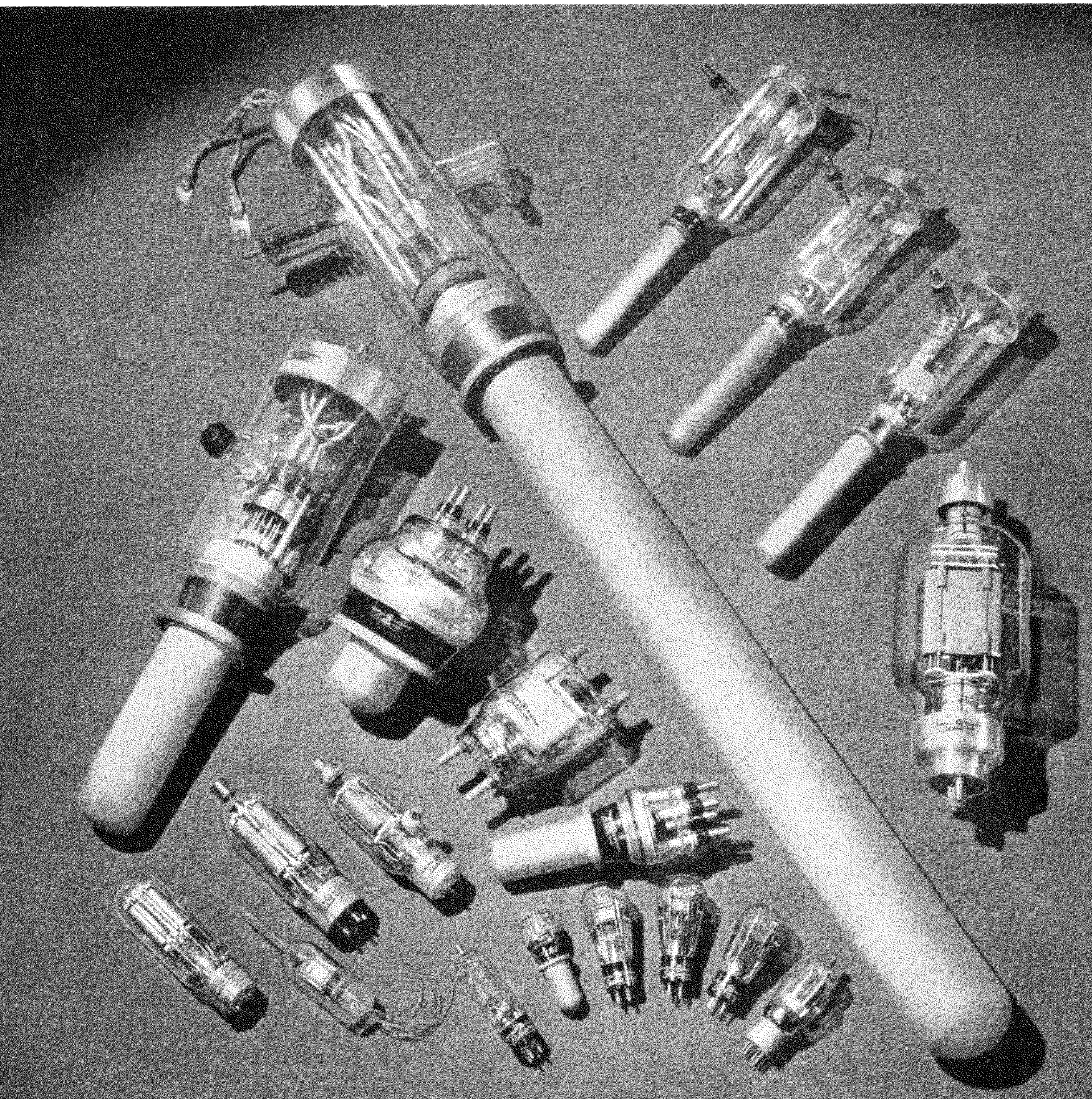
GENERAL ELECTRIC

PLIOTRONS



DESCRIPTION

A pliotron is a high-vacuum thermionic tube in which one or more electrodes are employed to control the unidirectional current flow.

