brought out separately through the top of the bulb; this, together with a ceramic base, reduces interelectrode capacitances and losses in the valve. Useful outputs can be obtained at frequencies up to 250 megacycles per second.

TYPE DET19



PUSH-PULL R F AMPLIFIER

(Component values are suitable for wavelengths between 10 and 50 metres)

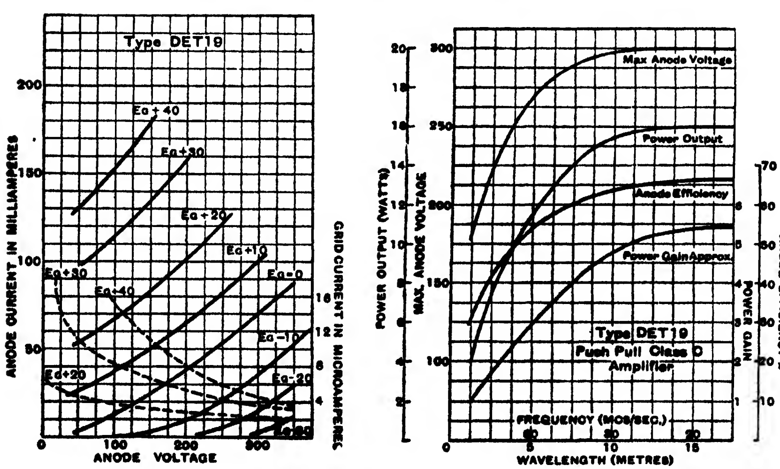


FIG. 8. DET19 IN PUSH-PULL AMPLIFIER AND CHARACTERISTIC CURVES

(General Electric Co. Ltd.)

The characteristics are—

Heater voltage		6·3
Heater current		0·8 amp approx.
Anode voltage		300 max.
Anode current (per anode)		40 mA max.
Anode dissipation (per anode)		5·0 watts max.
Amplification factor	measured at	7
Impedance	Ea = 300,	3 340 ohms
Mutual conductance	Ia = 25 mA	2·1 mA/volt

Interelectrode capacities—

Anode to grid (other electrodes earthed)	2·3 $\mu\mu$F
Grid to cathode	4·2 $\mu\mu$F
Anode to cathode	0·6 $\mu\mu$F
Anode to anode	1·0 $\mu\mu$F

The heater of the DET19 is designed to operate at 6·3 volts, and the supply may be either A.C. or D.C. The voltage between heater and cathode should be kept as low as possible, and should never exceed 100 volts; it is often possible to connect one side of the heater to the cathode. The anode supply may be obtained from any convenient source, and a circuit breaker or fuse should be provided in each H.T. supply lead so that the supply is removed in the event of excessive currents being drawn.

It is necessary to neutralize the valve under all conditions of R.F. amplifier service, two condensers are required for each valve, and they may have a maximum value of 5 $\mu\mu$F. All leads in the anode circuit must be as short as possible, and of heavy gauge copper, in order to minimize lead conduction and loss; this is particularly important at frequencies above 30 megacycles per second. Care must be taken to ensure that adequate ventilation is provided, since the valve becomes very hot under normal operating conditions. No visible heating of the anodes should occur at any time.

1. *Push-pull R.F. Amplifier—Class C Telegraphy.*

Key down conditions per valve without modulation—

Anode voltage	300 max.	
Grid voltage	— 150 max.	
Anode current	80 mA max.	Both triodes
Grid current	25 mA max.	Both triodes
Anode input	24 watts max.	Both triodes
Anode dissipation	10 watts max.	Both triodes

Typical operating conditions				
Frequency (megacycles/sec)	7	7	7	7
Anode voltage	300	250	200	150
Anode current (mA)	80	80	80	80
Grid voltage:				
From a fixed supply of.	50	50	- 50	50
From a cathode resistor of (ohms)	625	625	715	770
From a grid resistor of (ohms)	3 300	2 800	2 800	2 500
Peak R.F. grid voltage (grid to grid)	210	220	220	230
Power output (watts)	15·9	12·5	8·5	5·4
Anode efficiency (%)	66·5	62·5	60·5	55·5

2. *Push-pull Anode-modulated R.F. Amplifier Class C Telephony.*

Carrier conditions per valve for use with maximum modulation of 100 per cent.

Anode voltage	250 volts max.
Grid voltage	150 volts max.
Anode current	55 mA max.
Grid current	25 mA max.
Anode input	13·5 watts max.
Anode dissipation	6·5 watts max.

Typical operating conditions—		
Frequency (megacycles/sec)	7	7
Anode voltage	250	200
Anode current (mA)	50	50
Grid voltage:—		
From a fixed supply of.	— 45	- 40
From a cathode resistor of (ohms)	900	800
From a grid leak of (ohms)	6 500	5 000
Grid current	7·0	8·0
Peak R.F. grid voltage (grid to grid)	180	170
Power output (watts)	8·5	6·5
Anode efficiency (%)	69	65

Under maximum conditions for anode modulated service an audio power of 8·2 watts delivered into a load of 3 850 ohms is required.

Both triodes must be neutralized.

3. *Push-pull Amplifier—Class B Telephony.*

Carrier conditions per valve for use with a maximum modulation of 100 per cent.

Anode voltage	300 volts max.
Anode current	45 mA max.
Grid current	25 mA max.
Anode input	13·5 watts max.
Anode dissipation	10 watts max.

Typical operating conditions:—

Frequency (megacycles/sec)	7	7
Anode voltage	300	200
Anode current (mA)	40	40
Grid voltage: -		
From a fixed supply of.	21	- 13
From a cathode resistor of (ohms) (grid-leak operation is not permissible)	525	325
Grid current (subject to wide variation)	1·8	3
Peak R.F. grid voltage (grid to grid).	70	70
Power output (watts)	3·5	2·3
Anode efficiency (%)	29·3	28·5

TYPE DH63 (DOUBLE-DIODE-TRIODE). The Osram DH63 combines a double-diode and triode-electrode system on a common cathode, the two diodes being enclosed within a metal shield joined to the cathode, providing an electrostatic screen.

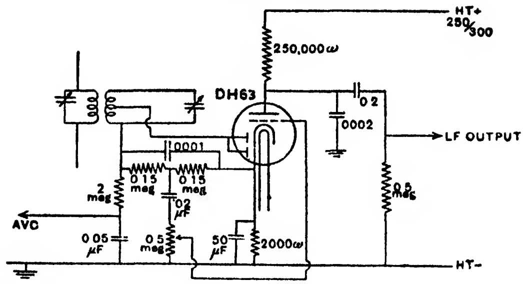
Its characteristics are:—

Heater voltage	6·3
Heater current (approx.)	0·3 amp
Triode characteristics:—	
Anode voltage	250 (max.)
Grid voltage	— 3
Anode current (average)	1·1 mA
Amplification factor	70
Impedance	58 000 ohms
Mutual conductance	1·2 mA/volt
Cathode bias resistance	2 000 ohms
Optimum load resistance	250 000 ohms

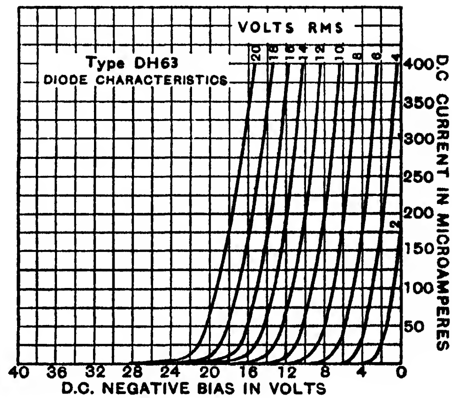
Output voltage with 0·25 megohm anode load resistance—

A.C input volts r.m.s	A.C. output volts r.m.s
0·1	3·0
0·2	6·0
0·4	12.0
0·8	25·0

TYPE DH63



CHARACTERISTIC CURVES
OF AVERAGE
VALVE.



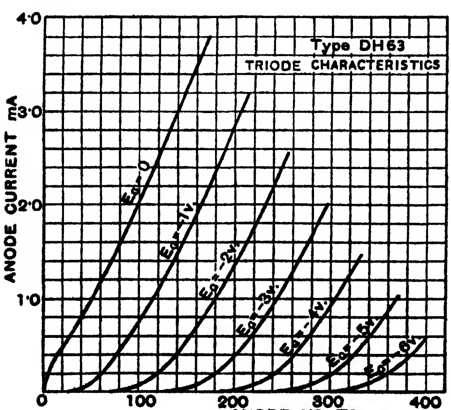


FIG. 9. DH63—CIRCUIT EMPLOYING AND CHARACTERISTIC CURVES OF

(*General Electric Co. Ltd.*)

Interelectrode capacities—

Grid to anode . . .	2·0 $\mu\mu$F (approx.)
Grid to cathode . . .	2·0 $\mu\mu$F (approx.)
Anode to cathode . . .	5·0 $\mu\mu$F (approx.)

Type DH63 must not be used in amplified A.V.C. circuits.

FIG. 10. OSRAM KT61 VALVE
(*General Electric Co. Ltd.*)

TYPE KTZ63/6J7G. This is an indirectly heated pentode suitable for use as a detector or in a H.F. or L.F. amplifier. The type may also be employed as a triode by external connexion of the screen grid and anode in cases where a triode of medium impedance is desired. The control grid is taken to a top cap connexion.

Type KTZ63/6J7G may also be used as an oscillator and as such is of great use in ultra-short wave superheterodyne receivers.

The characteristics are–

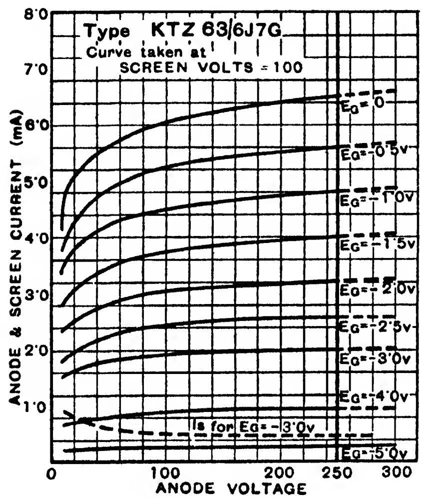
Heater voltage .	6·3
Heater current .	0·3 amp

	Max.	Recommended operating conditions
Anode voltage .	250	250
Screen voltage .	125	100

	AS PENTODE	AS TRIODE with screen grid joined to anode, suppressor grid to cathode
Control grid voltage . .	— 3	— 8
Anode current (average) .	2·0 mA	8 mA
Screen current (average) .	0·5 mA	
Impedance . . .	1·5 meg	10 500
Cathode bias resistance (ohms)	1 200	1 000
Optimum load in resistance Amplifier (ohms) . .	250 000	50 000
Mutual conductance . .	1·23 mA/volt	2·0 mA/volt
"Cut-off" bias . , .	— 7 volt (approx)	

Interelectrode capacities (as pentode):
(taken with metal shield)

Grid to Anode . . .	0·0046 $\mu\mu$F (approx.)
Anode to other electrodes .	10·4 $\mu\mu$F (approx.)
Grid to other electrodes .	5·1 $\mu\mu$F (approx.)



CHARACTERISTIC CURVES OF AVERAGE VALVE.

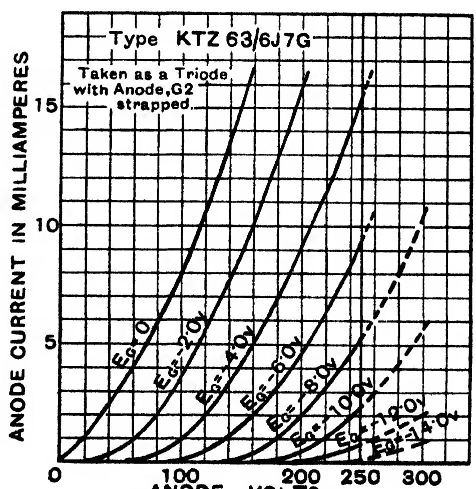


FIG. 11. CHARACTERISTIC CURVES OF KTZ63/6J7G
(General Electric Co. Ltd.)

When used as a grid-leak detector, it is essential to screen completely the KTZ63/6J7G valve, grid leak and condenser, owing to the high gain. With D.C.–A.C. receivers, the heater of this valve must be so connected that one end of it is joined to the cathode. When used in the early stages of a high gain A.C. mains amplifier, a variable potentiometer is recommended across the heater, so that the minimum hum position may be obtained. A suitable screening-can to maintain low grid-anode capacity would have a length of 75 mm from face to neck, and a diameter of about 42·5 mm.

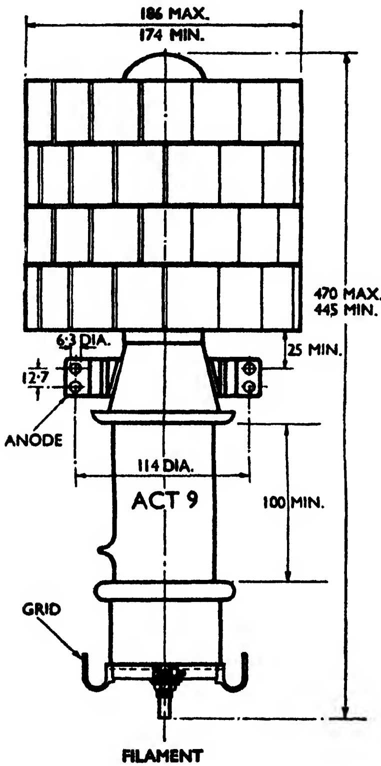


FIG. 12. DIMENSIONS OF ACT9 VALVE
(General Electric Co. Ltd.)

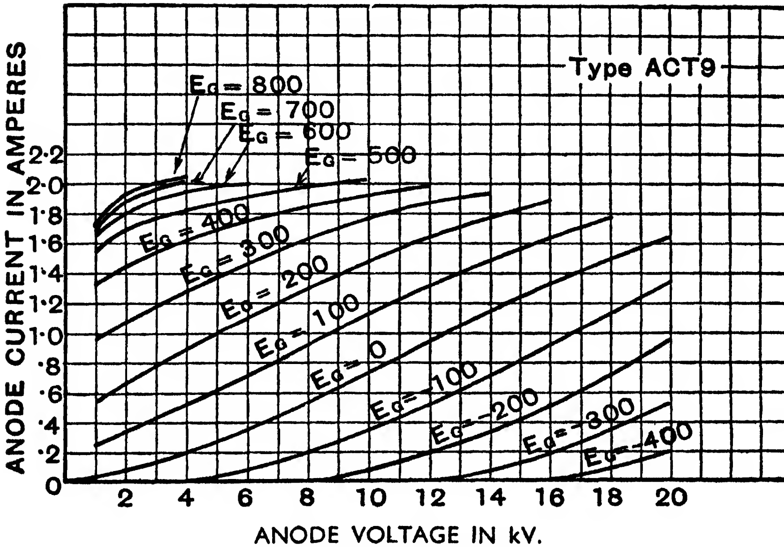
OSRAM TYPE ACT9 (H.F. POWER AMPLIFIER AND OSCILLATOR). This is an air-cooled anode transmitting triode, fitted with a bright-emitter tungsten filament, and is suitable for use at wavelengths down to 3·5 metres. For anode dissipations of 800 watts, maximum free air circulation is permissible. If forced air-cooling is employed (at a pressure equal to 3 inches of water), the anode dissipation may be increased to 1 100 watts maximum.

The figures quoted for maximum permissible ratings apply to operation at wavelengths down to 20 metres. At lower wave-lengths, the anode voltage must be reduced. As the efficiency falls with wavelength, the input must be reduced in order to avoid exceeding the permissible anode dissipation.

Ratings of the valve are—

Filament voltage	16
Filament current	22 amps

TYPE ACT9



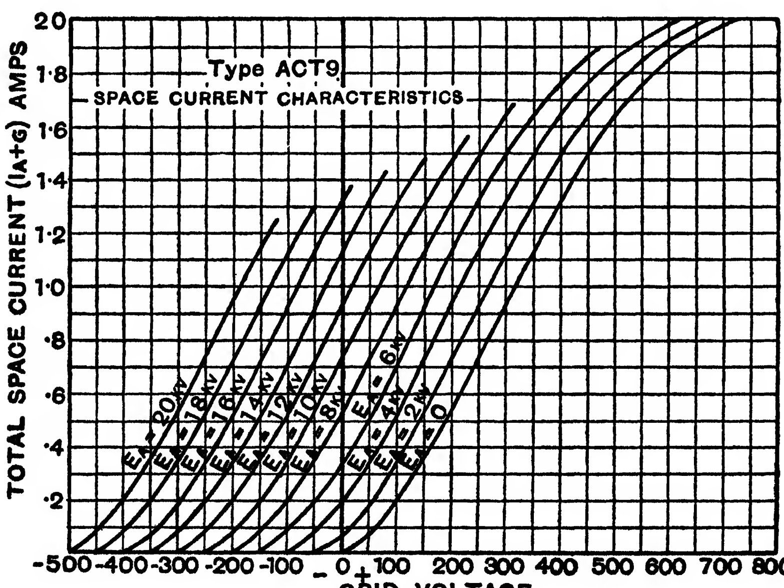


FIG. 13. CHARACTERISTIC CURVES OF ACT9

(General Electric Co. Ltd)

Mutual conductance, measured at	
Ea = 5 000 volts. Wa = 1 000 watts .	. 3·1 mA/volt
½ peak space current.	. 4·0 mA/volt
Amplification factor, measured at	
Ea = 5 000 volts. Wa = 1 000 watts.	. 40
Peak space current	. 2·0 amps
Interelectrode capacities –	
Grid to anode (other electrodes earthed).	. 15·9 $\mu\mu$F
Grid to Filament (other electrodes earthed)	. 23·2 $\mu\mu$F
Anode to filament (other electrodes earthed)	. 1·6 $\mu\mu$F

TYPE ACT9

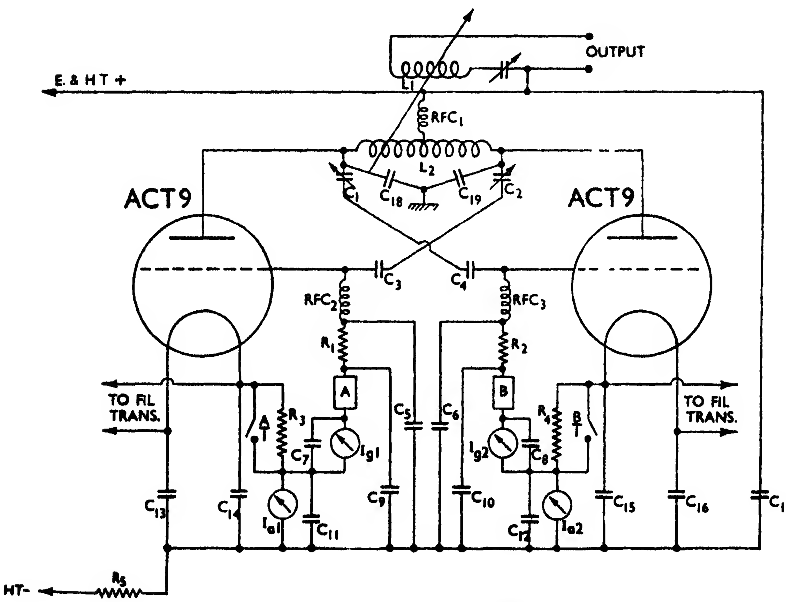
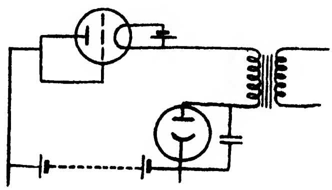


Fig. 14. ACT9 in Push-pull Oscillator

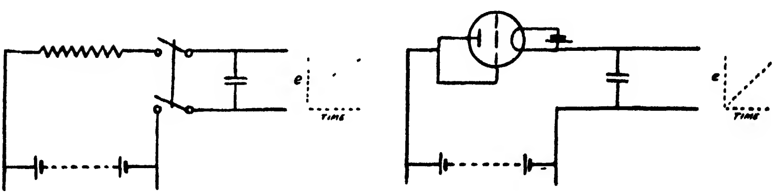
Applications. The triode, as an oscillator, is frequently used to produce high- or low-frequency waves. Since the anode current changes whenever a valve passes from quiescence to oscillation, this can be used as a form of control in burglar alarms and advertising displays.

