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Effects of AC Plate Voltages on Tube Performance.

INTRODUCTION

The operation of receiving type vacuum tubes from an ac plate supply is fairly common practice, especially in control applications. If unfiltered, pulsating dc current can be tolerated, or is desirable, a great degree of economy in materials may be realized by eliminating many of the conventional dc power supply components. Economy of components also results in space and weight savings, important factors to the equipment design engineers. There are, however, problems of tube reliability and performance involved in this type of operation not encountered in normal dc service. In general, these difficulties are related to the uncontrolled characteristics of the tubes.

UNCONTROLLED CHARACTERISTICS

It might appear that the only significance of operating a vacuum tube with a sinusoidal plate voltage would be that conduction would occur for one-half of the cycle and that the resulting current flow would be in pulses. However, the negative voltage appearing on the plate of the tube during the non-conducting half-cycle causes certain phenomena to occur which are unpredictable and, to some extent, uncontrollable. Since conduction occurs for one-half of the cycle, a high peak voltage and current are necessary to realize a reasonable output from the tube. These relatively high peak voltages and currents produce higher velocity electrons which cause increased bombardment of the tube elements and, consequently, higher values of secondary emission. During the negative excursion, the plate assumes a voltage reversed with respect to the other elements of the tube. Any tendency toward primary emission by the plate under normal conditions will become real under this reversed voltage condition. Thus, it may be seen that a relatively simple design problem can be made very complex by the presence of seldom encountered tube phenomena.

FACTORS AFFECTING BACK EMISSION

Realizing that there are possibilities of back emission currents in tubes operated with applied ac plate voltages, laboratory experiments were conducted to determine under what conditions back currents exist and are most pronounced, what factors influence them, and the corrective or preventative measures that can be taken to minimize their effects. Any reference to the plate shall imply the combination of plate and screen grid. The term back emission shall include primary and secondary emission, since both are included in the measurements obtained by present techniques.

Secondary emission occurs when high speed electrons bombard the surface of a metal. Kinetic energy is transfered to electrons in the metal, causing some to leave the metal entirely as emitted electrons. The temperature of the metallic surface affects the energy level of the electrons within the metal, making it easier for them to be released under the added energy given them during bombardment. The basic factors having greatest influence upon the ratio of primary to secondary electrons are: (1) composition and surface condition of the material, (2) velocity of the primary, or bombarding, electrons, and, (3) the angle at which the primary electrons strike the metallic surface.

Primary emission depends mainly upon the work function of the emitting surface. Although many factors have an effect upon the work function of a metallic surface, contamination is the most prominent. In rating vacuum tubes, the effects of plate temperature are taken into account by limiting the allowable dissipation. Contamination of the parts is controlled during production. However, these controls are not necessarily adequate when the tube is operated with ac plate voltages.

To understand how the operating conditions of the ac powered stage affect the degree of back emission from the plate, a series of measurements were performed to show the relationships between (1) ac plate voltage and back emission, (2) bulb temperature and back emission, and (3) plate dissipation and back emission.

Figure 1 shows the effect of plate voltage swing with respect to plate back emission for a constant plate dissipation. The curve shows a very steep slope at the higher voltages, which may indicate a greater degree of secondary electrons during the tube conduction period. At the higher voltages the electrons from the cathode assume higher velocities, and consequently, tend to bombard the plate to a greater degree, thus freeing more electrons from the metallic surface. When the plate swings negative and cathode current flow ceases, the plate becomes a primary emitter. If the plate of the tube is considered as the cathode of a diode, it can be seen that increases in diode voltage will cause increases in diode current.

The curve in Figure 2 was obtained to show the relationship between plate back emission and bulb temperature. Figure 2 might well be termed "plate temperature vs plate back emission", providing we can assume linear heat transfer from plate to bulb. All operating conditions, including plate dissipation, were held constant and the bulb cooled by external means. The curve shows an almost linear relationship in the higher range of bulb temperature and again in the lower range, the two ranges being separated by a very pronounced knee. This property was present in all the tube types investigated, both triodes and triode-connected pentodes. Holding the bulb temperature below the knee, which may be looked upon as a critical point, appears to be an important design note.