The succeeding paragraphs will describe the fundamentals of operation, ratings, classes of tubes, applications, maintenance and operation as well as other qualities which render these tubes particularly useful to industry.

FUNDAMENTALS OF THE PLIOTRON

The pliotron is a high-vacuum tube similar to the two-electrode kenotron. The difference lies in the addition of a grid or grids to control current flow to the anode (or plate). In a kenotron rectifier the amount of current which can be passed through the tube at a given positive plate voltage is limited by the building up of a negative space charge around the filament or cathode, caused by the electrons which are leaving it. If a positively charged grid is now interposed between filament and plate, this negative space charge is partially neutralized and more current is allowed to flow to the plate at the same plate potential. Conversely, if the grid is negatively charged, the current is decreased. If the grid is made sufficiently negative, the current flow can be completely cut off. Between the cutoff value of grid voltage and the maximum positive value of grid potential to which it is safe to go, the control of the grid over the plate current is continuous. Since the grid is located closer to the filament than is the plate, a given change in grid potential has a greater effect on plate current than an equal change of plate potential. Thus, the pliotron can be used to amplify voltage variations. If the variations of grid potential are maintained in the negative region, substantially no electrons can flow to the grid, so that it is possible to control considerable amounts of power in the plate circuit with the expenditure of very small amounts of power in the grid circuit. The pliotron can, therefore, be used as a very sensitive device.

Since the pliotron can amplify power, it is possible to make it generate sustained oscillations by feeding back a fraction of the power in the plate circuit to the grid circuit. Such an arrangement is commonly termed an oscillator.

From the foregoing discussion, it can be seen that pliotrons may be used in a variety of ways. No one design is best fitted for all of these uses, each is designed for particular types of service, and a wide variety is available.

Since a pliotron is exhausted to a high degree of vacuum, its operation is not limited by the vapor pressure of a condensable medium within and the permissible range of ambient temperature is thereby increased. Unlike gas-or vapor-filled grid-controlled tubes, the pliotron is designed to control both the starting and stopping of plate current and may be used to generate or control very high frequencies. It is, therefore, possible to obtain continuous control of plate current even with a positive d-c plate potential.

DEFINITIONS OF HIGH-VACUUM TUBE RATINGS

General

When the terms used in the rating of high-vacuum tubes are considered, it is important to realize that the application of the limits and values given for a particular tube depends upon the operating conditions. Any nominal rating can apply to one set of conditions and not to all the conditions encountered in practice.

For certain high-vacuum tubes two sets of ratings are given one designated as CCS (Continuous Commercial Service) and the other as ICAS (Intermittent Commercial and Amateur Service).

The former are for use in applications where the prime consideration is reliability of performance and long life. The latter can be used in applications where the service is intermittent in nature, i.e., where the operating period does not exceed five minutes and where this period of operation is followed by a standby period of at least the same duration. Although ICAS ratings are higher than those recommended for CCS and permit the use of greater power they do result in a decrease in tube life below what may be expected with CCS operation.

The cathode or filament information is given in terms of normal heating voltage. A current figure to indicate transformer rating is also given. The filament or cathode, except in unusual cases, should always be operated at this rated voltage rather than at rated current and the voltage should be adjusted so that the normal fluctuation in line voltage averages around this point. Normally, when this is done a plus or minus variation of five per cent heating voltage is allowable.

The maximum plate voltage of a pliotron is the highest d-c plate voltage which the pliotron can safely withstand. Equipment using these tubes should be so designed and operated that under no conditions will this value of plate voltage be exceeded. It is, therefore, desirable, when selecting a pliotron for a particular application to determine the changes in filament voltage and plate voltage that may be caused by line voltage fluctuation, load variation and manufacturing variations in the associated apparatus. Then, choose an average value of plate voltage so that under the usual operating conditions, the maximum rating will not be exceeded.