Oscillator. For this method of control a kind of aerial is coupled to the grid circuit; the aerial must be insulated and remote from any earthed metal. The valve is adjusted so that any change in capacity of the aerial to earth produces oscillation of the valve. Usually, the capacity change is brought about by a person going near the aerial. The resultant change in the valve anode current may be caused to operate a relay, or the first of a series of relays, controlling the load current.

This arrangement is due to feed back, and is fundamentally a practical application of the howling of a radio set caused by a person approaching the set or touching the tuning control.



(a)



(b)

FIG. 15. APPLICATION OF TRIODE (a) AS CURRENT LIMITER (b) AS CONSTANT CURRENT DEVICE

Voltage Regulator. A vacuum triode circuit is capable of giving close voltage regulation, with accuracy of as much as 0·1 per cent. One method is to feed the field circuit of a generator from the anode of the valve, when a potentiometer is connected across the supply with the grid circuit taken to the slider. An auxiliary battery may be included in the grid circuit in order that the grid-filament potential can be correctly adjusted; this would also serve to ensure that a mean value of current flows through the field under normal conditions.

Given correct polarity, a fall in generator voltage controlled in this way will cause the grid-filament potential to become less negative. Thus, under conditions of increased load, the anode current will build up, strengthening the field of the machine and, consequently, correcting the terminal voltage. Conversely, a rise in generator voltage will be automatically compensated by a reduction in field.

In a machine with a double-wound field, triode control can be connected in one section in order to give differential action.

The triode may be connected in parallel with the generator field winding. In practice, several power triodes can be connected in parallel, with fuse and indicator lamps in the anode circuits, so that should one valve fail, the others will take up the load. Alternatively, of course, the grid of the regulating triode in series with the field could be preceded by an amplifier.

Voltage control of A.C. generators can be obtained in a similar way, a full-wave rectifier being used to supply the triodes.

Constant Current Device. Under certain conditions, the hard vacuum valve can act as a constant current device. For this purpose the filament and anode circuits are adjusted so that all the electrons emitted by the filament reach the anode; in other words, a point of current saturation is reached and the current through the valve is, between limits, independent of the anode voltage.

In charging a condenser from a source of constant potential with a resistance in series, the voltage across the condenser increases exponentially; the condenser voltage does not rise uniformly and, in theory, becomes equal to the supply voltage only after an infinite time. If, however, a thermionic valve, operating under current saturation conditions, is included in the charging circuit, the increase in condenser voltage with time can be made linear. This fact is made use of in a time base for cathode-ray tubes.

Screen pentodes are usually preferable to triodes for this purpose, the rate of condenser voltage increase being controlled by adjustment of the screen potential.

High Resistance Measurement. U.S. Patent 1,966,185 concerns a method of measuring high resistances by means of a thermionic valve operating under conditions under which the grid is floating. If the grid is left unconnected in the circuit, it will have a negative potential with respect to the cathode, since electrons will be collected from the cathode emission. Finally, the grid will take up a potential in equilibrium with the electron stream. This potential may be reduced by connecting a high resistance between grid and filament. If the resistance is sufficiently high, a positive potential supply can be connected in series with it, which will further reduce the negative grid potential.

In the particular application described in the patent, a low-reading milliammeter is connected in the anode circuit. Naturally, its reading will vary in accordance with the grid resistance, and the relationship is such that the meter can be calibrated to read in megohms. Resistances of up to 1 000 megohms can be read when E is of the order of 1 000 volts.

For the measurement of high resistances on A.C. supplies, a condenser must be connected across the resistance to obviate the disturbance that might be caused by its self-capacity, and the circuit is modified to use only the positive half-cycle.

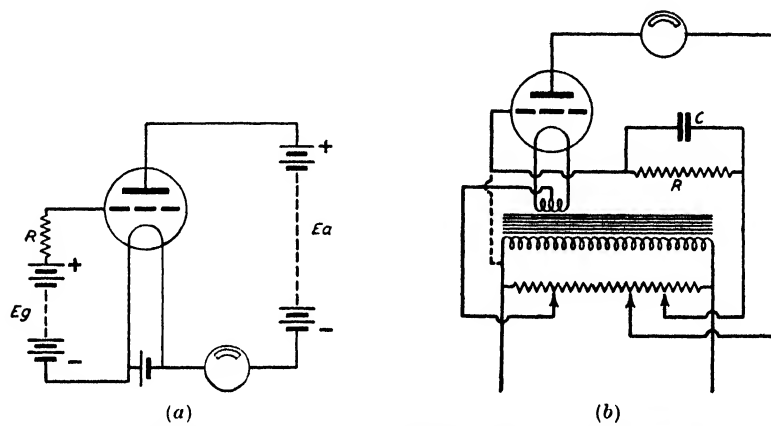


FIG. 16. MEASUREMENT OF HIGH RESISTANCES: (*a*) FUNDAMENTAL CIRCUIT, (*b*) AS MAINS OPERATION CIRCUIT
(*From "The Electrical Engineer"* [*G. Newnes Ltd.*])

Constant Frequency Source. For purposes in which a source of constant frequency is required, or where frequency stabilization is necessary, a valve-maintained tuning fork can be used with advantage. This consists essentially of a triode with a coil connected to the grid, and a similar coil connected to the anode. The coils are arranged one at the side of each prong of a tuning fork, and a polarizing permanent magnet is placed at the other side of each coil.

The function of the valve circuit is to maintain the natural vibration of the tuning fork, thus providing a constant frequency source for use in picture telegraphy, or in a multivibrator.

Motion of the prongs of the tuning fork will produce a change in flux through the coils, and this, in conjunction with the permanent magnet flux, will create a corresponding induced voltage, the magnitude of which will depend on the rate of change of flux at any particular instant. This potential is impressed on the grid of the valve, causing variation of the anode current, and thus keeping constant the frequency of vibration of the fork. To obviate any error that might be caused by temperature changes, the fork is made of Elinvar steel, which has an extremely low coefficient of expansion; sometimes, the apparatus is contained in a chamber provided with thermostatic control.

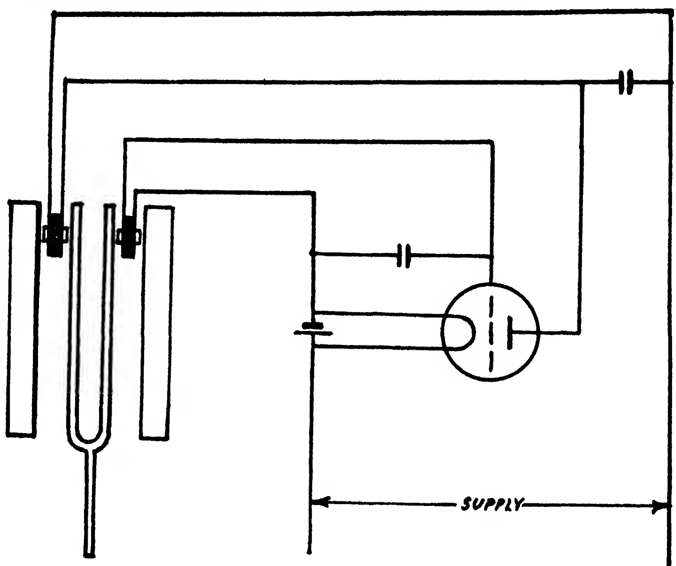
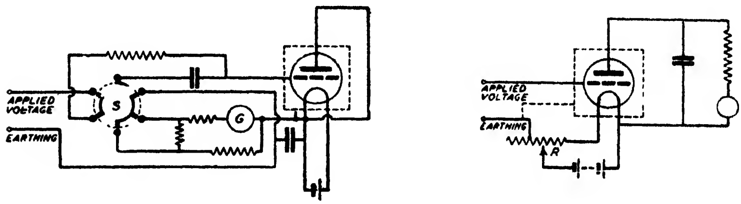


FIG. 17. TUNING FORK (VALVE-MAINTAINED)

By utilizing a piezo crystal vibrator controlled by a thermionic valve, much greater precision is obtained in providing a source of constant frequency. The crystal, connected to the grid circuit, communicates any change in vibration by producing a change in anode current, and the resulting change in anode voltage is used to maintain the piezo crystal vibrations.

Voltmeter. The employment of the thermionic valve as a voltmeter for use at high frequencies was introduced by Dr. E. B. Moullin. The triode voltmeter has an advantage over the ordinary A.C. instrument in that it absorbs far less power from the circuit to be measured. Since it is independent of frequency, it is often used for measuring ordinary commercial supply voltages, in preference to the low-range A.C. voltmeter.

The Cambridge Instrument Company manufactures five types of thermionic valve voltmeters, designated as patterns A–E. Pattern A is a low-reading, high-sensitivity voltmeter for use at supply or radio-frequencies, with a range of from 0·5 to 1·5 volts

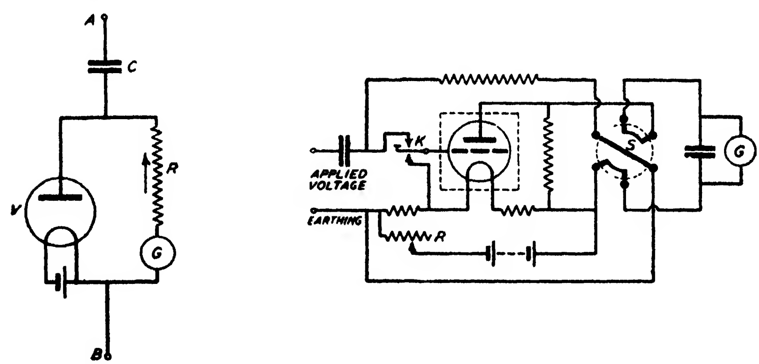


(a) (b)

Fig. 18. (a) Mean Range Voltmeter, (b) Low-reading High-sensitivity Voltmeter

(*From "The Electrical Engineer"* [*G. Newnes Ltd.*])

r.m.s. Pattern C, for commercial and low frequencies, has three ranges having r.m.s. readings of 2, 12, and 120 volts. Pattern D, employing grid circuit rectification, has two scales for use on



(a) (b)

Fig. 19. (a) Peak Voltmeter, (b) Thermionic Voltmeter (Grid Current Rectification)

(*From "The Electrical Engineer"* [*G. Newnes Ltd.*])

0·05 to 4·0 and 0·2 to 20·0 volts r.m.s. respectively. Pattern E is designed to measure peak and mean values of A.C. voltages, and has two evenly divided scales of 0–350 volts peak and 0–220 volts mean. The relative accuracy of these instruments is extremely high, the absolute error being less than 2 per cent. However, the readings are not true with unsymmetrical wave forms.

Thermionic valve A.C. ammeters are also extremely sensitive, and, unlike the thermal instruments, cannot be easily injured by overloading. In this case a triode is operated on the lower portion of the "grid volts–anode current" curve, so that alternating voltage applied to the grid will cause a corresponding change in average anode current.

Transformer Protective Relay. An instance of the employment of the triode in a control circuit is provided by the transformer

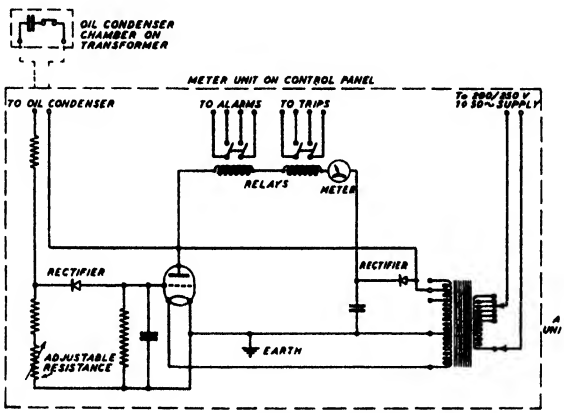


FIG. 20. TRANSFORMER PROTECTIVE RELAY
(From "The Electrical Engineer" [G. Newnes Ltd.])

protective relay evolved by the Hackbridge Electric Construction Company. The principle of this is that the capacity of a condenser alters with a change in its dielectric.

The valve circuit is connected to the condenser in such a way that change in dielectric causes a corresponding change in the valve anode current. This, in turn, is utilized to indicate on a milliammeter and, if the change exceeds a certain predetermined maximum, to operate an alarm circuit.

High-frequency Heaters. The generation of high-frequency currents by valve oscillator circuits is still in the process of development. A new field has been opened up by the recent introduction on a fairly large scale of high-frequency dielectric heating.

Prefabrication, which has become a prominent feature of our post-war reconstruction, will no doubt foster the use of laminated materials and plastics manufactured by such methods. Indeed, high-frequency heating may well be the future means of domestic cooking.

High-frequency eddy current heating, also based on the use of valve oscillators, is utilized in the manufacture of the electronic devices themselves, and also in the surface treatment of metals.

Frequencies up to 1 000 kc/s are commonly obtained from valve oscillators. For comparatively large outputs, four or six valves may be operated in parallel; a push-pull arrangement will naturally give the best efficiency. The leads to the output coil must, of course, be artificially cooled.

CHAPTER III

GAS-FILLED RELAYS

ALTHOUGH gas-filled relays contain a cathode and an anode as basic electrodes, and are in many ways similar in construction to vacuum valves, their properties and uses are entirely different. They have little application in radio engineering, but, on account of the comparatively large currents they can handle, are ideal for industrial purposes.

The immediate effect of introducing small quantities of gas or vapour into the valve is to reduce considerably the voltage drop between cathode and anode for the same current. Hence, the efficiency of power transfer is very much higher than that obtained by a vacuum valve of the same size, and the gas-filled relay can be operated at a far greater cathode-to-anode current. Unfortunately, the control provided is, in comparison with that of the vacuum valve, very rough, and the function of the device is limited to relay purposes.

Main Types. There are three main types of gas-filled relays. They are: (1) cold cathode, (2) thermionic or hot cathode, and (3) mercury arc.

Cold cathode relays are little used in practice. They consist fundamentally of a cathode, an anode, and a control electrode contained in a glass bulb which has been exhausted of air and filled with rare gas or vapour at low pressure.

Triodes of the cold cathode gas-filled type can be utilized for low-current intermittent service, or where consumption of power must be kept down to a minimum. A four-electrode neon-filled relay manufactured by the Westinghouse Company has the following characteristics—

Cathode-to-anode voltage drop (during conduction)	180 volts
Average anode current supplied	0·015 amp
Maximum peak anode current supplied	0·100 amp
Maximum peak inverse voltage	800

Gas-filled thermionic triodes and tetrodes, sometimes known as "thyratrons" (a trade name of the B.T.-H. Company), are by far the most important type. The grid structure in this device serves only to control the start of the discharge. That is to say, it may be used to prevent the electrons from acquiring sufficient energy for ionization. To increase the electron energy, the grid is made less negative. Once ionization has occurred and the discharge has commenced, the grid has no further function.

Presence of Ions. It should be noted that in the gas-filled triode there are, in addition to negative electrons, positive ions, which carry a tiny current from anode to cathode. The effect of the ions is to form an accumulation of positive charges at the cathode. As soon as the grid voltage obtains a certain value, an appreciable current begins to flow between cathode and anode, while the voltage across the electrodes drops sharply. It is these sudden changes, originating from the reduction in space charge at the cathode, that enable the device to be used as a relay.

As grid current will flow in these relays, whether the grid is positively or negatively charged, the grid control circuits must deliver far more power than would be required for vacuum triode control. The shield grid thyratron or gas-filled tetrode was, therefore, introduced to reduce grid current.

The most familiar type of the mercury arc or pool type is the A.C. rectifier. But the most modern form is the mercury pool triode or ignitron. This, as its name implies, has a pool of mercury as its cathode, which possesses the advantage of requiring no heating. It also has the advantage of an extremely high overload capacity, and has not the tendency to clean up, as does the inert gas in the thermionic type of relay. In view of the fact that operation at an anode current of less than 5 amp is unstable, this type is used mainly for heavy-duty service, such as welding control.

A starting or control electrode is arranged to be immersed in the cathode pool, so that when voltage is applied between the two, a cathode spot is formed. The device does not operate, however, until sufficient positive voltage is applied to the anode.

On starting up, an arc is struck, the cathode spot increases in size, and the anode attracts electron emission from the spot. The current required for starting varies between 3 and 40 amps at from 100 to 250 volts, but this need be applied only for a small fraction of a second.

In general, the construction of gas-filled relays is similar to that of thermionic vacuum valves, except for the introduction of small quantities of rare gas or mercury.

***Commercial Gas-filled Relays.** (*Osram Type GT*1): The Osram Type GT1 is a gas discharge valve consisting of a cathode, anode, and grid in a mercury vapour-filled bulb. The electron

* *By courtesy of The General Electric Co. Ltd.*

emission is obtained from a coated cathode indirectly heated by a 5·2 watt heater, which it encloses. This has the advantage, in combination with the standard heater rating of 4 volts, that, if desired, the filament may be heated from a transformer common to other indirectly heated valves.

FIG. 21. OSRAM GT1C GAS-FILLED RELAY (*General Electric Co. Ltd.*)

Under normal conditions of operation, the bulb is filled with a blue glow, due to ionization of the mercury vapour. When the discharge is in progress, the voltage drop across the gas-filled relay remains constant at about 15 volts, independent of the load.

It is important that the cathode should be allowed time (at least 1 minute) to attain its full operating temperature before the anode voltage is applied. Failure to observe this precaution will result in permanent damage to the cathode. For the first time of switching on after transit, a greater cathode heating time (5 minutes) should be allowed in order to ensure correct distribution of the mercury in the bulb.

The function of the grid is to control the anode voltage at which the discharge commences. A negative voltage applied to the grid will prevent the discharge from being established, its minimum value being dependent on the applied anode voltage and the "grid control ratio." In the gas-filled relay Type GT1, this ratio is approximately 25, that is, for example, a negative grid voltage of 10 will suffice to withhold the discharge up to an anode voltage of 250 (the discharge in no instance commencing under 15 volts). The moderate low value of control ratio avoids a highly critical operating condition.

The actual grid control ratio depends on the temperature of the surrounding air and of the gas-filled relay. A reduction in temperature will increase the control ratio (i.e. for a given anode voltage a smaller negative grid voltage suffices to withhold the discharge).

After the discharge has begun, the grid exercises no further control, and the anode current may, in general, only be stopped by breaking the anode circuit or reducing the anode voltage to a

TYPE GT1C

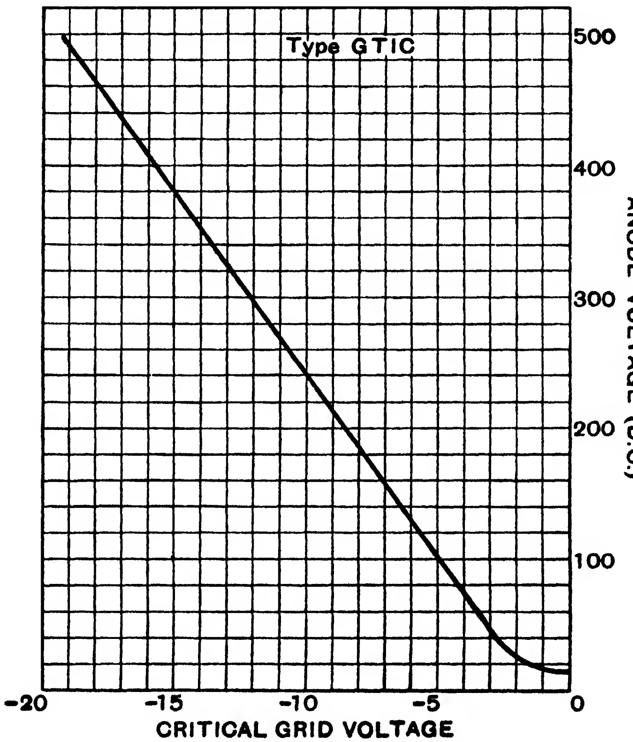


FIG. 22. CHARACTERISTIC CURVES OF GT1C
(General Electric Co. Ltd.)

condition below that of ionization—normally about 15 volts. The time required for the grid to regain control while the discharge is off is extremely small: a fraction of a millisecond.