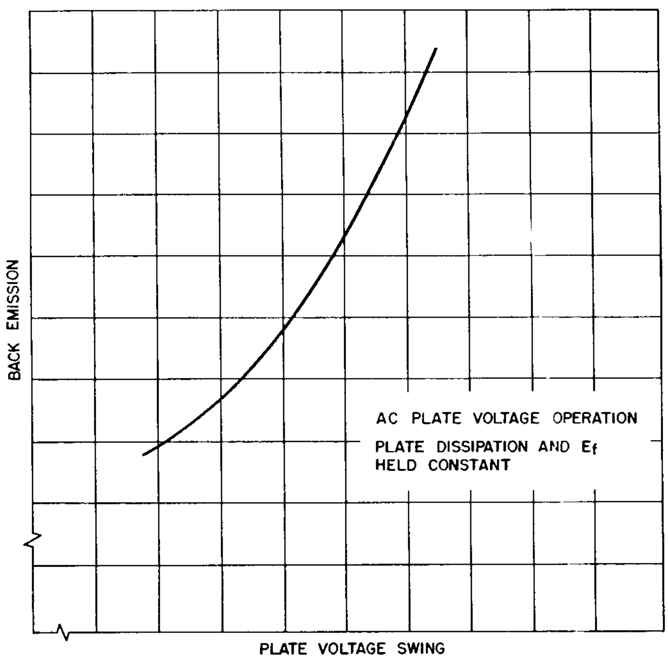

FIG. 1 — Curve showing the relationship between back emission and plate voltage swing for a triode-connected pentode.

The overall effects on back emission caused by increased ac plate voltage, increased current, and increased temperature can be shown by changing the plate voltage and holding the grid bias constant. A curve of plate back emission versus plate dissipation is shown in Figure 3. The exponential rise in back emission with increased plate dissipation further emphasizes the value of low voltage, low current operation.

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The curves are typical for both triodes and triode-connected pentodes. In general, no two tubes of the same type will display equal magnitudes of back emission, although the trends may follow much the same pattern.

In comparing triodes with pentodes one point having an important bearing upon their use in ac powered circuits is the relative emission tendencies of the elements. In triode-connected pentodes, the screen grid and plate both contribute to the measured plate back emission. However, when observed individually, it becomes evident that the screen grid contributes the major portion of the back current. This may be due to the materials, operating temperatures, or physical positioning of these two elements. It follows that a triode, lacking the contribution of the screen grid to the total back emission currents, should present less of a problem than a triode-connected pentode in the application. This has been observed to be true in experimental work.

Let us now consider the collector of the back emitted electrons. If a triode is operated in a dc circuit with zero signal applied to the grid and a finite value of grid resistance, the grid will assume a slight negative potential due to a tube property referred to as contact potential. However, if an ac plate voltage is applied between the plate and cathode, negative voltage pulses will appear on the grid. These pulses are the result of a voltage drop ($Icl \times R_G$) across the grid resistor and are in phase with the negative plate voltage swing. It is apparent that there is electron flow from the plate to the grid during the negative excursion of the plate. If the negative plate voltage