The grid ratings are given in terms of the maximum grid voltage and grid current that may be used for a particular class of service.

The plate dissipation rating is determined by the safe operating temperature of the plate which in turn is usually determined by the degree of evacuation possible with the anode material used.

In addition to these ratings there are a number of other tube characteristics. The amplification factor is the ratio of change in plate voltage to a change in control-electrode voltage under such conditions that the plate current remains unchanged and all other electrode voltages remain constant. It is a measure of the effectiveness of control-electrode voltage relative to that of the plate voltage upon the plate current.

The grid-plate transconductance is the quotient of the in-phase component of the alternating current of the plate by the alternating voltage of the grid, all other electrode voltages being maintained constant.

The resonant frequency is the frequency of the grid-plate circuit with the grid and plate of the tube connected together through the shortest possible lead.

The ratings for a particular pliotron are given on the Description and Rating Sheet for that tube.

Classes of Pliotrons

There are three general classes of pliotrons:

1. Radiation-cooled pliotrons, usually of the glass-envelope type.
2. Forced-air-cooled pliotrons which usually have a radiator to aid in dissipating heat. Such tubes are cooled by an air flow directed against the radiator.
3. Water-cooled pliotrons in which the plate is cooled directly by a flow of water.

APPLICATION CIRCUITS#

Pliotrons are useful in most applications requiring the generation or amplification of audio- or radio-frequency voltages, as well as in many applications which require accurate measurement of small signal voltages and their amplification for control purposes.

The great majority of pliotron applications are covered by six classes of operation designated as Class A audio-frequency, Class AB audio-frequency, Class B audio-frequency, Class B radio-frequency, Class C radio-frequency plated-modulated, and Class C radio-frequency amplifier and oscillator. All pliotrons are not necessarily recommended for each class of service. Some tubes are designed for only one or two classes of service while others may be rated for all types of service.

A Class A amplifier is an amplifier in which the grid bias and alternating grid voltages are such that plate current in a specific tube flows at all times. This class of service gives a large ratio of power amplification but with relatively low efficiency and low output. A typical single tube Class A amplifier is shown in Fig. 1.

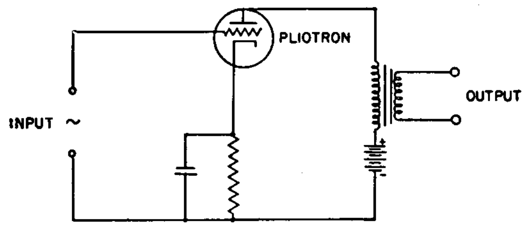


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Fig. 1—Single Tube Amplifier, Class A

A Class AB audio-frequency amplifier is an amplifier in which the grid bias and alternating grid voltages are such that plate current in a specific tube flows for appreciably more than half but less than the entire electrical cycle. This class of service produces a ratio of power amplification and an efficiency intermediate between a Class A and a Class B amplifier. (See Fig. 2.)

A Class B audio-frequency amplifier is an amplifier in which the grid bias is equal approximately to the cutoff value so that for a specific tube, plate current flows for approximately one-half of each cycle with an alternating grid voltage applied. In this service two tubes are used in a "balanced" circuit, each tube conducting only half of the time. This class of service gives a relatively large ratio of power amplification with medium efficiency and output.

Fig. 2 illustrates a typical push-pull circuit which may be used in Class A, AB or Class B amplifier operation.

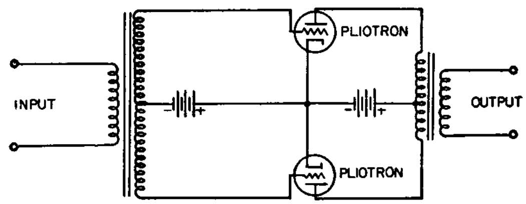

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Fig. 2—Circuit Diagram of Push-pull Amplifier

A Class B radio-frequency amplifier is an amplifier in which the plate is supplied with unmodulated direct voltage, and the grid is excited by modulated radio-frequency voltage. Such an amplifier gives a relatively large ratio of power amplification with medium efficiency and output.