Once the anode current is started, its value is limited only by the external impedance in the anode circuit. To avoid injury to the valve, it is essential that the anode current should not exceed the rated peak value of 1 amp. To this end, a suitable resistance, or other current limiting device, must always be included in the anode circuit. For example, in a resistance load, if the D.C. voltage is 200 and a 15 volts drop in the gas-filled relay is allowed for, this resistance may be obtained as follows—

$$\text{Resistance} = \frac{185}{1 \cdot 0} = 185 \text{ ohms}$$

where maximum permissible peak current = 1 amp
volts drop required across resistance = 185.

For A.C. voltages, the anode resistance must be calculated for the peak value of the voltage, i.e. $\sqrt{2} \times$ r.m.s. value

Thus, if the A.C. voltage is 200,

$$\text{Resistance} = \frac{(\sqrt{2} \times 200) - 15}{1 \cdot 0} = 265 \text{ ohms.}$$

If a tungsten filament lamp is connected in the anode circuit,

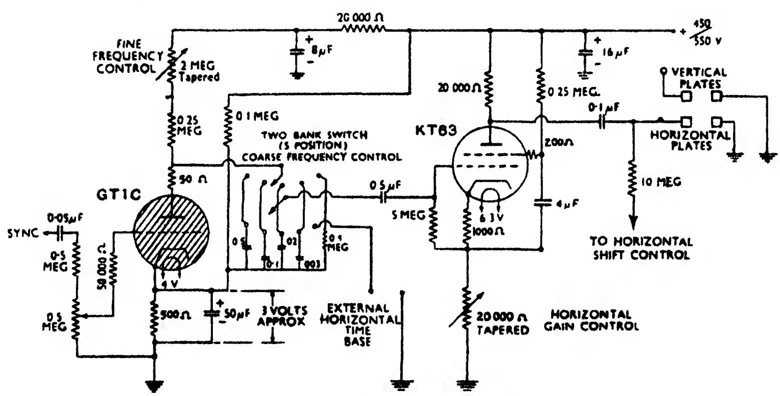


FIG. 23. TYPICAL CIRCUIT FOR GT1C
(*General Electric Co. Ltd.*)

it should be noted that the cold resistance of such a lamp is about one-fourteenth of the resistance when hot, and consequently an excessively heavy current will flow when first switching on.

Osram Type GT1C: The Osram GT1C gas-filled relay has an anode, an indirectly heated cathode, and a control grid enclosed in a glass bulb, which is filled with argon. It can be used to control current up to 1 amp (peak value) in either A.C. or D.C. circuits. It may be used in place of the GT1 in most applications where the peak anode voltage is less than 500. The substitution by the rare gas argon of the mercury vapour filling of the GT1 ensures a practically constant characteristic under all conditions of room temperature.

The ratings of the GT1C are as follows:

Heater voltage	4·0 minimum
Heater current	1·35 amp
Maximum safe anode current	1·0 amp (peak value) 0·5 amp (r.m.s. value) 0·3 amp (average value) (measured on a moving-coil meter)
Cathode-anode voltage drop	16 volts (max.)
Grid control ratio	28
Cathode heating time	30 sec minimum

Current is carried through the relay by the passage of electrons from the cathode to the anode under the influence of a positive potential applied to the latter. If, however, a sufficiently negative grid bias is applied before the anode is made positive, the flow of current between anode and cathode will be withheld. If the anode voltage is now increased, or the negative grid bias reduced to a critical ratio, anode current will begin to flow and the argon will become ionized.

Under this condition, the internal voltage drop between anode and cathode is about 12–16 volts, irrespective of the value of anode current. It is, therefore, essential that the impedance of the external circuit shall be sufficient to limit the anode current to the safe value.

Once the argon is ionized, the grid, as in other types of gas-filled relays, has normally no power to control the anode current. In D.C. circuits, the anode current can be stopped only by breaking the circuit, or by removing the applied anode voltage for a time long enough to allow the ions to disperse. In A.C. circuits, since the anode current falls to zero at some part of every cycle, the grid is able to control the instant in the succeeding cycle at which current will start again.

Type GT1C may be used to provide a "saw tooth" wave for a linear time base, if the required frequency is confined to the lower audio-frequencies. Up to about 500 cycles per second, the departure from the desired wave form is negligible.

Being designed primarily as a relay for handling relatively large currents, Type GT1C has a comparatively long de-ionization time—about 30–40 microseconds. For this reason, it may be said that the maximum operating frequency of a time base using this relay does not exceed 10 kc/s. The voltage developed by the relay under linear conditions is of insufficient amplitude to produce an adequate trace on a high vacuum cathode-ray tube, and a sweep amplifier is therefore provided. The stage gain of this amplifier is controlled by degeneration, using a variable unshunted cathode resistance.

It is essential that the cathode be allowed at least 30 seconds to reach full operating temperature before any anode current is permitted to flow; disregard of this precaution will cause cumulative destruction of the cathode.

It is also essential that the anode current shall never, even momentarily, exceed the rated peak value of 1 amp. This point needs special attention in circuits in which there are condensers which may charge or discharge through the gas-filled relay. In circuits where an accidental overload may be liable to occur, it is wise to protect the relay with an instantaneous overload circuit breaker set to operate at 1 amp; a fuse is not rapid enough to afford protection.

The peak voltage developed at the grid of the GT1C during the discharge period should not exceed 10 volts negative to cathode, and usually this can be achieved by the use of a grid resistance of value between 10 000 ohms and 1 megohm.

Applications. Thyratrons have been used widely in the U.S.A. for dimming the stage and auditorium lighting of theatres. The advantages of this form of control over the old variable rheostat method are: (1) it is more efficient; (2) a large number of circuits can be easily controlled; (3) changes can be effected from any distance; and (4) scenes or lighting schemes can be pre-set and switched on automatically.

Dimmer. The principle used is that of supplying the A.C. lighting load through a saturable core reactor, the saturation being provided by the rectified output of two grid-controlled gas-filled relays. Thus, under conditions of core saturation, little impedance is offered by the reactor, while if the rectified current is switched off, the appreciable impedance of the reactor causes the lighting load to be dimmed. A potentiometer rheostat is transformer-connected to the grids of the thyratrons.

The type of saturable reactor used consists of a laminated iron core, on which are two windings. One winding, in series with the lighting load, is connected to the A.C. supply; the other, supplied from the thyratron, carries D.C. Thus, when the lamps are completely dimmed and no D.C. saturating current is flowing, considerable impedance will be offered by the A.C. winding.

For particularly complex lighting control, utilizing the pre-set features, individual potentiometers are set to give the required lamp-brightness for each scene, and a high-resistance "scene-changing" potentiometer is utilized for fading each scene into the next. Total black-out control is provided for by a master potentiometer.

An interesting example of thyratron reactor control was installed just prior to the outbreak of war in the ballroom of R.M.S. *Queen Mary*.

In this ship, the equipment was arranged for sound control. and consisted of three banks of red, blue, and green lamps. By

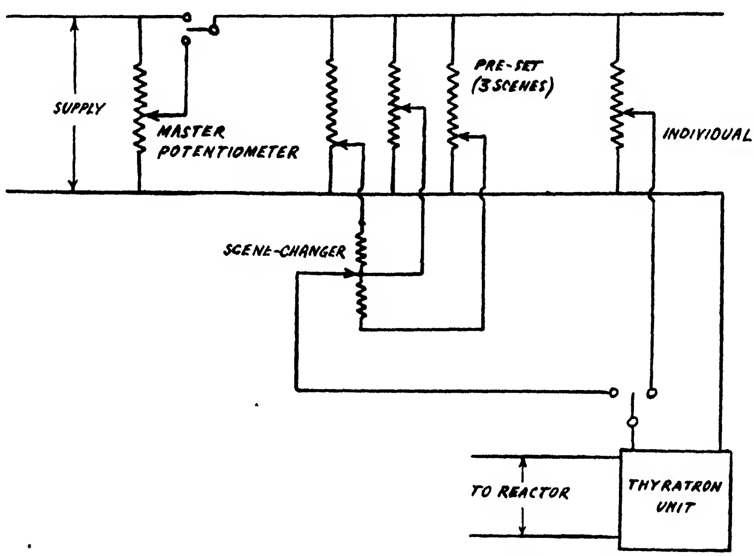


FIG. 24. THYRATRON-CONTROLLED THEATRE DIMMING ARRANGEMENT

the aid of a microphone in conjunction with the thyratron reactor circuit, the lighting could be varied according to the characteristics of the orchestral music. A great variety of tints could be obtained in this way, and the amplitude of sound emitted determined the intensity of illumination provided—the light altering automatically in sympathy with the music.

Generator Voltage Regulator. By the use of thyratrons for voltage regulation of generators, vibrating contacts and moving parts are eliminated and a far more rapid response is obtained.

One method of causing variations of generator output voltage to affect the grids of thyratrons is known as the "non-linear bridge network." In this circuit, two fixed resistances and two resistances with non-linear voltage/current characteristics (say, tungsten filament lamps) are connected in bridge form, the bridge being arranged to be balanced for a given voltage. Opposite corners of the network are taken to: (1) generator terminals, and (2) a thyratron. While the bridge is balanced there will be no voltage across the thyratron.

The result of any change in generator voltage will be to affect the non-linear characteristic resistances, there being thus applied,

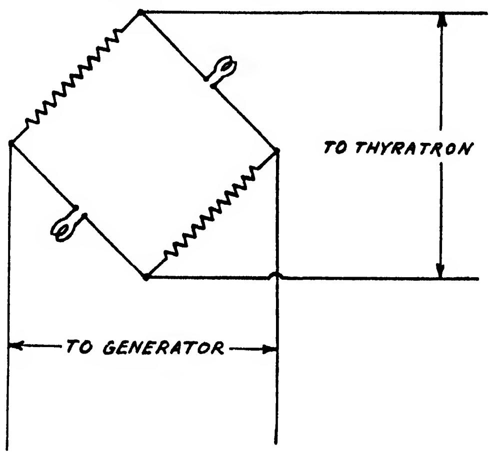


FIG. 25. THYRATRON VOLTAGE REGULATION (NON-LINEAR BRIDGE)

indirectly, voltage to the thyratron, which will then supply compensating current to the generator or exciter field.

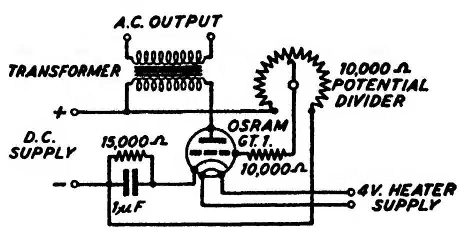
Rectifier. Rectification by grid-controlled gas-filled triodes is carried out by controlling the duration of the current flow in each cycle. The grid serves to withhold the flow of current until a particular part of the cycle, after which the current continues to flow until the end of the half-cycle.

In a half-wave circuit, the A.C. supply is connected to the anode and cathode, and an adjustable D.C. source is applied between the grid and the cathode. The part of the cycle at which the discharge starts, on which the power delivered by the circuit depends, is determined by the control characteristic of the gas-filled relay. The time during any part of the first half-cycle at which both anode and grid voltage are favourable to the discharge can be adjusted by variation of the direct grid voltage. This arrangement is likely to be unstable unless the grid voltage is kept constant throughout operation.

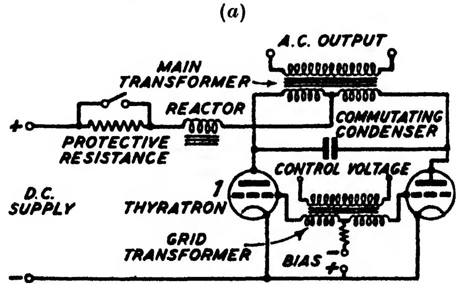
There is, however, an alternative type of grid control which has a wider control range and reasonably constant operation. It consists of applying either alternating current, or a combination of A.C. and D.C., to the grid of the gas-filled triode. In this case, although the frequency of the applied A.C. is the same as that of the anode supply, it has a phase displacement of 90°. Thus, by varying the applied D.C. in the second case, or by altering the amplitude of the A.C. in the first, the time of commencement of the discharge can occur over a wide range of the cycle (although not over the latter part of the period).

A further method of gas-filled triode rectification is available, which permits control during the whole of the period. In this system a variable reactor is connected in the grid circuit to control the phase displacement between grid and anode voltage. For three-phase circuits, a phase-shifting transformer may be used. Continuous power control from zero to full output is possible by this method.

Inverter. The application of inverters for producing A.C. from



(*a*)



(*b*)

FIG. 26. INVERTERS: (*a*) SINGLE-THYRATRON, (*b*) TWO-THYRATRON
(*From "The Electrical Engineer"* [*G. Newnes Ltd.*])

D.C. mains is well known. For inversion up to a frequency of about 5 000 cycles per second, gas-filled triodes are preferable to vacuum valve oscillators.

In the simplest type of inverter circuit the gas-filled triode acts merely as a switch. A combination of capacity and resistance is included in the grid circuit, so that the condenser, charged by the D.C. input, discharges through the primary of a transformer, thus producing pulsating current in the secondary. A bias voltage applied to the grid of the relay allows the passage of current whenever the condenser voltage attains a definite value, after which the condenser is discharged.

The relay, of course, is non-conducting until the condenser is fully charged—the inductance of the transformer primary then serving to maintain conduction for a short time. This gives sufficient time for the grid to regain control before de-ionization.

In this type of inverter, the power output depends on the characteristics of the gas-filled triode or thyratron, and the applied D.C. Unfortunately, the frequency may vary with changes in load; also, the wave form of the A.C. produced is in the form of a rough saw-tooth. However, given a suitable transformer, this circuit can be used to supply neon signs, to time spot welders, and to operate stroboscopes, or— with slight modification— tachometers.

By employing a two-thyratron inverter circuit a better wave form and a greater time-average economy are obtained. The grid circuit is controlled through a transformer, the secondary of which feeds alternating current alternatively to the two grids so that one is positive while the other is negative. The two anodes are interconnected through a condenser, and the anode currents are fed into opposing portions of the output transformer primary.

If the grid transformer primary is supplied from the output transformer instead of from an external source, the circuit becomes self-exciting. The frequency of inversion is then determined primarily by the transformer inductance, condenser capacity, and the grid circuit characteristics.

An alternative form of inverter, utilizing two thyratrons, is arranged to charge a condenser through one relay and discharge it through the other, the grids being excited from an external source. The principle of this circuit is the building-up of sudden voltage changes across a double-wound choke coil, raising the cathode potential of each valve in turn.

D.C. Transformer. A rather novel application of gas-filled relays, based on the two-thyratron inverter circuit, is the D.C. transformer. By means of this device it is possible to transform D.C. to an appreciably higher voltage than that of the supply. The method consists of inversion, transformation, and rectification.

In the U.S.A., experiments have been carried out in which inverter-rectifier circuits are used in the transmission of high-voltage D.C. The object is to generate A.C. at high voltage, rectify and filter it, and transmit the resultant high-voltage D.C. At the end of the line remote from the power station the supply is inverted and distributed as A.C. In this way, the many difficulties encountered in high-voltage A.C. line transmission are avoided.

Chapter IV

PHOTO-ELECTRIC CELLS

Photo-electricity was evolved from the experiments of Hertz. In 1887, Hertz made the discovery that a negatively charged body lost its charge after being exposed to light of short wavelength. It followed from the electronic theory subsequently established that this effect was due to electron migration. In other words, light energy is capable of liberating electrons from a given material.

The velocity of the electrons so liberated depends both on the material concerned and on the frequency of the incident radiation, and is in no way dependent on the intensity of the light; nor is it influenced by temperature between the limits of 180°C. and 800°C.

For each substance with which the photo-electric effect can be observed there is a definite threshold frequency of the incident light below which the effect does not occur. This agrees with the quantum theory, in that a certain amount of energy is required to enable the photons to dislodge the electrons. The time lag between the application of the light and the photo-electric effect is extremely small; some thousand-millionths of a second.

Copper, gold, and platinum require light of very high frequency for production of the photo-electric effect (i.e. the ultra-violet end of the spectrum). Alkali earth metals are activated by visible light. The introduction of hydrogen into a photo-electric device increases the sensitivity to low-frequency radiation.

Principle of Cell. The photo-electric cell is a contrivance that is rendered extremely sensitive to light changes. If a voltage is applied to the terminals while the cell is completely in darkness, no current flows between the anode and cathode. When light falls upon the cathode (the light-sensitive surface), electrons are emitted, which can be made to control the grid potential of a radio valve, and so operate a sensitive relay.

Construction. The manufacture of vacuum-type photo-cells is by no means simple. Indeed, it is one of the more difficult processes in high-vacuum technique.

After the bulb is blown to shape, a capillary tube is attached, which, after being constricted, is sealed to the vacuum system. In addition, another glass tube connexion is provided for admitting the light-sensitive material; for the purpose of illustration this material will be assumed to be caesium. The admission tube, therefore, will contain caesium bromide and a small quantity of calcium; sometimes, caesium chromate, chromic oxide, and powdered aluminium on a metal disc are arranged for eddy current heating.

In the centre of the bulb itself is a spiral of tungsten, enclosing a short length of silver wire, shielded on one side by a sheet of mica. The nickel wires that support the spiral are taken through a pinch at the base of the tube in a similar manner to radio valve leads.

The apparatus is exhausted to about 10^{-6} mm Hg. Some caesium is then driven into the bulb by the application of heat in order to caesiate the glass (which has an affinity for caesium). After baking for about half an hour, or possibly less, and testing, the tube is ready for photo-activation.

To activate the tube the tungsten spiral is pre-heated for de-gassing purposes, and then for evaporation of the silver. Thus, an almost opaque layer of silver will form on the interior of the glass bulb, except where shielded by the mica. Another short baking period is then advisable. Sufficient oxygen is admitted from a side trap to raise the pressure to about 10^{-2} mm Hg—the tube having been previously cut off from the vacuum pump by the main stopcock. By means of a probe connected to a high-frequency generator, the oxygen—and consequently the silver surface—is ionized. Again, the tube is baked to remove occluded gases. The sublimation of the caesium is then carried out until the requisite photo-sensitivity is recorded by means of a micro-ammeter test circuit. When this value is constant, the photo-cell is sealed off from the vacuum system.

Several substances are used alternatively to caesium to meet different requirements—silver, gold, sodium, potassium, and rubidium, among others.

Commercial Photo-cells. The Osram caesium-silver oxide or CM type is a gas-filled photo-cell. It is made in three standard patterns, designated as CMG8, CMG25, and CMG22, which differ only in size and arrangement of electrodes. Their sensitivity is more than 75 μA/lumen, although Grade A cells, which are usually adequate for simple relay circuits, have a sensitivity of between 50 and 75 μA/lumen; their working voltage is 80–110.