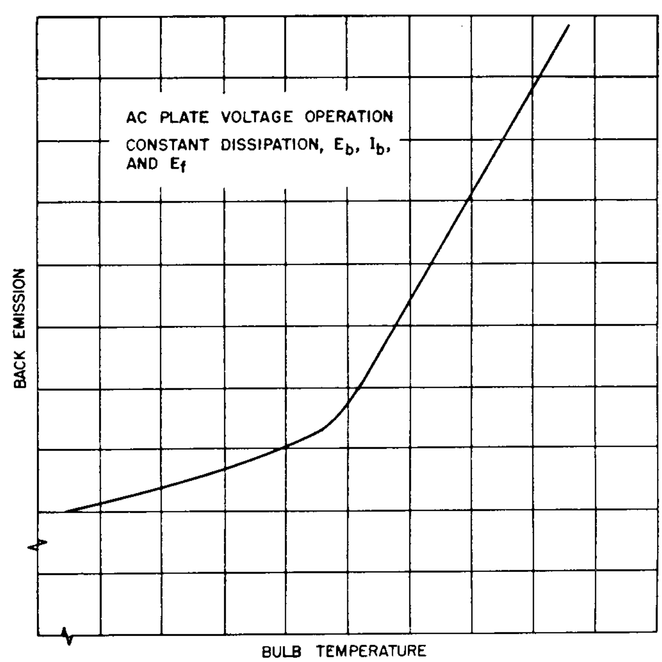

FIG. 2 — Curve showing the relationship between back emission and bulb temperature for a triode-connected pentode.

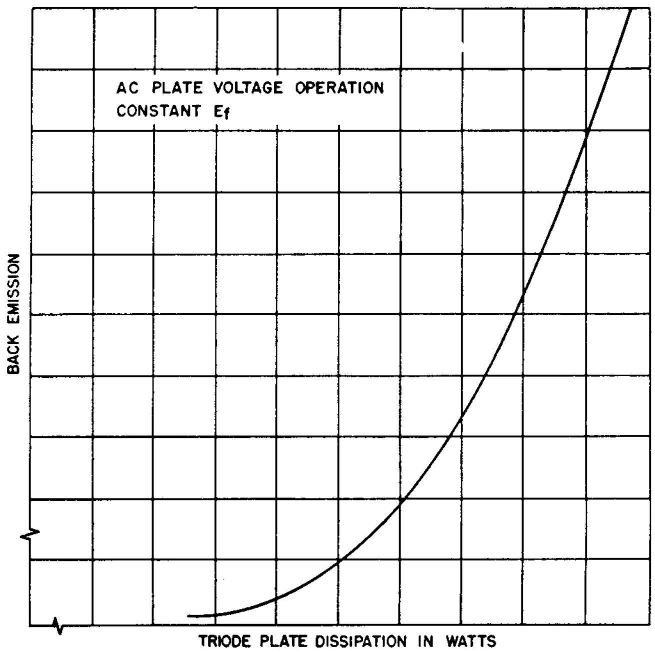

FIG. 3 — Curve showing the relationship between back emission and plate dissipation for a triode-connected pentode.

swing is removed, the negative grid pulses also disappear. Electron flow from plate to grid explains, in part, where the electrons emitted from the plate go. The voltage developed on the control grid as a result of plate back emission may be of appreciable value. This voltage can be reduced, for a given plate voltage condition, by lowering the value of the grid circuit resistance.

It has been shown that operating a tube with an ac plate supply can cause the plate to become an emitter of electrons. It has also been shown that back emission current, when present, is affected by temperature, voltage, and tube current, as well as the condition of the tube element surfaces and the grid resistance employed.

INFLUENCE OF BACK EMISSION ON CIRCUIT PERFORMANCE

Having investigated the phenomena which occur in the vacuum tube, and the measurable effects upon tube properties resulting from operation with ac plate voltages, we must go one step further and consider the effects upon the operation of the circuit employing the tube. A typical application is the power amplifier or driver stage in servo systems, Figure 4. In such a circuit, it is common to use medium or low mu triodes. However, the miniature power pentodes, when connected as triodes, are very popular since they display the low mu, high perveance qualities desirable in this type of circuitry. The triode-connected pentodes in Figure 4 are operated with their grids in parallel and their plates in push-pull. The common cathode resistor is normally chosen as a protective element while