A Class C radio-frequency amplifier—plate modulated, is an amplifier with the plate supply

 # Circuits shown in ETI-156 are examples of possible tube applications and the description and illustration of them does not convey to the purchaser of tubes any license under patent rights of General Electric Company.

Fig. 2—Terman, F. E., Radio Engineering, P-305; McGraw-Hill Book Co., Inc., 1937

voltage modulated so that the tube output is modulated radio-frequency. For this type of service the grid bias is approximately the same as for a Class C amplifier or oscillator. Assuming a value, P, of plate input power to be modulated, the amount of audio-frequency power to be supplied is equal to $\frac{m^2P}{2}$ where m is the modulation factor. For further information consult the Description and Rating Sheet for the particular type tube in question.

A Class C radio-frequency amplifier or oscillator has the grid bias appreciably greater than the cut-off value so that the plate current in each tube is zero when no alternating grid voltage is applied, and so that the plate current in a specific tube flows for appreciably less than one-half of each cycle when an alternating grid voltage is applied. Such an amplifier gives high efficiency and output with a relatively low ratio of power amplification.

A typical example of a Class C amplifier is given in Fig. 3 which illustrates a direct-coupled Class C amplifier with fixed bias, capacitively coupled load and Rice neutralization (which is a method of neutralizing the effects of the interelectrode capacitance of the tube). Fig. 4 illustrates a neutralized Class C push-pull amplifier with grid-leak bias and an inductively coupled load.

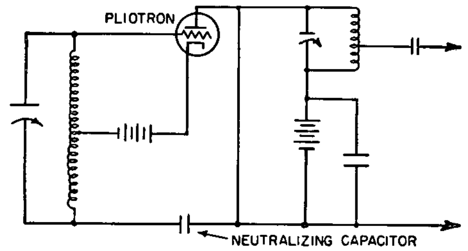

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*Fig. 3—Direct-coupled Class C Amplifier with Fixed Bias, Capacitively Coupled Load and Rice Neutralization

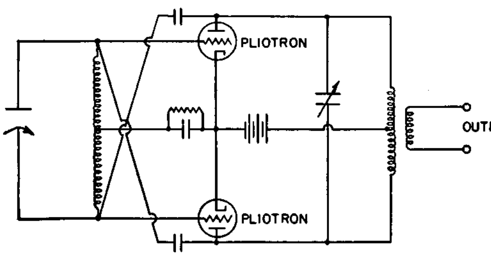

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*Fig. 4—Neutralized Class C Push-pull Amplifier with Grid Leak Bias and Inductively Coupled Load

When selecting a tube for a particular application and consequently a particular class of service, it is, of course, necessary to be certain that the requirements of the application are within the maximum ratings of the tube as given in the Description and Rating Sheet. The maximum ratings should not be exceeded if satisfactory performance and life are to be realized. The typical values given are not to be considered as ratings, because the tube may be used at any suitable condition within the maximum ratings to secure the required output. The output values are approximate tube outputs, i.e., tube input minus the plate loss. When useful output is calculated, circuit losses must be subtracted from tube output. For this reason the typical values of power output are not to be considered as ratings. The approximate values of grid driving power shown under typical operating conditions are calculated values for a particular instance only and do not include power lost in the circuit or in the bias resistors.

It is advisable to provide sufficient driving power in excess of the circuit losses plus the minimum tube requirements in order to cover the different conditions of operation in the particular application. This is particularly true when the frequency is above that at which full plate input may be employed. It is of course understood that at all times the driving power must be such as not to exceed the maximum allowable peak grid voltage or the maximum d-c grid current. In general, radio-frequency circuits should be arranged to prevent parasitic oscillations so that the tube will not be subjected to excessive voltages and currents. The arrangement of apparatus adjacent to the pliotrons, particularly in the case of high-power or high-frequency applications, should be such that the glass envelope is not subjected to concentrated voltage stress.