At a low voltage, of the order of 20, the photo-electric current is due to the primary cathode emission, and is practically proportional to the illumination. At high voltages the ratio of current to light increases with the voltage due to gas ionization, the increase over the primary current being termed the "gas magnification." A gas magnification of 10 is about the safe limit. A higher value may produce a glow discharge in the cell, which persists after the light has been removed, and. which will, if continued, damage the cell. A high resistance should always be

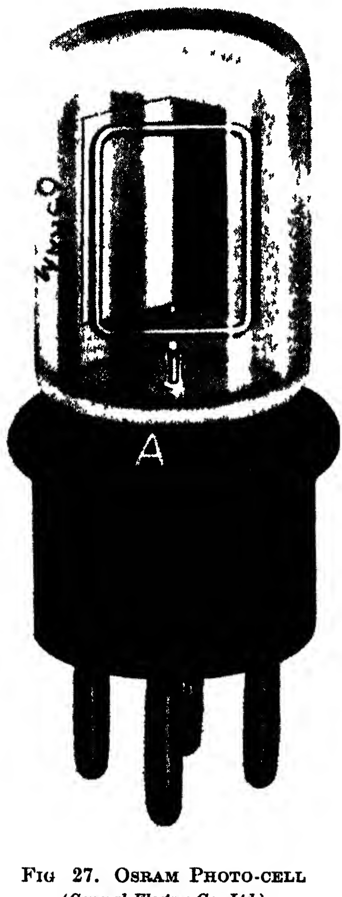


FIG 27. OSRAM PHOTO-CELL
(*General Electric Co Ltd*)

in circuit to protect the cell against a glow discharge which may result from a sudden increase in voltage or illumination.

The sensitivity in microamps per lumen is measured under an illumination of approximately 30 millilumens from a gas-filled lamp and with the voltage marked on the bulb applied between the electrodes. Under these conditions, the applied potential is called the "working voltage." It is marked on each cell and represents the maximum voltage which should normally be applied to the cell to secure adequate emission without seriously impairing the frequency response for acoustic reproduction or incurring danger from a glow discharge.

Although the photo-electric current depends on the total light reaching the cathode, and not on its distribution, the light should preferably be spread over the cathode surface to avoid local inequalities of sensitivity.

The peak spectral sensitivity is at the red end of the spectrum, and the response extends into the near infra-red. By the use of a filter over the light source to cut out visible rays, relay circuits can be operated with invisible radiation. For making measurements of light, specially designed vacuum cells are used.

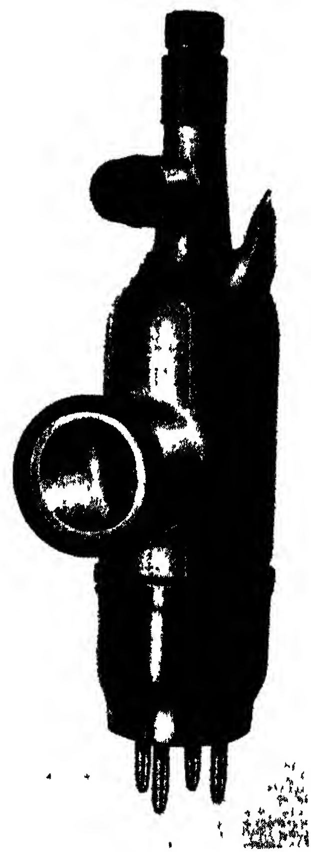


FIG. 28. OSRAM PHOTO-CELL. (*General Electric Co. Ltd.*)

Gas-filled photo-cells are, on the whole, more sensitive than are the vacuum type, but their characteristics are, unfortunately, not so constant. The light/current relationship in a vacuum type photo-cell is linear, since the current flow is made up entirely of photo-electrically emitted electrons—their number increasing in direct proportion to the amount of incident light. In gas-filled photo-cells, however, besides those emitted photo-electrically, some electrons are due to secondary emission, and some due to the presence of positive ions. This explains why the current values of gas-filled photo-cells are about five times as great as those of vacuum cells.

Photo-electric Relays. A typical unit for photo-electric control consists of a transformer (when used on A.C.), a relay, a small contactor, two adjustments "on" and "off," a photo-electric cell, and an amplifier valve. For indoor situations these components are usually enclosed in a pressed steel case provided with a window to permit access of light to the photo-cell. A hole may be provided

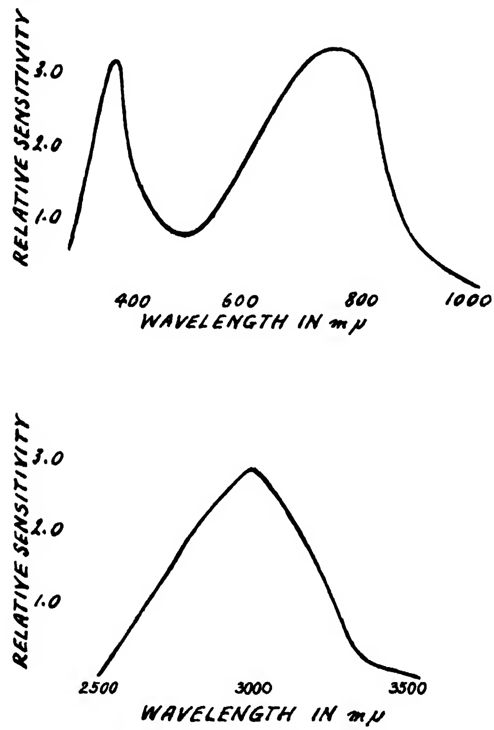


FIG. 29. SPECTRAL SENSITIVITY CURVES

Top · Caesium-oxide silver cathode.
Bottom : Thorium on nickel cathode.

in the cover to allow sensitivity adjustments to be made with a screwdriver.

Where the photo-cell is external to the remainder of the apparatus, it is generally accommodated in a cast aluminium holder, which is connected to the relay by a length of flexible tubing that acts as a shield for the leads joining the photo-cell to a four-pin adaptor. The adaptor is plugged into the exisiting cell holder on the relay panel.

If the relay unit is to be installed out of doors, it is cased in

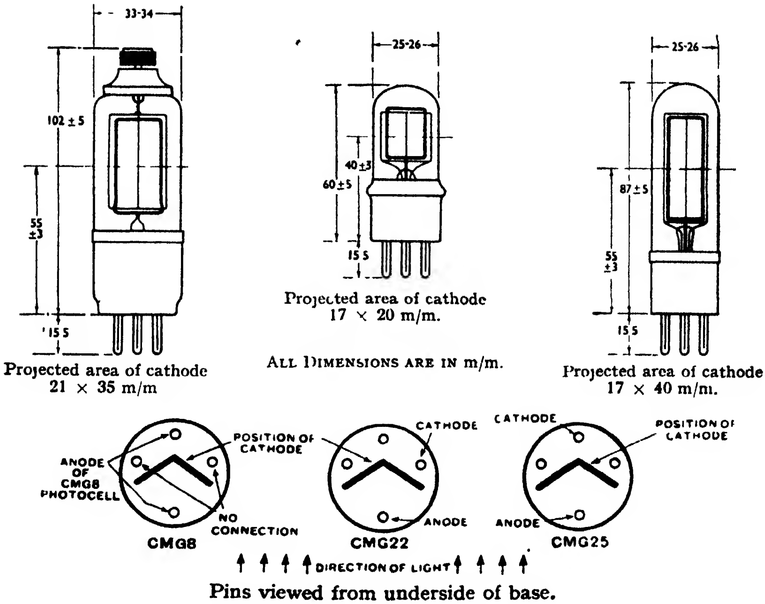


Fig. 30. Dimensions of Osram Photo-cells
(*General Electric Co. Ltd.*)

cast iron, and the hole for adjustment should be fitted with a screwed plug.

For use on D.C. supplies, an external resistance box must be connected to the relay.

When shielded from sunlight, very little change will take place in the characteristics of the photo-cell, and the average life,

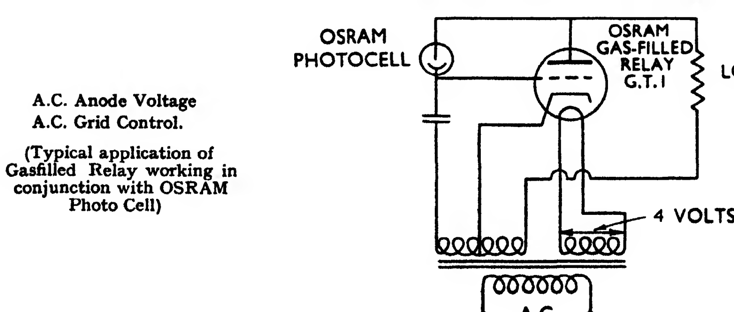
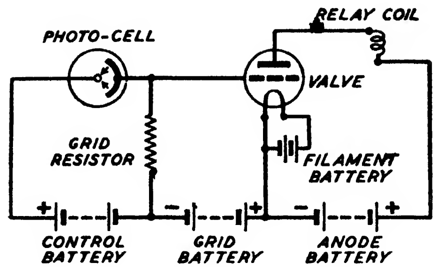
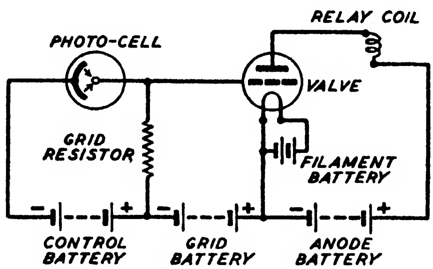


Fig. 31. Typical Application of Gas-filled Relay and Photo-cell



(a)



(b)

FIG. 32. D.C. PHOTO-CELL AMPLIFIER CIRCUIT

(a) Action of light increases valve anode current.
(b) Action of light decreases valve anode current.
(*From "The Electrical Engineer"* [*G. Newnes Ltd.*])

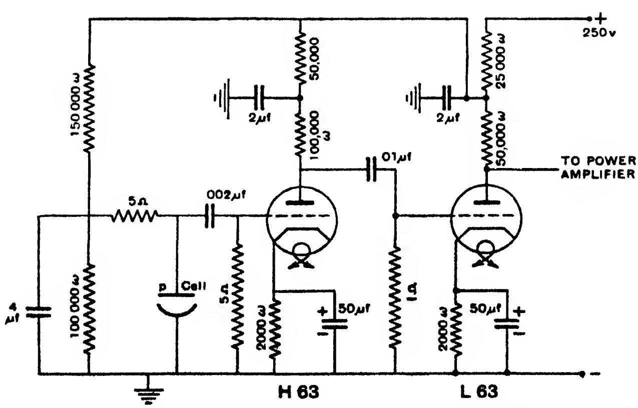


FIG. 33. PHOTO-CELL USED ON A SOUND HEAD AMPLIFIER
(General Electric Co. Ltd.)

compatible with that of other electronic devices, is reasonably long. The power consumption is exceedingly low—typical values for a standard relay unit on A.C. being 15 watts with the contactor energized, and about 8 watts with contactor de-energized. On D.C. circuits the total consumption is approximately 200 watts on 230 volts.

A resistance is sometimes included in the circuit to provide a certain amount of sensitivity control. Decreasing the resistance causes the apparatus to operate at a higher light intensity.

Usually, the relay contacts will be designed to carry about 0·25 amp on a 230 volt non-inductive circuit, and about 0·5 amp

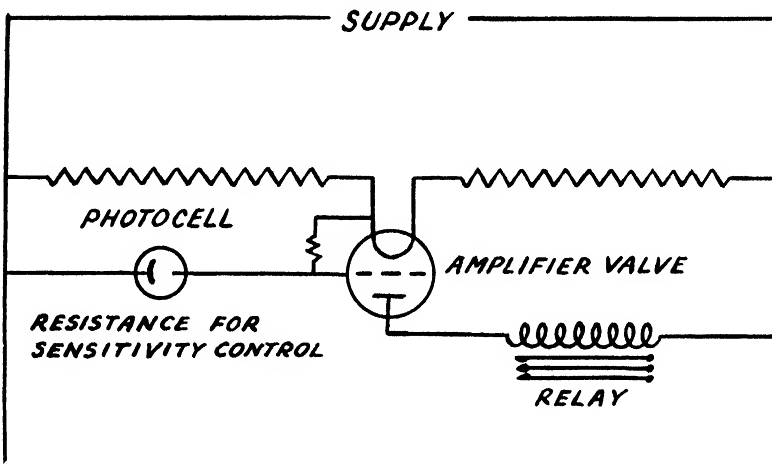


FIG. 34. AMPLIFYING CIRCUIT FOR USE EITHER ON A.C. OR ON D.C.

on 230 volts A.C., but the incorporation of a mercury switch enables larger currents (e.g. up to 7·5 amps) to be controlled. When switching still greater loads, an external contactor must be used.

The step up obtained by a single valve amplifier will be found sufficient to control a relay designed to operate at about 5 mA. Much greater amplification can, of course, be obtained from a transformer coupled stage, but it is essential to remember that in this case an alternating light source (to obtain A.C. from the photo-cell) is necessary. If the light source takes the form of an ordinary 60- or 100-watt lamp on A.C. mains, then a transformer can well be employed.

To prevent damage from sparking at the relay contacts when the circuit is suddenly opened, a neon lamp can be connected

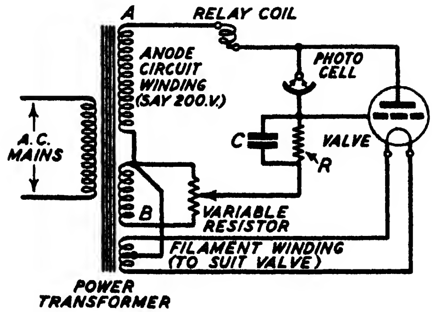


FIG. 35. A.C. OPERATED PHOTO-CELL CIRCUIT
(*From "The Electrical Engineer"* [*G. Newnes Ltd.*])

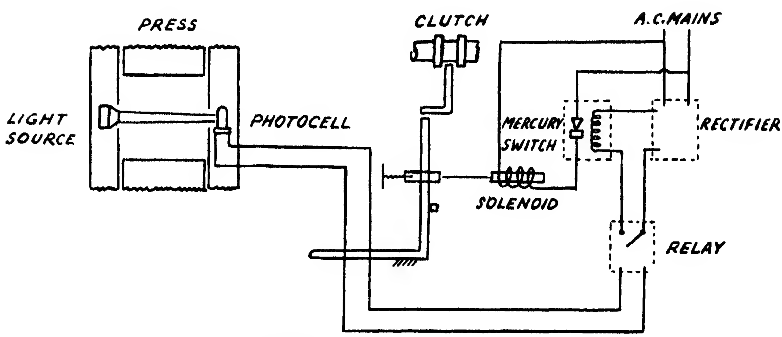


FIG. 36. SCHEMATIC ARRANGEMENT OF PHOTO-CELL PROTECTIVE DEVICE FOR POWER PRESS

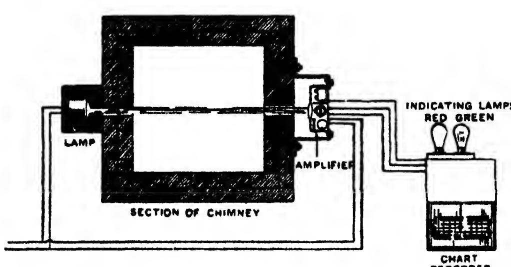


FIG. 37. ILLUSTRATING USE OF A PHOTO-CELL AND AMPLIFIER TO DETECT AND RECORD DENSITY OF SMOKE IN A CHIMNEY
(*General Electric Co. Ltd.*)

across the operating coil. This also serves as an indicator to show when the contactor is in the "on" position.

For public lighting control it is possible to obtain a relay with two independent adjustments ("on" and "off") so that switching off may be set to occur at some lighting intensity quite independent of that at switching on. Since the change-over of control takes place immediately after the relay has operated, the "off" intensity must at least be slightly higher than the "on" intensity. If

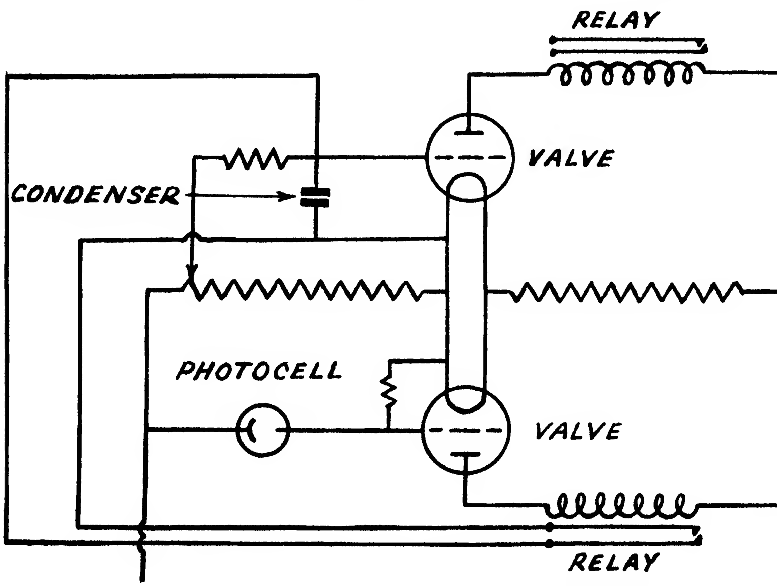


FIG. 38. LIGHTING CONTROL CIRCUIT INCORPORATING TIME DELAY

necessary, a time delay may be introduced between the change-over of the two controls.

Normally, the contactor is required to close at nightfall, but, if a small switch is provided, this setting may be altered to suit special conditions.

The usual range of adjustment is from 0·2 to 10 foot-candles, although the upper limit can easily be extended if, for instance, it is desired to control interior lighting. An independent "off" control provides a means of compensating for the possible effect of artificial light on the photo-cell when lights are switched on.

Applications. Used in conjunction with relay gear employing amplifying vacuum valves or gas-filled relays, photo-cells have an extremely wide range of application. Automatic counting, burglar and fire alarms, measurement of illumination, colour matching, chemical analysis, and sound reproducing are some of the more obvious uses. Two examples of their employment in connexion with civil engineering are the docking of the Kincardine Swing Bridge in Scotland, and the recording of unsafe heights of vehicles approaching the entrance to the Mersey Tunnel.

D.C. Motor Control. The photo-cell and gas-filled relay combination can be used, without the addition of any mechanical device, to start, stop, or reverse a small D.C. motor. Where reversal is desired, the motor has two field windings, one for each direction of rotation, and each is in series with the anode circuit of a gas-filled relay. Three photo-electric relays are required, the resetting of the relay circuits after each operation being carried out by a condenser discharge circuit. The armature is permanently in circuit with a series resistance to limit the current when the field is not excited. To speed up the interchange of current through the relays, a choke may be inserted in the common anode circuit: this retards changes of armature current owing to variation of field. To improve the acceleration and secure very rapid operation, the third relay may be used to excite an eddy current brake to pull up the motor quickly.

Protective Device. Standard photo-cell units can be used as protective devices on power presses, thus preventing injury to the hands of machine operators. The usual practice requires a solenoid consuming approximately 100 watts A.C. The solenoid is connected through a contactor or mercury switch to the power line that supplies the press. If the light beam is allowed to pass across the dies on to the photo-cell, any obstruction in the light will cause the power drive to be disconnected.

Lift Door Control. A fairly recent application of the photo-electric relay is the control of power-operated lift doors—either electric or pneumatic. In this case the beam of light is focused across the lift car entrance, so that it is impossible to enter or leave the lift without breaking the ray. A photo-electric cell, fixed on one side of the gate, controls a relay which operates the door-opening mechanism fitted with a time delay device. By this means, passengers are protected from injury through the closing of the gates.