The above considerations in the design of radio-frequency circuits, such as the electronic heating and diathermy circuits to follow, will be repaid by increased operating efficiency.

The electronic heating (or induction heating) circuits illustrated in Figs. 5 and 6 are typical of applications in which pliotrons are used extensively.

In the coupled-grid circuit, Fig. 5, the voltage is developed across a coil inductively coupled to a portion of the resonant circuit. By proper connections this voltage can be phased nearly 180 degrees, but due to the resistance inherent in any inductance, this phasing must be corrected in many cases by adding a phase-correcting capacitor.

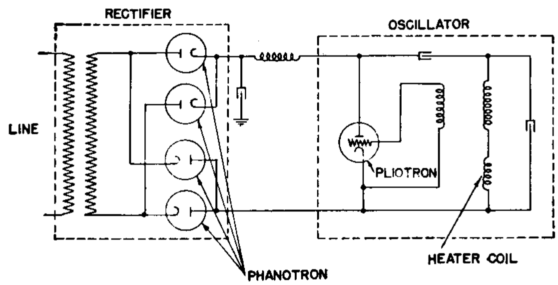

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Fig. 5—Basic Coupled-grid Oscillator Circuit as Used for Induction Heating

*Reference for Figs. 3 and 4—Terman, F. E., Radio Engineering, P-322, McGraw-Hill Book Co., Inc., 1937

In the Colpitts circuit (Fig. 6) the grid voltage is obtained by direct connection to the resonant circuit by splitting the capacitor into two series sections. If the plate-to-cathode voltage is impressed on one section (Ep), the voltage across the other section (Eg) will always be of opposite polarity, thus giving a 180-degree phase angle.

The Colpitts circuit of Fig. 6 has the advantage of greater stability than that of Fig. 5 since the capacitance ratio which determines Ep/Eg is always fixed, thus providing a "stiffer" voltage source as well as better efficiency because the phasing is more exact. However, the coupled-grid circuit of Fig. 5 affords a ready means of adjusting the amplitude of the grid voltage which is advantageous in some cases.

Another important use of the pliotron is in diathermy. In these applications the pliotron is employed in an oscillator circuit to transmit high-frequency waves which produce heat inside the human body. A circuit illustrating the use of the pliotron in a diathermy application is shown in Fig. 7 below.

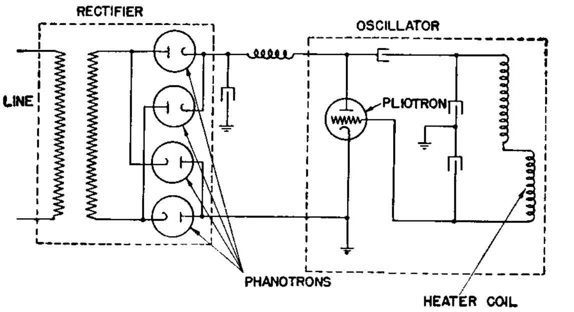

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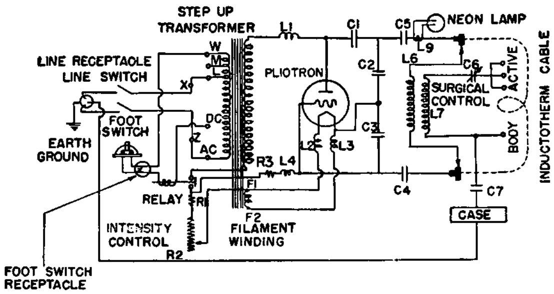
Fig. 6—Basic Colpitts Oscillator Circuit as Used for Induction Heating



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(Courtesy of G. E. X-Ray Corporation)

Fig. 7—Circuit of Inductotherm Unit with Surgical Attachment

CONVECTION-COOLED PLIOTRONS—INSTALLATION AND OPERATION

INSTALLATION

Mechanical

Mountings must be of good quality and should be so installed as to minimize danger from impact. If the set is subject to vibration, a shock-absorbing suspension must be employed.