Poisonous Gas Detection. By the aid of a photo-electric apparatus poisonous gases can be detected and automatically dealt with. A bridge circuit employing two vacuum type photo-cells is required, so arranged that the relay is actuated whenever the illumination on one cell exceeds that of the other. The relay controls an alarm circuit, consisting of a bell, buzzer, and/or pilot light, simultaneously with an electric fan for reducing or dispersing the gas.

Gas-furnace Fuel Control. If the fuel supply to a gas furnace is controlled by a photo-cell and relay, the supply will be instantly cut off should the flame become extinguished. The photo-cell is arranged in front of the gas flame so that the contactor will be released when the flame goes out. This automatically causes the main supply of gas to be shut off, and, at the same time, stops the induced-draught fan motor from which the supply to the photo-electric relay has been taken.

Sign Control. It sometimes happens that an outdoor neon sign is not sufficiently effective in broad daylight to justify continuous operation. Yet at all times of the year there are certain periods during which such a sign could be illuminated to advantage in the daytime. Here is yet another application of the photo-electric relay. Whenever the daylight falls below a stipulated minimum, the photo-cell will close the contacts and bring the sign into operation.

One of the many potential applications of the photo-cell in advertising is the following—

A mirror is hung at a convenient height in the lobby or waiting-room of a cinema. Directly under the mirror is a recess containing programmes or leaflets advertising forthcoming attractions. When a lady patron stops to adjust her hat, she catches sight of a notice at the bottom of the mirror which requests her to take a leaflet. As she puts her hand into the recess in order to comply with this request, she unwittingly breaks the light ray which is focused across the recess entrance on to a photo-cell. This actuates the relay which, in turn, causes the mirror to be immediately illuminated from behind, possibly displaying a coloured announcement of a coming film.

For hotels and garages—particularly those situated near main roads—an illuminated sign, operated by a photo-electric relay, can be installed to advantage. The photo-cell unit is fixed in such a position that it will be operated at night by the headlights of approaching vehicles, and will thus switch on the sign. By this means the sign can be illuminated for, perhaps, a hundred yards, before a car reaches it, so that the driver or occupants can hardly fail to observe it. The distance of the car from the relay necessary to cause the sign to light up will, of course, depend on the power of the headlights and the sensitivity of the photo-cell.

Similarly, signs erected adjacent to a railway line can be put into operation by trains interrupting the light beam directed on to a photo-cell. The incorporation of a time delay switch will ensure that the sign remains on long enough to be seen by passengers throughout the length of the train.

Innumerable display novelties can be actuated by photo-electric relays: revolving turntables, animated figures, pouring liquids, and bullet-less rifle ranges.

Pyrometers. Photo-electric pyrometers, like optical pyrometers, can be used to measure the temperature of some distant hot body. The photo-electric instrument, however, possesses the advantage that temperature can be indicated directly; the speed of response here is such that a full scale deflection of a milliammeter can be obtained within a second of the appearance of the hot body before the photo-cell. The cell, of course, is housed in a water-cooled pyrometer head.

The pyrometer equipment is operated from A.C. mains, its temperature range being above 700° C. Accuracy, which is adequate for most purposes, is within plus or minus 7° C. In conjunction with a thyratron relay panel, photo-electric pyrometers may be utilized for temperature control.

Speed Measurement. Speeds of rapidly moving objects can be measured by means of an A.C. photo-electric thyratron relay. The method consists of focusing two parallel beams of light on to two photo-cells, the time interval between the interruption of the light beams by the moving object being thus registered electrically.

For some devices, selenium generator photo-cells are preferable to the ordinary type. These convert luminous energy into electrical energy with a sensitivity as high as 500 μA/lumen.

CHAPTER V

CATHODE-RAY TUBES

IN a suitably designed electron tube in which the cathode emits electrons which are directed through a small hole, and the anode is cylindrical in shape, a beam of high-speed electrons may be collected by the anode. If the electron beam strikes a fluorescent screen (such as Willemite), a bright spot will show the point of contact. Such an arrangement is called a cathode-ray tube.

FIG. 39A. MULLARD ECR60 CATHODE-RAY TUBE
(*Philips Lamps Ltd*)

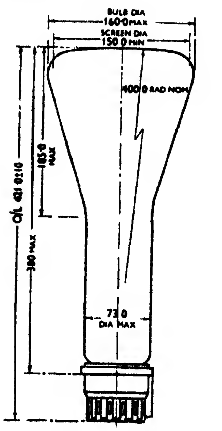
Electron Beam Control. Movement of the electron beam can be controlled, and any change in direction of the beam is indicated by the fluorescence of the screen There are two methods of control available: (1) electrostatically- by connecting a battery across two plates arranged one on each side of the beam, and (2) magnetically— by energizing two coils similarly arranged in respect to the beam.

As long ago as 1897, Sir Joseph Thomson succeeded in determining the charge-to-mass ratio of electrons by using both electrostatic and magnetic control equal in magnitude, so that the beam was not deflected at all. This was termed the "crossed fields" method.

Essential Components. A typical modern cathode-ray tube consists of a highly exhausted funnel-shaped glass bulb containing an electron gun to provide a narrow beam of free electrons, an anode system to focus the beam, two sets of deflector plates (for electrostatic control), and a fluorescent screen.

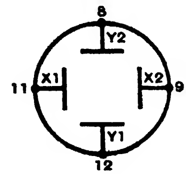
The free electrons, provided by a thermionic cathode, flow through a modulator, the first anode, the second anode, the third

DIMENSIONS

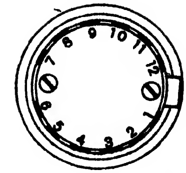


All dimensions are in m/m and are max. except where otherwise stated.

DEFLECTOR PLATES



BASE



View of underside of base.

Fig. 39b. Arrangement of E-4504 B 16 Cathode-ray Tube
(*General Electric Co. Ltd.*)

PIN CONNECTIONS

Pin 1 : Modulator
2 : Cathode
3 : Heater
4 : Heater
5 : A1
6 : A2
7 : Graphite
8 : Y2 deflector
9 : X2 deflector
10 : A3
11 : X1 deflector
12 : Y1 deflector

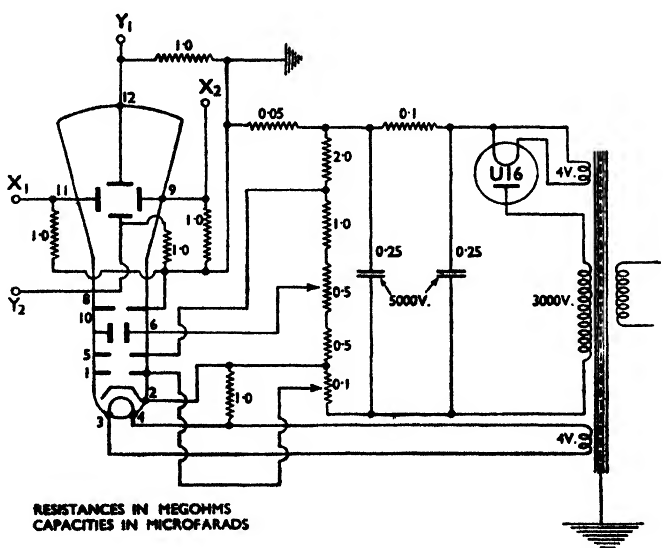


Fig. 40. Typical Circuit showing High-voltage Power Supply to Tube E–4412–B–9
(*General Electric Co. Ltd.*)

anode, and thence between the X and Y deflector plates to the screen.

The secondary emission resulting from the impingement of the electrons on the screen is conducted away by a coating of graphite electrically connected to an anode.

Gas-filled cathode-ray tubes have not so far been used to any great extent. In this type of tube a small quantity of inert gas is included, which is thus ionized by the electron energy. This tends to make the tube unstable.

FIG. 41. TYPE 4102 CATHODE-RAY TUBE
(*General Electric Co. Ltd.*)

Types of Fluorescent Screens. The material of which the fluorescent screen is made varies for different applications. The material most commonly used, suitable for most general purposes, is Willemite, which produces a green glow. Where very rapid action for photographic work is required, cadmium tungstate, giving a blue trace, is used. For certain special purposes in which persistence of light is desirable, zinc phosphate screens are necessary to obtain the desired phosphorescence.

Construction. Cathode-ray tubes are exhausted to a high degree of vacuum (10^{-6} to 10^{-9} mm Hg). Since a number of tubes may be pumped at the same time in the factory, a high-speed pumping system is essential.

The tube is baked and exhausted first to the necessary degree of vacuum (after allowing for cooling). A cut-off test is then made, using a McLeod gauge. The electron gun, which must be vacuum stoved before mounting in the tube, is out-gassed by eddy current heater bombardment for about 10 minutes at 800° C. Preparation for cathode activation is carried out by applying from a half to one and a half times the normal operating voltage across the cathode heater; then, after strapping together the other electrodes of the gun, a gradually increasing positive voltage is applied to them.

When the correct emission, as shown by the cathode current meter, is obtained, the gun electrodes are again bombarded, the getter (which has been pre-heated) is flashed, and the tube is sealed off the pumping system.

Activation of the cathode is carried out by again strapping together the other gun electrodes and drawing current to them, the tube being afterwards run at normal operating potentials. The free barium, which is to form the active emitter, is thus formed electrolytically on the cathode surface.

As the fluorescent material is already contained on the inner surface of the bulb before these operations are carried out, it is essential that water-vapour should not enter the tube during processing.

Commercial Cathode-ray Tubes. The range of G.E.C. cathode-ray tubes includes E 4504 B-16 (6 in. screen), E-4412-B-9 ($3\frac{1}{2}$ in screen), E 4102 B 7 ($2\frac{3}{4}$ in. screen), and E-4103 B 4 ($1\frac{1}{2}$ in. screen). These are all high-vacuum tubes with indirectly heated cathodes, and have screens with a green fluorescence of negligible persistence. The characteristics of each are tabulated below:—

	E 4504 B 16	E 4412 B 9	E 4102 B 7	E 4103 B 4
Ratings				
Heater voltage	4 volts ± 5%	4 volts ± 5%	4 volts ± 5%	4 volts ± 5%
Heater current (approx.)	1.1 amp	1.1 amp	1.1 amp	1.1 amp
First anode voltage (VA_1)	2 500 volts max	2 500 volts max	400 volts min	400 volts min
Second anode voltage (VA_2)	$VA_3 \times 0.175$	$VA_3 \times 0.175$		—
Third anode voltage (VA_3)	mean {5 000 max, 1 000 min}	mean {5 000 max, 1 000 min}	1 500 max	1 000 max
Brightness control mod. voltage (VM)	$-(VA_1 \times 0.04)$ max	$(VA_1 \times 0.04)$ max	$(VA_1 \times 0.025)$ max	$(VA_1 \times 0.025)$ max
Deflection Sensitivity				
Deflectors nearest base X_1 and X_2	$\frac{1\,100}{VA_3}$ mm/volt mean	$\frac{750}{VA_3}$ mm/volt	$\frac{170}{VA_3}$ mm/volt	$\frac{100}{VA_3}$ mm/volt
Deflectors nearest screen Y_1 and Y_2	$\frac{600}{VA_3}$ mm/volt mean	$\frac{350}{VA_3}$ mm/volt	$\frac{170}{VA_3}$ mm/volt	$\frac{90}{VA_3}$ mm/volt
Interelectrode capacities—				
Modulator to all other electrodes	25 pfds max	25 pfds max	20 pfds	20 pfds
Either X or Y to other electrodes	25 pfds max	25 pfds max	15 pfds	15 pfds
Either X to either Y deflector, all other electrodes earthed	6 pfds max	6 pfds max	5 pfds	5 pfds

All of these tubes should be operated in accordance with the "Code of Practice for the use of Cathode-ray Tubes in Equipment,"

B.S. No. 1147—1943. Failure to observe the recommendations may result in poor performance.

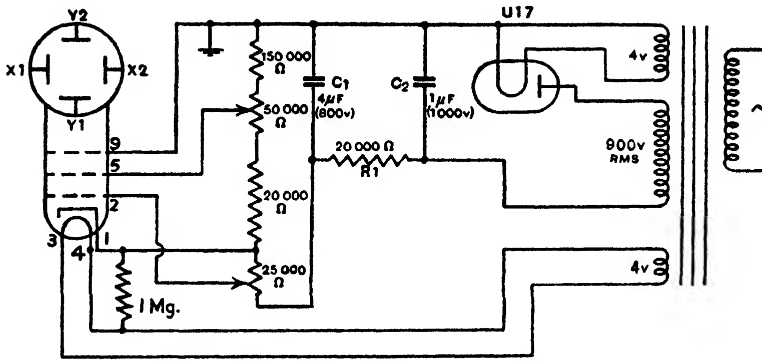


FIG 42 TYPICAL CIRCUIT SHOWING HIGH VOLTAGE POWER SUPPLY TO E 4102 B 7
(General Electric Co Ltd)

The modulating voltages can, in these tubes, be applied between cathode and modulator without the distortion that might be caused without separate connexion by the capacity to earth of the heater transformer. The tubes are intended for use in portable or fixed oscillograph apparatus for studying a variety of phenomena at high or low frequencies. A particular feature of the tubes is their short overall length for the high deflection sensitivities obtained

In Types 4504 and 4412 a positive potential applied to the X_1 deflector will deflect the spot to the left and a positive potential applied to the Y_1 deflector will deflect the spot upwards. A typical circuit for these types is shown from which the various electrode potentials can be obtained. Normally, the internal conducting coating of the tube should be connected directly to the third anode, but if it is desired to read the current in the spot (beam current), a meter

FIG. 43. TYPE 4103 CATHODE-RAY TUBE
(General Electric Co Ltd)

reading 0–100μA may be connected. If it is not desired to apply any modulation between cathode and modulator, one side of the heater should be connected to the cathode, either directly or through a resistance of approximately 1 megohm.

The circuit shown applies approximately 4 000 volts between the third anode and the cathode. If the tube is to be operated on some other voltage, proportional modifications should be made

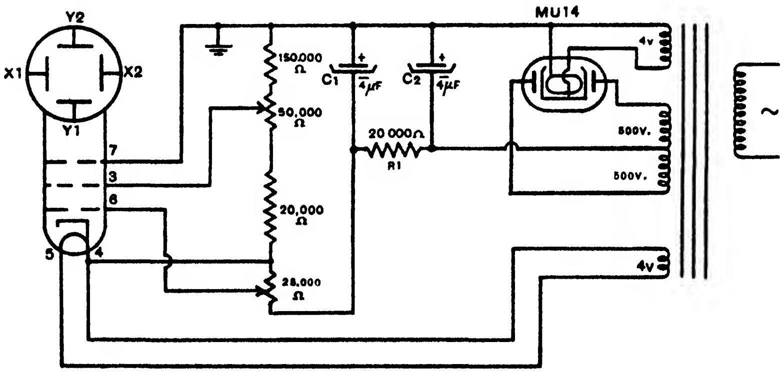


FIG. 44. TYPICAL CIRCUIT SHOWING POWER SUPPLY TO E-4103 B-4 TUBE
(*General Electric Co Ltd*)

to the output voltage of the high-tension windings, to the insulation between the windings of the transformer, and to the rating of the condensers employed.

E–4102–B–7 is a small high-vacuum cathode-ray tube designed for electrostatic focus and deflection. It is intended for use in portable oscillograph apparatus such as that used for radio servicing, and may also be employed where a visual means of studying transient or recurrent phenomena is required. Features of this type are the small overall length and comparatively low operating voltage with a screen of adequate dimensions.

With the tube viewed from the screen end, and with the spigot uppermost, a positive potential applied to the X_1 deflector will deflect the spot to the left, and a positive potential applied to Y_1 will deflect the spot upwards.

Supplies for the tube may be conveniently obtained from A.C. mains by the use of the rectifier circuit shown.

The miniature tube designated as E–4103–B–4 has only a 1½ in. screen. Like the 4102, it is designed for electrostatic focus and deflection and is intended for use in portable equipment.

In this tube all four deflector plates are brought out to separate pins, so that symmetrical (push-pull) deflection can be used if desired: the tube can also be used with unsymmetrical (non-push-pull) deflection, with some deterioration of performance.

With the tube viewed from the screen end, and the arrow mark on the base pointing downwards, a positive voltage applied to X_1 and Y_1 simultaneously will deflect the spot downwards.

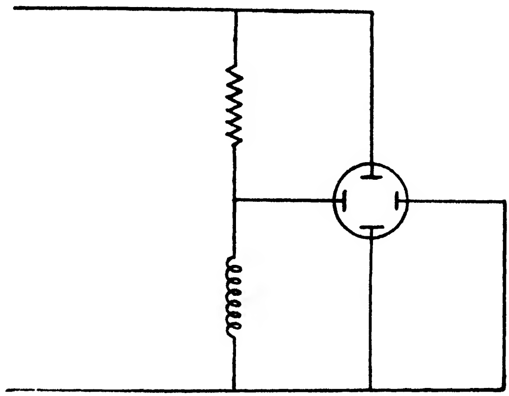


FIG. 45. CATHODE-RAY TUBE AS WATTMETER

Tolerances should be allowed for by mounting the tube holder in such a way that it may be rotated to accommodate individual tubes.

Supplies for the tube may conveniently be obtained from the A.C. mains by a transformer, rectifier and smoothing circuit as shown. It should be noted that A.C. supplies for operating these tubes should be obtained from transformers provided with an earthed screen between primary and secondary windings in order to protect the main supplies from any high-voltage surges produced under fault conditions to the equipment. This applies equally to type E–4102–B–7.

Applications. In so far as the measurement of transient or recurrent phenomena is concerned, the electrostatically controlled cathode-ray tube has two distinct advantages. They are: (1) voltages may be measured without consumption of power from the test circuit, and (2) the tube will follow changes of as much as 100 000 000 per second.

The deflection sensitivity of the tube varies from 0·05 mm/volt for high accelerating voltages to about 0·6 mm/volt for low accelerating voltages. Owing to the difficulty of measuring spot deflections of less than 1 mm, 2 volts is the lower limit of direct measurement. In practice, however, amplification is used for most measurements of 10 volts and under.

In cathode-ray oscillography it is possible to plot voltage against time by utilizing a special circuit, so arranged that a condenser is charged slowly and then suddenly discharged. The voltage across the condenser will, naturally, increase in proportion to the time of charge and, applied to the deflection plates, can thus be made to cause the spot to move horizontally across the screen.

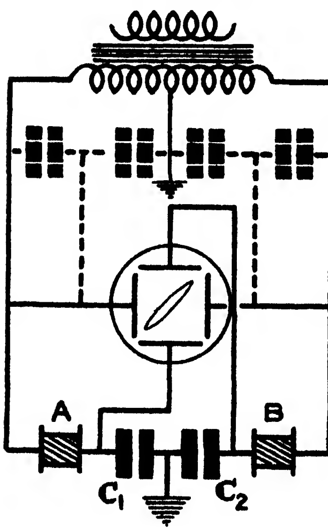


Fig. 46. Measurement of Power Loss in Dielectrics by Cathode-ray Tube

(*From "The Electrical Engineer"* [*G. Newnes Ltd.*])

It is essential to bear in mind that the electrostatically controlled cathode-ray tube is a potential operated device. Thus, for the measurement of current, a shunt must be connected in circuit. The appearance of an ellipse on the fluorescent screen indicates that there is a phase difference between the current and the voltage.

Power Measurement. To calibrate the tube for measurements of power, each pair of plates, X and Y, must be switched off separately, so that the scale can be marked off. The shunt factor must, obviously, be taken into account. In measuring the power when voltage and current are out of phase, it is necessary to obtain the area of the ellipse.

Television Reception. The application of the cathode-ray tube to television reception is well known. Since the amount of deflection of the electron path is proportional to the potential charge or charges given to the plates, the visible spot may be made to describe the necessary path to conform with the scanning at the transmitting end.