Sets using more than one tube should provide adequate spacing between tubes so that adjacent portions of the bulbs do not operate appreciably hotter than the other sections.

Electrical

The filament should be operated preferably from an a-c source, although a d-c supply may be used. The filament supply should be designed to allow operation at rated filament voltage. The filament transformer shall have good regulation and should be designed for at least thirty per cent above rated filament wattage.

The circuits should be arranged to prevent parasitic oscillations so that the tube will not be subjected to excessive voltages and current.

The plate circuit should be provided with a protective device such as a fuse in order to prevent overheating caused by improper circuit adjustments or overloading. This device should remove the plate voltage instantly if the direct plate current reaches a value 50 per cent above normal.

In rating pliotrons, certain values are given as maximum; that is the values beyond which it is unsafe to go from the viewpoint of life and performance. In order not to exceed the *maximum ratings, changes in plate and filament voltage caused by line-voltage fluctuation, load variation, and manufacturing variation of the associated apparatus must be determined. Then, an average value of plate voltage should be chosen so that under the usual operating conditions the maximum ratings will not be exceeded.

In trying out a new circuit or when adjustments are being made, the plate voltage should be reduced in order to prevent damage to the pliotron or associated apparatus in case the adjustments are incorrect.

OPERATION

General

Maximum ratings and typical operating conditions are given on the Description and Rating Sheet covering the individual type of pliotron. The typical values given must not be considered as ratings, because the tube may be used at any suitable conditions within the maximum ratings.

Class C Radio-Frequency Power Amplifier and Oscillator

In this service, the plate input power is keyed, i.e., is on and off alternately in accordance with the characters of some code. During the "key-down" periods, the tube functions as an unmodulated radio-frequency power amplifier. The tube may be used also as an amplifier or oscillator without keying. In both types of service, the ratings given are for "Key-down" conditions.

Certain methods of modulation may be applied to this class of service provided the modulation is essentially negative and the positive peak of the audio-frequency envelope does not exceed 115 per cent of the carrier conditions.

Grid bias for Class C service may be obtained from a grid leak, from a battery, from a rectifier of good regulation, or from a self-biasing resistor by-passed with a suitable capacitor. With the grid-leak method, the grid excitation must not be removed without also removing the plate voltage. Grid-bias values are not particularly critical, and correct circuit adjustment may be obtained with widely different values.

FORCED-AIR-COOLED PLIOTRONS—INSTALLATION AND OPERATION

INSTALLATION

Cooling

The air-cooling system for the anode consists of a blower with a suitable air duct leading to the fin cooler of the tube. The air flow required is specified on the Description and Rating Sheet for each type. The temperature of the incoming air should not exceed 45 C.

Proper cooling must be provided to limit the glass temperature to not more than 150 C at the hottest point. Usually deflecting vanes diverting the outgoing air toward the terminal seals provide sufficient cooling. In some cases it may be necessary to provide a separate cooling system. This system may consist of a blower and an air duct of suitable cross-sectional area leading to a nozzle directing the air flow.

The cooling air must not contain any foreign matter. The air-cooling systems should be properly installed to insure safe operation of the tube under all conditions and for this reason should be electrically interconnected with the filament and plate supplies to prevent the application of voltages to the tube without suitable cooling.

Electrical

Suitable meters should be provided for reading filament voltage, plate voltage and current and d-c grid current. A tube life recording meter (to read hours of operation) is also necessary.

The installation of all wires and connections must be made so that they do not lie on or close to the glass of the tube. Otherwise, severe trouble may arise from corona discharge or increased dielectric loss which will result in almost certain puncture.

The filament circuit carries a high current at low voltage. Therefore, precautions should be taken against loss of voltage and heating due to poor connections. The filament connectors particularly should be large and make good contact.

For multiphase filament tubes it is essential that the connections for each type of filament voltage supply be made according to the circuit diagram* to prevent distortion and possible failure of the filament.

The plate circuit should be provided with protective devices to prevent the tube from drawing a heavy overload.

Plate series protective resistors should also be provided to protect the tube from excessive energy dissipation during instantaneous failure of insulation, within the tube or within the transmitter.

The grid circuit should be provided with heavy conductors, carefully connected, in order to prevent overheating of the grid terminal due to r-f currents

In Class C service, the bias voltage may be supplied by a grid leak, or by a combination of grid leak and generator, grid leak and rectifier, or grid leak and cathode-bias resistor suitably by-passed. The combination method is particularly suitable to reduce distortion, especially in plate-modulated operation. Since the grid-bias voltage for Class C service is not particularly critical, correct circuit adjustment may be obtained with values differing widely from those indicated for this service.

The circuits should be arranged to prevent parasitic ocillations so that the tube will not be subjected to excessive voltages and currents.

*Note: *The ratings and characteristics of a particular pliotron are given on the Description and Rating Sheet for that tube.*

OPERATION

When a new tube is first placed in operation, it should be operated without plate voltage for fifteen minutes at rated filament voltage. After this initial preheating schedule, plate voltage can be applied. Operate for fifteen minutes at approximately one-half the usual plate voltage. Full voltage may then be applied and the tube operated under the normal load conditions for a period of one hour or more. Every three months spare tubes should be given this preheating and initial operation schedule.

The filament should be operated at constant voltage rather than constant current. From the viewpoint of tube life, it is usually economically advantageous to provide good regulation of the filament voltage. For example, if the filament is operated continuously at six per cent above normal voltage, the evaporation life will be reduced to approximately one half.

When a multiphase filament-supply voltage is used, the phase voltages must all balance within fifteen per cent during the filament starting period. During normal operation the phase voltages must never, even momentarily, exceed ten per cent unbalance.

Maximum ratings and typical operating conditions are given on the Description and Rating Sheet. The amplifier classifications used are those given in the Report of the Standards Committee of the Institute of Radio Engineers.

The output values given in the tabulation on the Description and Rating Sheet are approximate tube outputs under certain typical operating conditions. These must not be used as output ratings; circuit losses must be subtracted from the tube output in calculating the useful output.

In determining the value of plate voltage for normal operation, the line voltage fluctuation, load variation, and maufacturing variations must be estimated so that the maximum rated values will not be exceeded.

WATER-COOLED PLIOTRONS—INSTALLATION AND OPERATION

INSTALLATION

Cooling

The water-cooling system for the anode consists, in general, of a source of cooling water, a water jacket, and a feed-pipe system which carries the water to and from the jacket.

Proper functioning of the water-cooling system is of the utmost importance. Even a momentary failure of the water flow will damage the tube. It is, therefore, necessary to provide a method for preventing operation of the tube during such a condition. This may be accomplished by the use of water-flow circuit breakers, or interlocks, which open the filament and plate power supplies whenever the flow is insufficient or ceases.

The rate of water flow given on the Description and Rating Sheet is usually sufficient for all types of service. Under abnormal conditions an increased rate of flow may be necessary to prevent overheating.

Distilled water is recommended for cooling because it greatly reduces the probability of scale formation on the anode during life. Scale hinders proper transfer of heat from the anode to the water. The mineral content, flow, heat dissipation, temperature, etc., of undistilled water are so varied that no specific recommendations to prevent scale can be made. In general, water which shows a hardness greater than 10 grains per gallon should not be used.

When forced-air cooling is called for on the Description and Rating Sheet a system should be used which consists of a blower with air ducts of proper cross-sectional area which supply air to suitable air nozzles. In certain of the larger tubes (such as the 862-A and the 898-A both the bulb and the stem must be air cooled. In these tubes the nozzle which supplies air to the filament stem is incorporated in the base, and the nozzle which supplies air to the bulb is part of the water jacket and acts as a combination air nozzle and electrostatic shield.