There is a primary and a secondary scanning movement. These, of course, divide the picture and the number of picture repetitions per second respectively. For example, in 180-line pictures, the primary movement may take place 4 500 times per second, and the secondary movement—the number of picture repetitions—25 per second. In a 441-line picture with a width equal to $1\frac{1}{3}$

times its height, something like 8 million variations of light and shade would have to be handled each second by the cathode-ray tube.

Saw-tooth motion of the spot is brought about by the use of a thyratron or gas-filled discharge tube. The grid voltage is fixed at some definite figure above which no anode current can flow. Thus, the anode current is "triggered." A "time-base," consisting essentially of a saturated diode valve and a condenser, is connected in circuit with the thyratron so that the potential applied to one pair of deflector plates in the cathode-ray tube is increasing uniformly. The electron stream, therefore, takes a linear path across the screen for the required distance, whence, owing to the action of the thyratron, it returns to its starting point.

However, the other pair of deflector plates are also influencing the scanning motion simultaneously with the first pair. Their function is to direct the spot in another direction, so that, instead of returning to its starting point after triggering, it makes a saw-tooth motion during its traverse across the fluorescent screen and, under the action of a second thyratron, returns to its original starting point after the whole area is scanned.

Measurement of Dielectric Loss. In the measurement of dielectric loss in high-tension cable insulation, two identical specimens are connected across the secondaries of a mains transformer in series with two condensers. When the horizontal deflectors of a cathode-ray tube are connected across the specimens, a deflection will be obtained proportional to the total applied voltage. The vertical plates are connected across the condensers in order to give the deflection due to current.

It will be seen that the vertical movement of the electron beam differs by 90° from the applied potential with a low power factor, and a long thin ellipse will be shown on the fluorescent screen.

Sometimes, for instance in ascertaining the power loss in E.H.T. cables, a form of potential divider is used. This can consist either of a chain of condensers or be achieved by the insertion of variable "tapping" plates.

Frequency Measurement. In frequency measurement by means of cathode-ray tubes, Lissajous figures are produced on the screen whenever the frequency of the potential applied to one pair of plates is greater than that applied to the other pair. For example, if the frequency of potential applied to the vertical plates is three times that of the potential applied to the horizontal plates, the trace will have three loops. Rapidly changing the phase of the higher frequency will result in an interwoven effect. Beyond a ratio of about 10 to 1, the trace appears almost as a solid figure, and is too complicated to follow visually.

An important application of the cathode-ray tube in frequency measurement is the checking of momentary variations. As soon

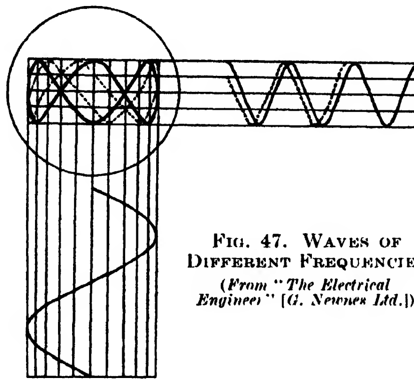


FIG. 47. WAVES OF DIFFERENT FREQUENCIES
(*From "The Electrical Engineer"* [*G. Newnes Ltd.*])

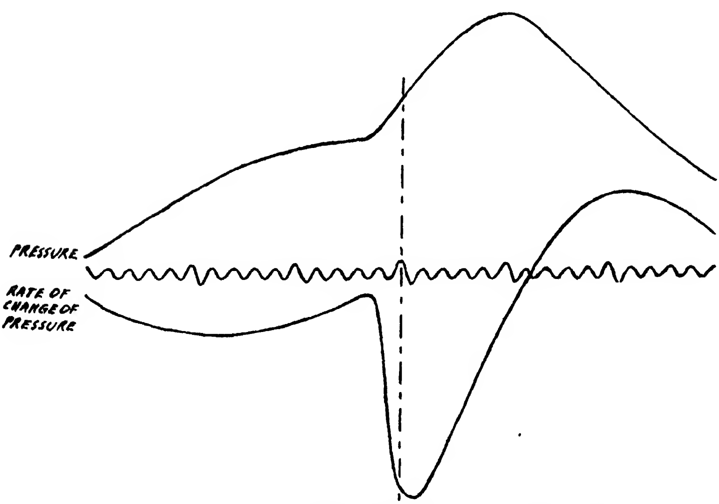


FIG. 48. CYLINDER PRESSURE INDICATION (SUNBURY)

as the waves become asynchronous, the trace on the screen will apparently begin to rotate.

Engine Indicators. There are several types of commercial cathode-ray tube engine indicators which differ in design features.

In the Sunbury indicator the pressure changes or mechanical movement in an engine are converted magnetically into electrical voltages. These are amplified and then applied to the deflector plates of the cathode-ray tube. The trace resulting from movement of the electron beam is thus representative of the phenomenon investigated.

Three obvious methods of co-ordinating mechanical movement and electrical impulse are (1) by movement of a coil in a magnetic field, (2) by a mechanically-regulated variable resistance, and (3) by compression of crystals ("piezo-electric" effect).

In the Sunbury instrument, if a crank angle voltage be applied to X plates, and a pressure voltage to the Y plates, the trace on the fluorescent screen will be in the shape of the orthodox indicator diagram.

For most purposes, engine indicators are required to plot some variable, such as cylinder pressure, against engine speed. This necessitates a time base, either of the hard or the gas-filled relay type, which must be tripped by a small controlling voltage derived in some way from the engine. This "time sweep" circuit may also be utilized to calibrate the time base.

Chapter VI

X-RAY TUBES

X-rays are generated by stopping high voltage electrons in a discharge tube. The voltage applied to a discharge tube determines the speed of the electrons which, in turn, decides the penetrating power of any X-rays produced. The number of electrons present is dependent on the current passing, which also determines the intensity of radiation produced; the characteristics of X-rays emitted vary with the metal used to stop the electrons.

Development. Originally, an X-ray tube consisted of a highly exhausted glass tube with two main electrodes--a cathode and an anticathode. Sometimes, an auxiliary electrode was included. Cathode rays were focused by the saucer-shaped cathode on to the surface of the anticathode, which thus acted as a kind of target, and which was inclined to the cathode-ray stream in order to direct the resultant X-rays clear of the cathode.

Owing to the fact that high-vacuum practice was at that time in its infancy, some residual air was left in the tubes, and this necessitated the application of very high voltages generated by means of Rhumkorff coils, usually supplied from accumulators. Since these coils required interrupters in the primary, the resulting secondary current was intermittent, and the "inverse" current had to be suppressed by means of spark gaps with one electrode larger than the other.

The "Coolidge" tube, introduced later, was the first of the present thermionic types of X-ray tubes. In the meantime, methods of obtaining a much higher degree of vacuum than hitherto had been perfected, so that the required voltage was considerably lower. These tubes, however, passed current only when the cathode was hot. In operation, the applied voltage served to draw the electrons from the heated cathode to the anode, where X-rays were emitted as before. But in this case it was possible to pass much higher currents, owing to the cathode temperature; consequently, the intensity of the radiation was much greater.

Transformer Operation. The next major development was the introduction of transformer operation, which obviated the complicated and expensive apparatus necessary for directly producing high voltage D.C. The secondary A.C. was rectified, for, in spite

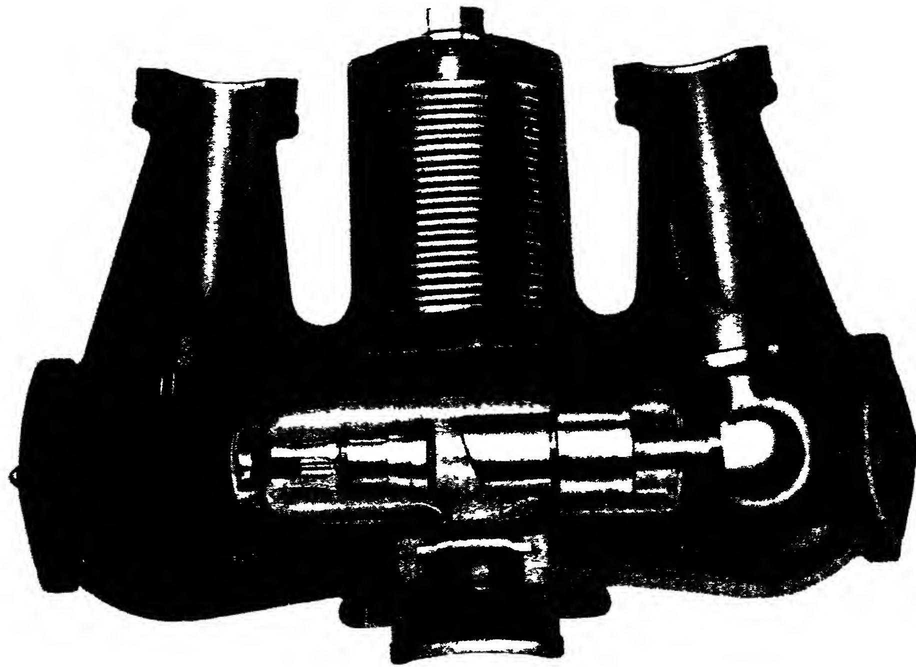


Fig 49 Solus X ray Tube
(Solus Electrical Co Ltd)

of the fact that the X-ray tube is itself a rectifier, the rise in anode temperature after some period in use tended to make the tube pass current in both directions. The type of rectifier used was, more or less, dependent on the application of the tube. A pulsating wave was found best for diagnostic or examination work, while constant current was better for therapeutic purposes.

As the cathode stream in the Coolidge tube was directed on to a small area of the anode, this type was known as a "spot focus" tube. A subsequent type of tube, introduced, among others, by Philips Lamps Ltd., has a "line focus." The target here is electronically in the form of a narrow rectangle or line. These tubes are generally rated from 3 to 10 kW, and various circuits can be used for operation and control. If X-ray tubes are intended to be run for long periods, they are usually cooled.

Modern X-ray Tubes and Equipment. Modern X-ray tubes generally have cathodes of pure tungsten, operated at about

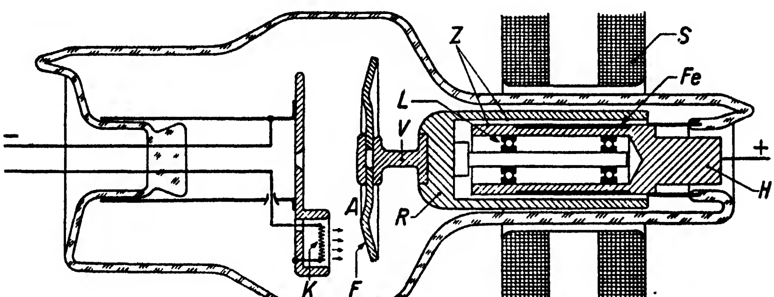


FIG. 50A. "ROTALIX" X-RAY TUBE
(*Philips Lamps Ltd.*)

2 500° K. The Solus-Eureka tube is designed in eight different focal spots, and so is suitable for almost any type of work. It is oil-immersed, and fitted with an outer case of special aluminium alloy, lead-lined inside and out. It weighs 26 lb.

The maximum heat capacity of the Solus-Eureka tube, as measured in kVp × mA × seconds, is 350 000 units. The filtration of the X-ray beam provided by the oil and window is equivalent to 0·5 Al.

Superficial therapy rating is 85 kVp at 5 mA for 20 minutes.

Valve generator and co-ordinator control, suitable for operating up to three tubes, comprise the following equipment—

A high-tension transformer, oil insulated in welded steel tank, in which are housed the filament transformers for the rectifying valves, and filament transformers for the tubes.

A high-tension three-way switch is also fitted for tube selection. On the top of the transformer are provided the sockets for receiving the high-tension shockproof cables to the X-ray tubes.

The control table, which is mounted on easy running castors, comprises –

An auto-transformer for tension control, giving 16 steps for radiography (40-100 kVp) and 5 steps for screening (60-100 kVp voltage compensator).

A master switch for selecting one of the three tubes and one of the five current values chosen according to the tubes to be used. Separate tension controls for radiography and screening are provided so that both can be pre-set, and change over from one to the other is automatic.

A valve time-switch 0·02 to 8 seconds.

An automatic overload protective device, arranged so that any load pre-set which exceeds the capacity of the tube in use is signalled by lamp and buzzer and the set is rendered inoperable. This device does not limit the power in any way; maximum current can be used at any tension and time provided it is within the capacity of the tube.

A master co-ordinating meter, which indicates at a glance which tube is in circuit, and the settings of the three variables—current, kilo-voltage, and time.

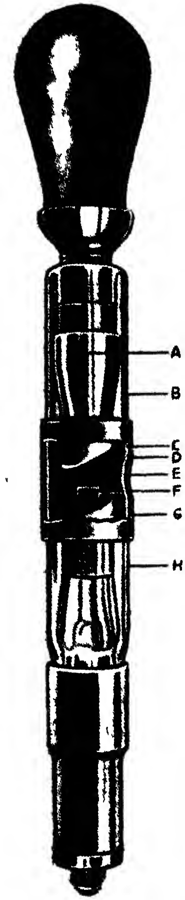


FIG. 50B. HEAVY ANODE INSERT TUBE FOR "METALIX" UNIVERSAL SHOCKPROOF SHIELD

Cooling is effected by thermal storage in a solid metal body, specially shaped to conform with the electric field, and having a blackened surface, from which the heat is continuously dissipated by radiation. In the illustration, part of the centre of tube is cut away, to show its internal arrangement.

(*Philips Lamps Ltd*)

A static stabilizer for compensation of voltage to tube filament.

For the purposes of regulation, the auto-transformer is provided with additional windings in order to compensate for voltage drop at high currents.

A filament switch is fitted for switching out the filaments of valves and tubes to conserve life; also a foot switch for screening, which works on its own contactor. There is a pear switch for

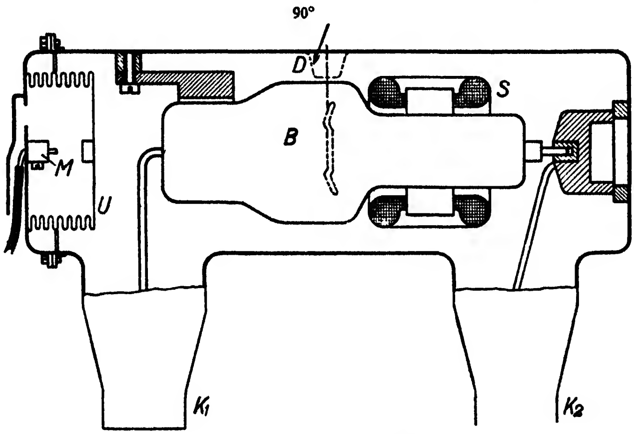


FIG. 51A. HOUSING OF "ROTALIX" TUBE

The *B* tube of Fig. 50 mounted in the metal housing *S* is the stator. At K_1 and K_2 are the connexions for the high-voltage cables. *U* accordion-shaped box for sealing off the oil-filled space. Because of the shape, the oil can expand when warm without appreciably increasing the pressure. If the temperature of the oil rises above a certain value, the compression of *U* closes a switch, *M*, which switches off the supply voltage of the X-ray tube. *D* is a cup made of insulation material (shifted about 90° in position in the drawing) which keeps the oil away from the spot where the X-rays leave the tube. In this way the absorption of the useful X-rays by the oil is kept as small as possible. By making the tube wall and the thickness of *D* small, the filter of the tube with housing is kept small, namely less than corresponds to a thickness of 1 mm of aluminium. The housing is made of iron, with a thin lead covering on the inside to prevent the passage of X-rays.

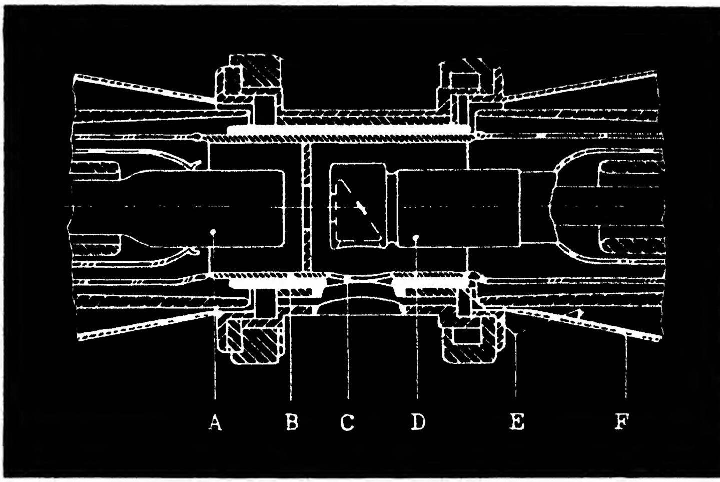
(*Philips Lamps Ltd.*)

radiography exposure. This works on the valve timer and a special contactor. When it is first depressed, all settings are changed from screening to radiography; at the desired instant it is released, and exposure follows immediately. The time switch then returns all settings to screening. No additional delay devices are required for operation of rotating anode tubes. The filaments of both tubes and valves are also "idling" at the low screening values, so that maximum filament life is obtained.

Screening currents are fixed at 3 mA, and radiographic output is 100 kVp maximum tension and 400 mA maximum current.

Industrial Applications. The employment of X-ray equipment for engineering inspection—notably of castings and welds—is well known. For the examination of thin steel plates and light alloys, 200 kV apparatus is sufficient, but in the heavier industries 400 kV sets are often necessary.

During the war, the General Electric Company of America introduced a 1 000 000 volt, 3 mA, mobile X-ray set eminently



A-Cathode — C-Aperture — E-Lead lining
B-Chrome-iron centre part — D-Anode — F-"Metalix" Shield

FIG. 51B. HOUSING OF "METALIX" TUBE

This diagram of the centre part of the "Metalix" insert tube for therapy shows the protection against stray radiation

(*Philips Lamps Ltd.*)

suited to engineering and industrial purposes. A coreless low-frequency resonance transformer, insulated by compressed freon gas, was used in the generator unit, and the power input was about 3·5 kW. The total weight of the apparatus, which was contained in a 4 ft. long sheet steel tank, was 1 500 lb. Sheet steel up to 8 in. thick could be radiographed by this equipment.

Industrial X-ray units that operated at 2 million volts, with focal spots of something like 0·01 in., have been constructed. These large equipments, employing electrostatic type generators, are said to be capable of penetrating 14 in. steel with reasonable duration of exposure. Experiments carried out at Woolwich indicate that this type of apparatus may in the near future be superseded by a new device, the "Betatron."

Crystallography. In addition to being used to detect flaws in metals, X-ray equipment has been employed with great success in crystallographic analysis. This application of X-rays is used, not only in metallurgy, but in the field of organic chemistry.

X-ray crystallography is applied to a considerable extent to routine and process laboratory work, particularly in the fields of ceramics and powder metallurgy. Notable examples of the application of X-ray diffraction are the checking of metallurgical

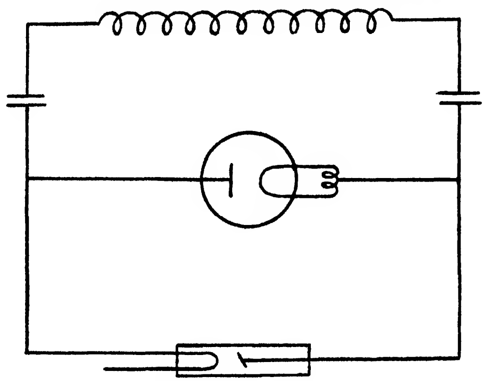


FIG. 52. PULSATING VOLTAGE GENERATOR

reactions and composition, the analysis of crystalline compounds, and identification of minerals present in fluxes.

Visual Inspection of Small Parts. For the visual inspection of small parts (e.g. sparking plugs), a fluorescent screen method is largely used. The image produced on the fluorescent screen is not directly viewed, but is reflected on to an inclined mirror; this is necessary on account of the risk of injury from accidental exposure to the X-rays. Examination of light-alloy castings is sometimes carried out in this way.