Tubes which require forced-air cooling on the stem only have an air nozzle incorporated in the cathode base.

The system should be arranged so that the temperature of the glass is not more than 150 C at the hottest point. Even when forced-air-cooling is not called for on the Description and Rating Sheet, free circulation of air must be provided to limit the temperature of the glass to this value. When there is inadequate ventilation or where a tube is used at the higher frequencies, forced-air-cooling may be required. In such cases a small blower may be used with suitable nozzles directing the air to the areas where cooling is necessary.

Electrical

Suitable meters should be provided for reading filament voltage, plate voltage and current, and d-c grid current. A tube life recording meter (to read hours of operation) should also be provided.

The installation of all wires and connections must be made so that they do not lie on or close to the glass of the tube. Otherwise, severe trouble may arise from corona discharge or increased dielectric loss which will result in almost certain puncture.

The filament circuit carries a high current at low voltage. Therefore, the usual precautions should be taken against loss of voltage and heating due to poor connections. The filament connectors particularly should be large and make good contact.

For multiphase filament tubes it is essential that the connections for each type of filament voltage supply be made according to the circuit diagram to prevent distortion and possible failure of the filament.

The plate circuit should be provided with protective devices to prevent the tube from drawing a heavy overload. Plate series protective resistors should also be provided to protect the tube from excessive energy dissipation during instantaneous failure of insulation, within the tube or within the transmitter. The grid circuit should be provided with heavy conductors, carefully connected, in order to prevent overheating of the grid terminal due to r-f currents.

In Class C service, the bias voltage may be supplied by a grid leak, or by a combination of grid leak and generator, grid leak and rectifier, or grid leak and cathode-bias resistor suitably by-passed. The combination method is particularly suitable to reduce distortion, especially in plate-modulated operation. Since the grid-bias voltage for Class C service is not particularly critical, correct circuit adjustment may be obtained with values differing widely from those indicated for this service.

The circuits should be arranged to prevent parasitic oscillations so that the tube will not be subjected to excessive voltages and currents.

OPERATION

When a new tube is first placed in operation, it should be operated without plate voltage for fifteen minutes at rated filament voltage. After this initial pre-heating schedule, plate voltage can be applied. Operate for fifteen minutes at approximately one-half the usual plate voltage. Full voltage may then be applied and the tube operated under the normal load conditions for a period of one hour or more. Every three months spare tubes should be given the preheating and initial operation schedule discussed above.

The filament should be operated at constant voltage rather than constant current. From the viewpoint of tube life, it is usually economically advantageous to provide good regulation of the filament voltage. For example, if the filament is operated continuously at 6 per cent above normal volage, the evaporation life will be reduced to approximately one-half.

When a three-phase or six-phase a-c filament-supply voltage is used, the phase voltages must all balance within 15 per cent during the filament starting period. During normal operation the phase voltages must never, even momentarily, exceed 10 per cent unbalance.

Maximum ratings and typical operating conditions for each recommended class of service are given on the Description and Rating Sheet. The amplifier classifications used are those given in the Report of the Standards Committee of the Institute of Radio Engineers.

The output values given in the tabulation on the Description and Rating Sheet are approximate tube outputs under certain typical operating conditions. These must not be used as output ratings; circuit losses must be subtracted from the tube output in calculating the useful output.

The approximate anode dissipation may be calculated from the following expression:

$$P \text{ (kilowatts)} = \frac{n(T_2 - T_1)}{(\quad 4 \quad)}$$

in which (T_1) is the known initial temperature of the cooling water in degrees centigrade, (T_2) the temperature of the water at the water jacket outlet in degrees centigrade, and (n) the water flow in gallons per minute.

In determining the value of plate voltage for normal operation, the line voltage fluctuation, load variation, and manufacturing variations must be estimated so that the maximum rated values will not be exceeded.

***Note:** *The ratings and characteristics of a particular pliotron are given on the Description and Rating Sheet for that tube.*

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