High-speed Radiography. Some important research work has been made possible by the recent developments in high-speed radiography. This type of X-ray apparatus employs a modified form of tube used at 100 kV with a maximum load of about 2 000 amps. The necessary time of exposure is in the neighbourhood of 1 microsecond. The high-voltage source is obtained from a bank of capacitors, and the X-ray tube itself has a cold cathode and an auxiliary electrode.

Cine-radiography. The image produced in the fluorescent screen type of apparatus may be photographically recorded on

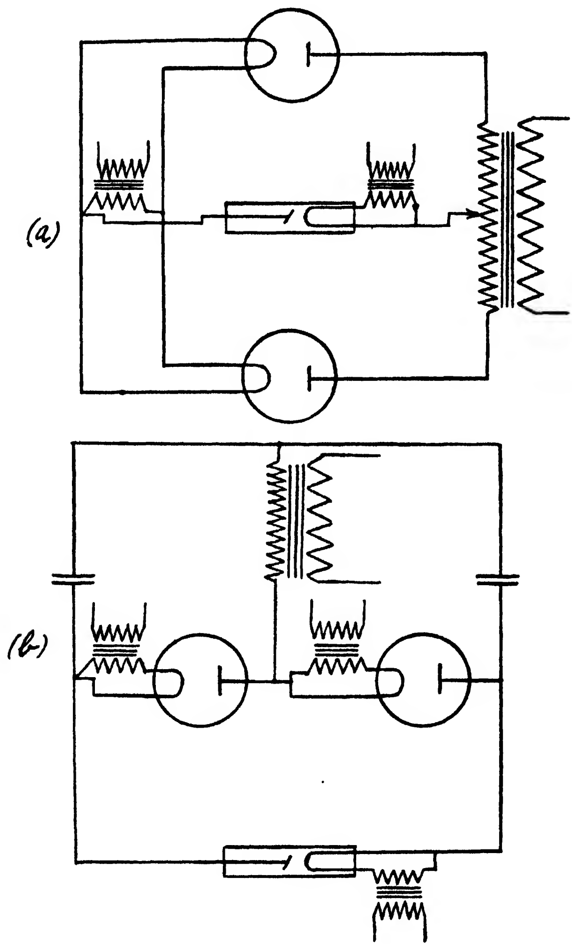


FIG. 53. (*a*) POTENTIOMETER CIRCUIT, (*b*) GREINACHER CIRCUIT

cine film. Thus, a record of changing phenomena can be obtained in the form of serial photographs. The technique of cine-radiography has been used to produce, without the use of any

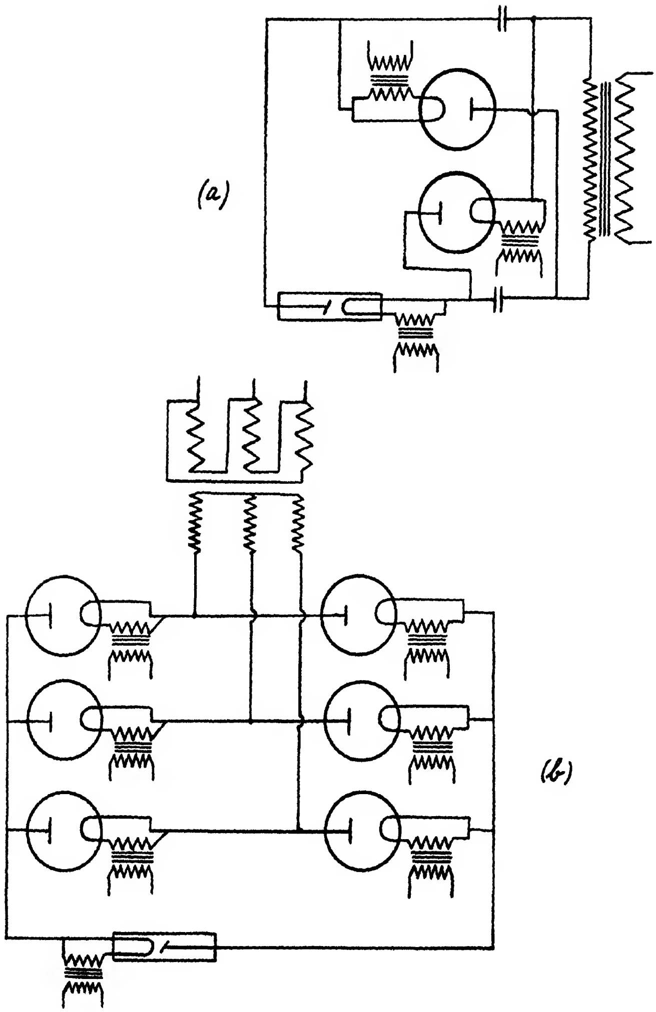


FIG. 54. (a) "WITKA" CIRCUIT, (b) SIX-VALVE THREE-PHASE RECTIFICATION CIRCUIT

intermediate screen or lens system, a continuous record of the drop formation in electric welding.

X-ray Micrography. In X-ray micrography, enlargements are made of radiographs. Prior to the war, this method was utilized to study sodium-silicate bonds in corrugated cardboard.

At the present time, X-ray equipment applicable to the shipbuilding industry is being developed. This, of course, will require very special features in design.

Chapter VII

MISCELLANEOUS ELECTRON TUBES

The devices dealt with under this heading have diverse applications. Some, like the iconoscope, are highly specialized; others, such as neon tubes, have many uses. But in all the fundamental principle is the same, viz., electronic emission.

In view of the many different types of apparatus concerned, most constructional detail has had to be omitted, and only a short description of each device has been possible.

The Iconoscope. Invented by Dr. V. K. Zworykin, the iconoscope employs a combination of thermionic emission, cathode-ray focusing, and photo-electricity for the viewing and conversion of images to be televized. It is fundamentally an electron tube containing a mosaic of tiny photo-cells arranged on a sheet of mica.

The object or scene in the studio is focused by an optical lens on to the mosaic plate. Each photo-cell will thus emit electrons proportionally to the amount of light falling on it. These electrons are collected by the anode and thence conducted, via the cathode-ray beam and the external circuit, to the plate. The cathode-ray scanning is, of course, controlled.

At the back of the photo-cell mosaic is a thin metallic film, so that the device can be considered as a system of small condensers. Since the electronic emission results in a deficiency of charge, each minute condenser unit will store up a charge deficiency according to the illumination it receives; this deficiency is subsequently restored by the cathode rays. In effect, the picture is converted into a system of voltage or current variations in accordance with the illumination changes.

The electrical variations are amplified and transmitted by short-wave radio carrier methods, and the televized scene is re-created on the screens of cathode-ray tube receivers.

The Electron Telescope. This tube, also developed by Dr. Zworykin, can transform images obtained from subjects irradiated by infra-red (invisible) rays, transform them into visible images, and magnify their size. At one end of the tube is a photo-sensitive cathode, and at the other end a fluorescent screen. Contained in the body of the tube are an aperture and a series of anodes which direct the electrons from cathode to screen.

By means of a lens system the image is focused on the cathode, whence it is conveyed as an electron image to the fluorescent screen and converted into a visible image. The electrons, however, during their passage to the screen, are made to diverge by application of various voltages to the electrode system, which thus acts as an "electron lens."

The Electron Microscope. In its simplest form, the electron microscope is a cylindrical tube, coated internally with a fluorescent substance, against which is wound a spiral of wire to act as the anode. Fixed in the centre of the tube, and throughout its length, is a straight wire, the cathode, which is arranged to be heated.

A high voltage applied between anode and thermionic cathode causes electrons to travel radially from the straight wire to the fluorescent coating. At the wall of the tube a magnified image of the wire is created, its size depending on the difference between the diameter of the tube and that of the wire.

Irregularities in the surface of the wire are clearly shown in the magnified image shown on the fluorescent wall of the tube due to the variation in electrode emission, sharp ridges, for example, give greater emission than the even portions.

Electron microscopes used in actual research are naturally much more elaborate, but are based on fundamentally the same principle.

Zworykin's Electron Multiplier. The cylindrical tube of this device contains two sets of plates, the upper set being accelerating anodes and the lower set photo-sensitive cathodes. The individual anodes and cathodes are connected in series, and a high voltage is applied across the first anode and the last cathode, so that every anode is positive with respect to the opposite cathode.

Electrons are liberated by focusing light on to the first cathode. By means of an external magnetic field, the electrons are forced to travel from cathode to cathode, resulting in increasing secondary emission with each impact. The resulting electron stream is finally collected at the last anode and conducted to the external circuit. Assuming a tube with ten cathodes and a secondary emission of five electrons for each impact, the multiplication would be roughly of the order of 2 millions.

The Multipactor Tube. Farnsworth's Multipactor tube contains caesium-coated plates at each end, with a ring anode mid-way between them. In operation, electrons, liberated by the action of light, are attracted both by the anode and by an external magnetic field, and impinge on the opposite plate. Secondary electrons are, therefore, emitted and, owing to the application of high-frequency alternating voltage, build up to a predetermined equilibrium. Once started, and with a battery connected in series with the anode, the tube will deliver an alternating voltage.

The Dynatron. Another tube that may be used as a source of alternating supply is the Dynatron, designed by A. W. Hull.

This device utilizes the collection by a positive grid of secondary electronic emission, and is really a particular application of the tetrode valve or the positive grid triode. Since the secondary emission current may be made larger than the primary plate current, the negative dynamic plate resistance so provided can be used to neutralize positive external resistance. If the external circuit has zero net resistance, oscillatory currents will flow continually.

The Image Dissector. Like the iconoscope, this is an electron tube for converting optical images into electric signals. Invented by Farnsworth, it consists of a tube containing a flat photo-sensitive cathode, on to which the image is optically focused. In this, the whole plate emits electrons at the same time, the number liberated from each particular spot being dependent on its degree of illumination.

The whole of the freed electrons are attracted to an anode situated at the opposite end of the tube and thence focused magnetically in front of a small aperture. At the other side of the aperture is an electron multiplier, which intensifies the electron currents directed to it in scanning sequence.

The Electron-ray Tube. This consists of a triode with a fluorescent target at the top of the bulb. A ray-control electrode is fitted between the cathode and the target.

When electrons strike the target, the fluorescent coating glows and, if the electrons flow to the whole circumference of the target, a ring of light is produced. If, however, the potential of the ray-control electrode is less positive than that of the target, the electrons are repelled by the electrostatic field, and a shadow is cast on the target.

The tube is widely used as a tuning indicator in radio receivers and as an indicator in vacuum tube voltmeters.

The Ionization Gauge. This also is virtually a triode. The grid is operated at positive potential and the plate at a negative potential with respect to the cathode. A small quantity of rare gas is contained in the tube.

The action of the tube depends on the production of an "ion" current at the plate, which is measurable by a meter connected externally. Since this current is directly proportional to the number of ions, which is, in turn, a function of the gas pressure in the tube, the device indicates continuously the vacuum conditions attained during the processing of large electron tubes.

As a rule, the grid is maintained at a positive potential of about 100 volts, and the anode at a negative potential of about 20 volts with respect to the cathode. The filament current is then adjusted to give a grid current of, perhaps, 5 mA which, of course, will vary according to the vacuum pressure of the device being tested.

A calibration constant is generally provided by the makers of the gauge.

The Strobotron. The strobotron, a source of stroboscopic light, is essentially a neon-filled tube with a caesium-coated cathode. It was developed by Germeshausen and Edgerton, and is described as "a stroboscopic light source with control abilities."

A control voltage is applied between two grid structures, causing the discharge to strike up, after which it transfers to cathode spot and anode. No heating is necessary for this cathode, and the apparatus can be operated from batteries.

A form of dual control can be obtained from the two grids by arranging that the discharge starts only when the voltage between each of them and the cathode has a predetermined difference. In addition to its employment in stroboscopic apparatus, this tube can be applied to welding control.

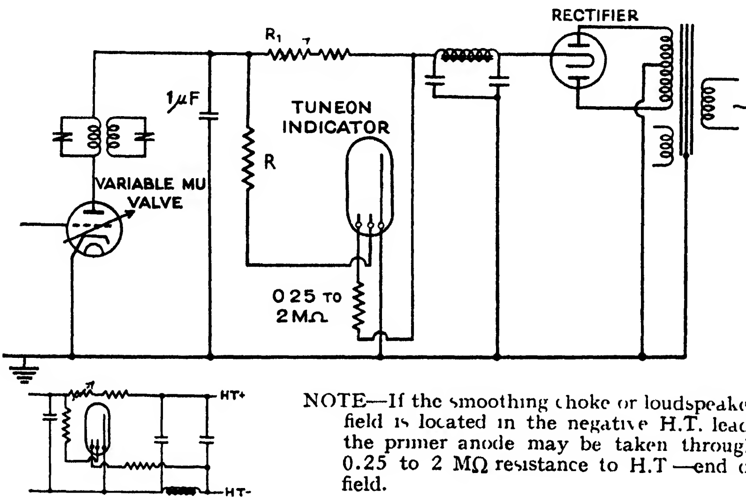
The Tuneon Indicator. The G.E.C. Tuneon indicator consists of a neon-filled tube containing three electrodes, two short and one long. It is intended for use as a visual indication of the correct tuning point in an A.V.C. receiver.

On a small current being passed through the tube, a luminous glow appears on the main electrode (cathode). If the tube is connected in a suitable circuit, in conjunction with automatic volume controlled variable-mu valve, correct tuning is indicated when the glow is of maximum length.

A voltage of about 180 volts is required between the anode and the main cathode to produce maximum glow (i.e. completely to cover the cathode). The current in these circumstances will be about 1·4 mA. The glow commences at 0·15 mA. The voltage across the tube for minimum glow is roughly 165. The indicator should therefore be used in a valve anode circuit where there is about 0·1 mA or less on the strongest station, with full A.V.C. volts, which increases to about 1·5 mA on the weakest stations before A.V.C. has commenced. The length of glow obtained on the strongest station can be controlled by a variable resistance in series with the anode and having a maximum value from 20 000 to 80 000 ohms depending upon the H.T. voltage available. Either this resistance should have a definite minimum or else a fixed resistance of about 5 000 ohms should be in series with it. The variable resistance may be of the pre-set type requiring little adjustment once it has been adjusted in any given circuit.

The resistance should never be reduced below a value sufficient to give a full length glow on the strongest station required. If an excessive brightness of glow is permitted under this condition, the life of the tube may be appreciably shortened.

A fixed resistance must be inserted in the circuit if, as will usually be the case, the range of current variation obtained from



NOTE—If the smoothing choke or loudspeaker field is located in the negative H.T. lead, the primer anode may be taken through 0.25 to 2 MΩ resistance to H.T —end of field.

FIG 55. "TUNEON" INDICATOR
(*General Electric Co. Ltd.*)

the valve is greater than that required by the tube. The value of this resistance may be 10 000 to 60 000 ohms.

Barretters (Current Regulators). Osram barretters are designed to maintain the current passing through them substantially constant within certain limits, although fluctuating values of voltage be applied across the barretters in series with the load.

These devices may thus be employed with advantage to obviate the necessity for external tapped resistances in receivers operating from A.C. or D.C. mains in which the valve heaters are wired in series and the full heater current is drawn from the mains without (in A.C. mains) the intervention of a filament transformer.

Osram barretters for use with 0·3 amp valves are supplied in

OSRAM 0.3 AMP. BARRETTERS

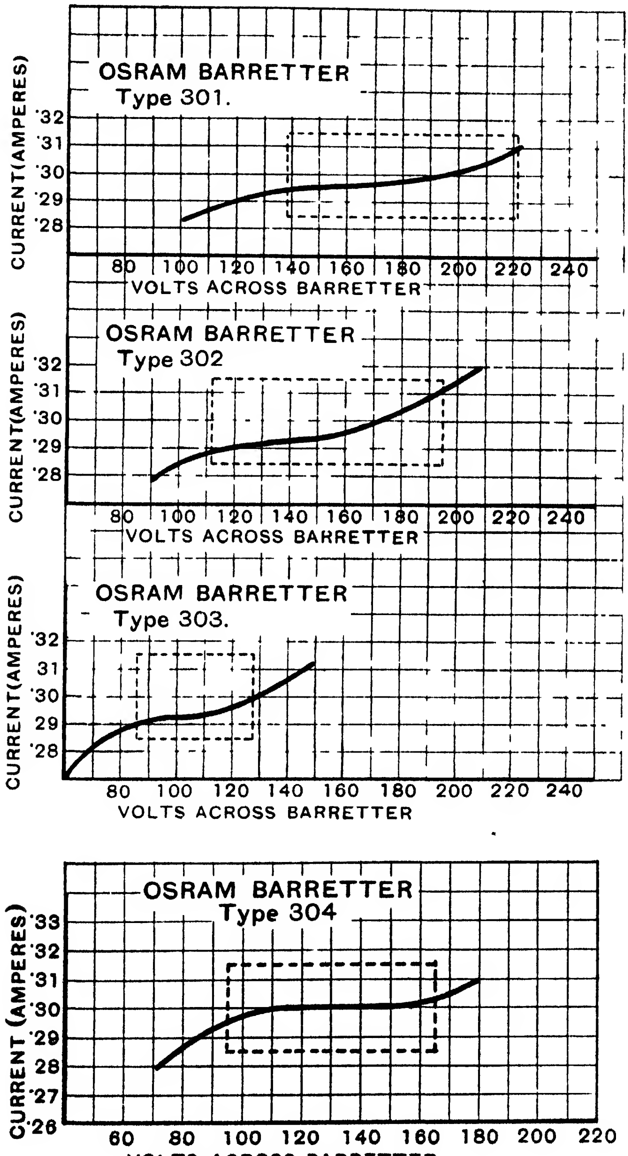


FIG. 56. BARRETTER CHARACTERISTICS

four types as under-

Type 301.	Voltage range	138–221
Type 302.	,, ,,	112–195
Type 303.	,, ,,	86–129
Type 304.	,, ,,	95–165

Barretters, Types 301, 302, and 304, accommodate the regulation of from three to seven 0·3 amp heaters in series respectively for a mains supply of from 190 to 260 volts. In the barretter Type 303, however, when employed on a voltage supply of from 230 to 260 volts, a small additional series resistance of approximately 150 ohms is required.

In operation, ample air circulation should be allowed round barretters. Care should be taken in handling, as the bulb becomes hot on circuit and remains so for some time after the current is switched off. Approximately five minutes should be allowed for a barretter to settle to its steady current regulation.

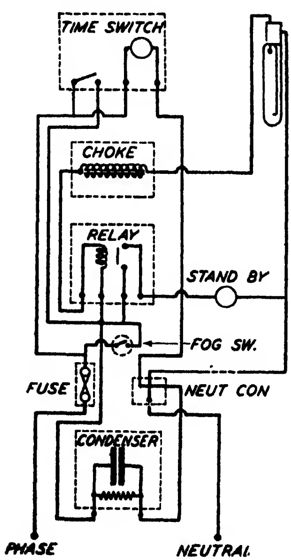


Fig. 57. Wiring Diagram for Electric Discharge Lamp

(Edison Swan Electric Co. Ltd.)

Discharge Lamps. Although they are definitely electronic devices, a description of the different types of discharge lamps would be redundant here, since there are already many treatises on this subject. The later developments in this type of lamp are the high-pressure mercury-vapour lamp and the 5 ft. long fluorescent lamp. In the former a relatively small, but intensely brilliant, cord of bluish-white light is produced by a low-voltage discharge in mercury vapour at high pressure. The fluorescent tubular lamp makes use of the fact that invisible ultra-violet radiation may be converted into visible light of an "off-white" colour by applying a mixture of luminescent powders to the interior wall of the discharge tube. Recently, a so-called "warm-white" lamp has been introduced which, by modification of the fluorescent powder mixture, provides a more cheerful light output for situations where colour rendering is unimportant.

The electronic sources of light described herein are the less familiar types which are not usually included under the heading "lamps."

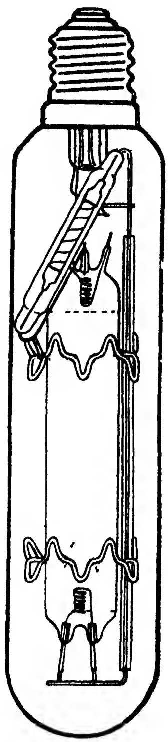


FIG. 58. 150-WATT MERCURY-VAPOUR DISCHARGE LAMP (*B.T.H. Co. Ltd.*)

FIG. 59. "OSIRA" HIGH PRESSURE MERCURY LAMP (*General Electric Co. Ltd.*)

Neon Tubes. The term "neon tube," although frequently a misnomer, is now applied generally to high-voltage cold-cathode discharge tubing as used for illuminated sign purposes.

A neon tube consists essentially of a length of soda, lead, or pyrex glass tube, usually of from 9 to 30 mm diameter, fitted with a hollow cylindrical metal electrode at each end, de-gassed, exhausted of air, and filled with rare gas at low pressure (sometimes with the addition of a small quantity of mercury). Such a tube may be straight, curved, or in conformity with any desired contour.

The shaping of the tubes is carried out by coal gas with compressed air burners where soft glasses are used, but a flame enriched with oxygen is required for borosilicate glass. Tubing

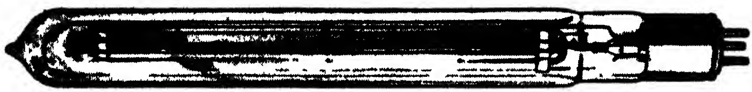


FIG. 60. SODIUM VAPOUR DISCHARGE LAMP
(*General Electric Co. Ltd.*)

FIG. 61. ULTRA-VIOLET "BLACK" LAMP
(*General Electric Co. Ltd.*)

coated internally with fluorescent powder is bent after being treated with the luminescent substance.

After being bent (if necessary) and fitted with an electrode at each end, the tubing is sealed on to the manifold system. For most purposes a rotary vacuum pump alone is adequate for exhausting. In addition to the pump line, the manifold will include connexions to rare gas containers, moisture trap and gauge, and will be controlled by a sufficient number of stopcocks.

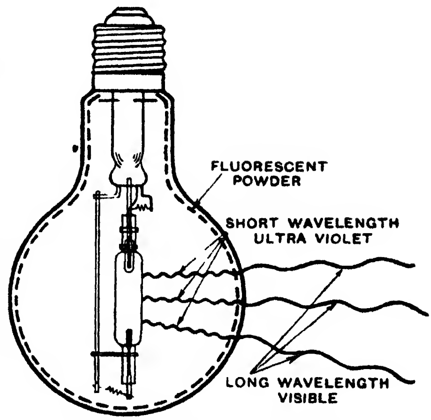


FIG 62. EFFECT OF FLUORESCENT POWDERS
(*General Electric Co. Ltd*)

Liberation of extraneous gases from glass wall and electrode metal is carried out as a rule by internal bombardment, an oil-filled transformer being used. However, an alternative method of de-gassing electrodes, which is particularly advantageous in the case of oxide-coated electrodes, consists of heating the metal by high-frequency eddy currents.

The de-gassed and exhausted tube is filled with spectroscopically

FIG. 63. FLUORESCENT LAMP
(*General Electric Co. Ltd.*)

pure rare inert gas (usually either neon or argon) at a pressure of something like 10 mm Hg.

Most neon tubes for advertisement display purposes are operated by high-voltage step-up transformers. Since the voltage required to strike up the discharge is very much in excess of that necessary to maintain it, the transformers must be designed with poor regulation. For outside situations, either oil- or compound-filled transformers in sheet steel cases may be used: the wiring from the secondary terminals must be carried out in special lead-covered high-tension cable.

The application of neon tubing is by no means confined to sign work. The long life, flexibility, and low surface brightness of the tubes make them admirable for certain types of interior lighting. During the war, "cold-cathode lighting," as it was termed, gained a certain amount of popularity—particularly in the U.S.A.

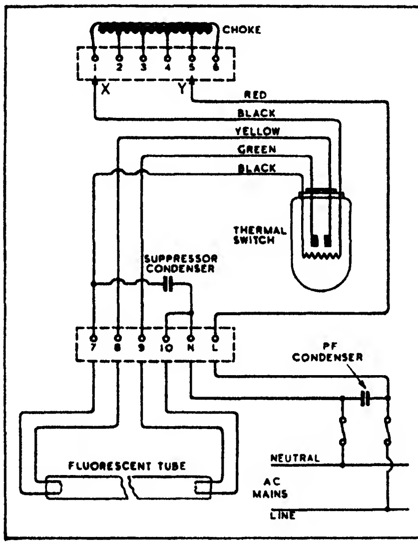


FIG. 64. CIRCUIT DIAGRAM OF FLUORESCENT LAMP
(*Edison Swan Electric Co Ltd*)

Neon Tube Beacons. Heated cathodes were used for this type of tubing, which, of fairly large diameter, was operated at currents as high as one ampere (in contrast with the ordinary neon sign tubing, which was usually run at from 15 to 35 mA).

The beacon tubes were often bent U-shaped, or in the form of a spiral or some other design, to concentrate the radiation. In some cases, large numbers of such tubes were assembled in a single beacon.

Some years ago, the Air Ministry installed straight neon tubes on each side of an aerodrome run-way. Several tests under different conditions were made, and an observer in a balloon reported that in foggy weather the tubes were visible at a height at which all other ground illumination had disappeared.

One beacon, erected in the U.S.A., was said to be of 500 000 000

FIG. 65. FLUORESCENT LIGHTING IN DESIGN DEPARTMENT
(*General Electric Co Ltd*)

spherical candle-power and to have been visible for a distance of over 100 miles.

Interior Decorative Lighting. Cold-cathode neon tubing was found to form an excellent medium for interior decorative lighting in restaurants, cinema and theatre foyers, etc. By the use of the tubing as a subsidiary to the general lighting scheme, many attractive effects can be obtained when the tubing is designed to harmonize with the interior decoration Neon tubes, being of

FIG 66 FLUORESCENT LIGHTING IN ASSEMBLY DEPARTMENT
(*General Electric Co Ltd*)

reasonably small diameter, can be fashioned into almost any desired outline.

One instance of a decorative lighting display is the luminous frieze. Usually in this type of installation the neon tubing is mounted direct to frieze panels of some fire-resisting material, provision being left behind for housing the transformers and high-tension wiring and connexions. Hinged doors, or sliding panels must, of course, be provided, to permit ready access by maintenance engineers. In view of the high voltage necessary to strike and operate the tubing, special precautions are taken in an

FIG. 67. FLUORESCENT LIGHTING IN MACHINE SHOP
(*General Electric Co. Ltd.*)

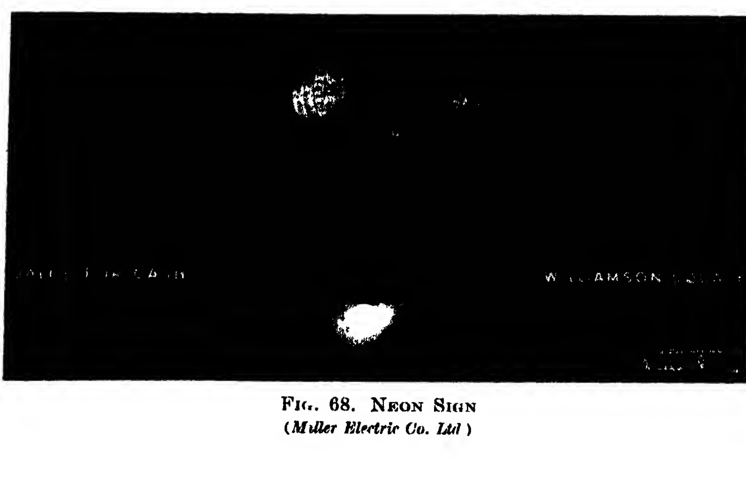


FIG. 68. NEON SIGN
(*Miller Electric Co. Ltd*)

installation of this kind and, before the war, some authorities were reluctant to approve of such a scheme.

A neon tube interior lighting installation can be effectively dimmed by means of adjustable chokes. Also, by separately controlling each colour, the harmony of the scheme can be varied at will. In hot weather the predominant colour should be blue, in order to create a cool atmosphere, while in the winter-time reddish illumination gives the impression of warmth.

By thyratron reactor control coupled to a microphone, the decorative lighting could be made to change according to the frequency of musical notes emitted, thus creating a light of changing mood in sympathy with the orchestra.

Floodlighting. The introduction of the G.E.C. Osira red floodlighting was yet another instance of the application of neon tubing. In comparison with the old method of using incandescent lamps

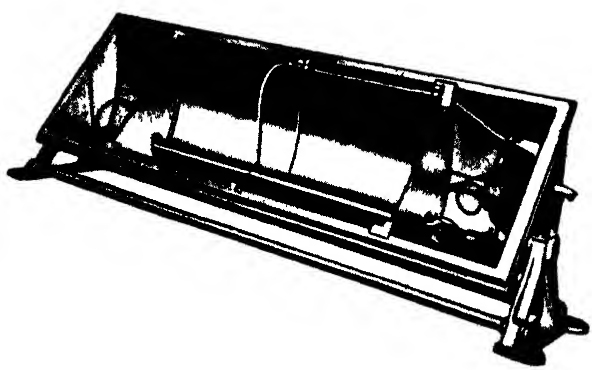


FIG. 69. FLOODLIGHTING DISCHARGE LAMP
(*General Electric Co. Ltd.*)

in conjunction with gelatine or glass filters, the neon discharge tube shows an increase of over 100 per cent in lumens per watt efficiency. Apart from this, the colour is very much more vivid and is constant throughout the life of the tube.

The Osira neon tube is a hot-cathode device consuming approximately 470 watts. It is 34 in. long and requires a Tesla coil, a filament transformer, and a choke for its control. The Tesla coil and transformer are accommodated in the floodlight housing, while the choke can be placed in any suitable position between the floodlight and the main control board. The power factor of

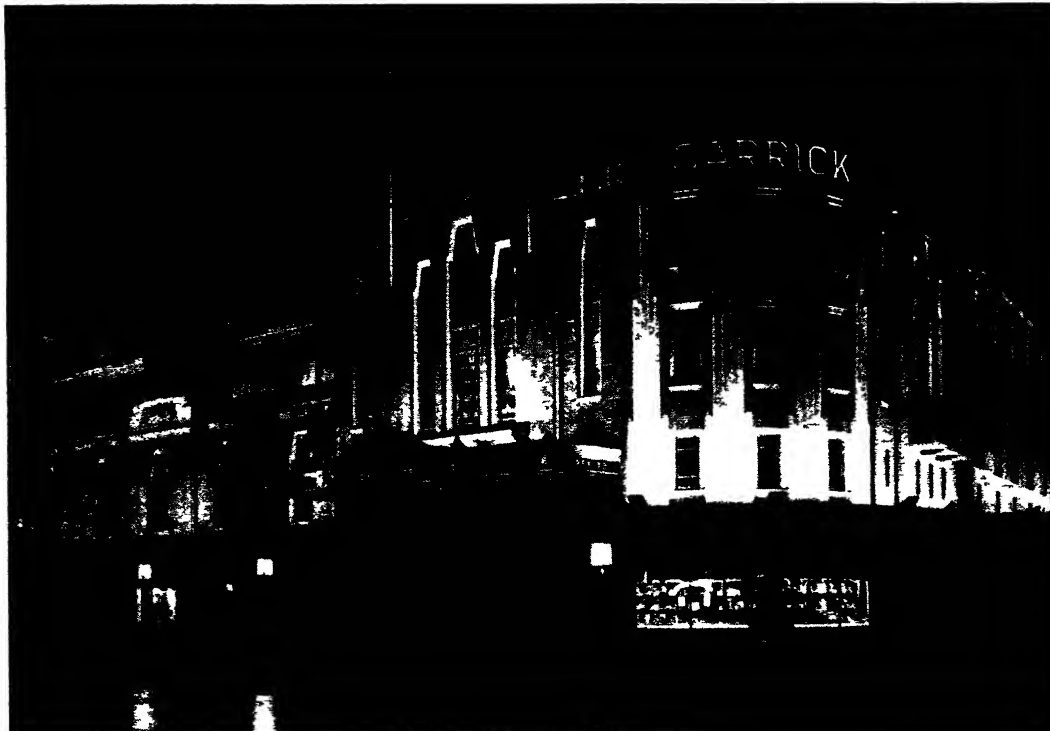


FIG. 70. DISCHARGE TUBE FLOODLIGHTING OF GARRICK THEATRE, SOUTHPORT, LANCS
(General Electric Co Ltd)

FIG 71 'OSIRA" COLOUR FLOODLIGHTING OF NEW BRIGHTON, CHESHIRE BATHING POOL the apparatus is roughly 0·3, but on a 50-cycle supply this can be improved to about 0·8 by connexion of an 80 μF condenser.

Plant Irradiation. Another application of hot-cathode neon tubing is the irradiation of hot-house plants. This device, manufactured by Philips Lamps Ltd., is 25 in. long, consumes about 100 watts, and has an effective surface cover of 28 in. square when used in accordance with instructions

Plants irradiated by neon tubing are found to have much greater resistance against disease, and the development of seedlings is vigorously stimulated. The beneficial effect of the radiation is perceptible for some time after the irradiation has ceased.

The neon tubes are fitted into elongated reflectors so that the radiation is directed on to the plants. The suspension height of the irradiator may be varied to suit various plants and situations. Illumination values obtained from the Philips equipment are tabulated below –

Irradiation	Distance from Rim of Reflector to Leaves (approximately)	Illumination in Foot candles (Neon Tube)
Weak	7 ft	10 30
Medium	5 ft	30 70
Strong	3 ft	70 130
Very Strong .	2 ft	over 130

Safety Fuses. Another application of the cold-cathode type of neon tubing is the "tell-tale" fuse. This consists merely of a short tube fitted with an electrode at each end and containing neon gas at low pressure. Advantage is taken here of the comparatively high striking voltage of the tube compared with that necessary to maintain the discharge.

The tube is connected in the high-voltage circuit (usually to protect a sensitive instrument) and normally is not illuminated. If an abnormal voltage surge occurs, the neon discharge strikes and warns the operator that a fault has developed. At the same time, the voltage across the instrument is reduced to a safe value.

Testers or Probes. The neon tube element of these instruments is an extremely small tube, with only one electrode—usually a straight wire. It is designed to glow when the live wire of a 200–250 volt A.C. supply is in contact with the electrode, the other end of the tube being earthed by application of the finger.

There are several uses for this kind of tube. It can be made up in the end of a screwdriver as a means of ascertaining the live pole in testing electrical installations. It can also be housed in a fuse-carrier as an indicator on normal A.C. mains.

Larger adaptations of this tube are used as a kind of current-measuring device in radio-frequency circuits, the length of the glow providing an indication of the relative current. Known as "internal-electrode-glow" tubes, these are employed in testing sparking-plugs, ignition coils, diathermy radiations, radio transmitter tuning, and the insulation efficiency of high-tension cables.

APPENDIX

SOME PIONEERS OF ELECTRONICS

A.D.		
140	PTOLEMY .	. Astronomical refraction and reference to magnetism.
1302	GIOIA . .	. North-pointing compass needle.
1473	DE BEAUVAIS	. Magnetic North and South poles.
1663	BOYLE. .	. Observation of light from rubbed diamonds.
1671	VON GUERICKE	. Invention of air pump.
1672	NEWTON .	. New theory about light and colour and emission of light.
1672	PICARD .	. Observation of light in Torricellian tube.
1675	HAWKSBEE .	. Emission of light by passing air through mercury.
1684	CASSINI .	. Zodiacal light.
1705	BERNOULLI .	. Path described by ray of light passing through strata.
1750	NOLLET .	. Luminous discharges in partially exhausted glass bulb.
1751	WATSON .	. Luminous discharge in highly exhausted tube 3 ft long.
1755	MORGAN .	. Non-conductive vacuum and green fluorescence with air.
1765	FRANKLIN .	. Investigation of lightning.
1782	HAUY . .	. Piezo-electric effect.
1783	CAVENDISH .	. Discovery of a new gas (later identified as argon).
1785	COULOMB .	. Leakage of electricity through air.
1822	DAVY . .	. Discharge through highest vacuum then obtainable.
1838	FARADAY .	. Cathode dark space, and liquifaction of gases.
1850	MATTEUCCI .	. Different rate of escape of electricity for gas pressures.
1850	RHUMKORFF.	. Coil.
1855	PLUCKER .	. Luminescence due to low pressure discharge.
1862	GEISSLER .	. Observation of beautiful luminous effects.
1868	RAYLEIGH .	. Discovery of helium.
1874	STONEY .	. Electron.
1876	JABLOCHKOV	. First practical form of arc light.
1879	CROOKES .	. Low pressure discharge tube.
1886	HERTZ. .	. Length and speed of electro-magnetic waves.
1886	MAXWELL .	. Electro-magnetic theory of light.
1883	EDISON .	. "Edison" effect.
1884	LODGE. .	. Speed of the ion.
1893	RAMSAY .	. Discovery and identification of argon.
1894	MOORE .	. Nitrogen and carbon-dioxide discharge tubes.
1895	RÖNTGEN .	. Discovery of X-rays.
1896	BECQUEREL .	. Discovery of radio-activity.

1897	THOMSON	Theory of positive nucleus and negative electrons.
1898	RAMSAY	Discovery of neon, krypton, zenon.
1898	CURIE	Polonium and radium.
1898	ZELENY	Mobility of negative ions.
1899	RUTHERFORD	Alpha, beta, gamma rays.
1901	PLANCK	Law of radiation.
1901	COOPER-HEWITT	Mercury vapour lamp.
1901	WILSON	Rate of leakage of electricity through gases.
1901	TOWNSEND	Coefficient of diffusion of ions.
1901	GEITEL	Conductivity of electricity through gases.
1902	SODDY	Generally accepted theory of radio-activity.
1903	LANGEVIN	Variation of "coefficient of recombination" with press.
1904	WEHNELT	Cylindrical electrode of oxide-coated filament.
1904	MOORE	First CO_2 tube installation for "New York World."
1904	FLEMING	Thermionic valve.
1906	DE FOREST	Grid.
1907	ROSING	Cathode-ray tube.
1908	SWINTON	Development of cathode-ray tube.
1908	FRANCK	Velocity of ion.
1909	ERIKSON	Variation of "coefficient of recombination" with temp.
1909	THOMSON (J. J.)	Variation in electrical force along discharge.
1910	PHILLIPS	Variation with temperature of recombination.
1910	CLAUDE	Demonstration of neon tubes at Grand Palais, Paris.
1912	McCLENNAN	Conductivity of gas.
1912	GAEDE	"Molecular" pump.
1913	BOHR	Application of quantum theory to structure of the atom.
1914	LANGMUIR	Grid-controlled mercury arc rectifier.
1918	LANGEVIN	Generation and reception of supersonic waves.
1922	CODY	Master oscillations.
1924	HERTZ	Sodium vapour lamp.
1928	THOMSON (G. P.)	Wave nature of electrons.
1930	LANGE	Photo-electric cell.
1932	CHADWICK	Discovery of neutron.
1933	BLACKETT	Discovery of positron.
1933	ADAMS	Variations in electric discharge tube by oscillatory circuit control.
1934	FISCHER	Luminescent glass tubing.
1936	SCHALLREUTER	"Ripple" tubes.

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