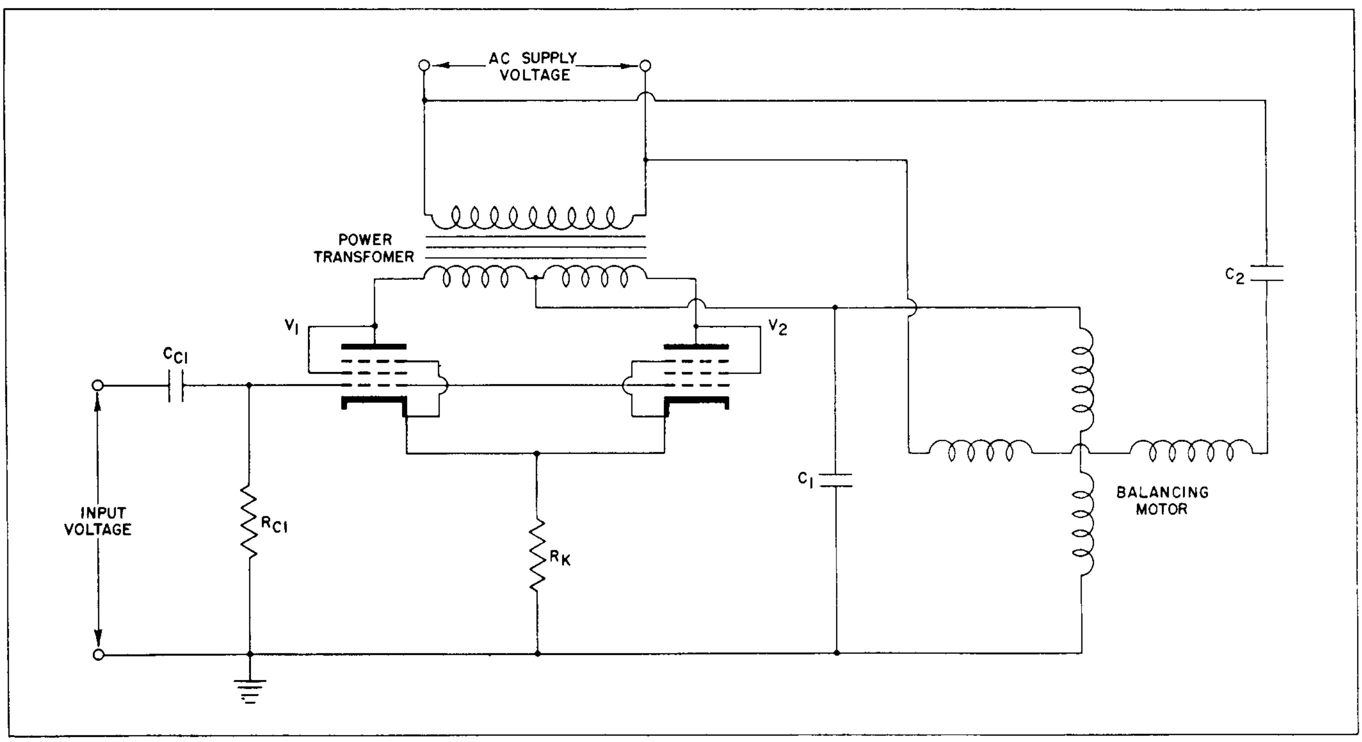

FIG. 4 — Simplified Typical Power Amplifier, Servo Driver Stage.

the grid resistor is selected on the basis of circuit requirements. By disregarding the operation of the balancing motor, except to say that the direction of rotation is determined by the relative phase of the current supplied by the amplifier, the explanation of the circuit operation is greatly simplified. Under zero signal conditions, each tube should conduct when its plate swings positive, the combined plate current appearing as full-wave rectification with a frequency of twice the supply frequency. The balancing motor should not rotate. Consider what happens if one of the tubes displays appreciable back emission from the plate. When the plate voltage on V1, Figure 4, swings negative, V2 should be in a conducting state. However, back emission in V1 will cause its grid to become negative during this period. Since the grids of the two tubes are in parallel, the grid of V2 will also become negative. Depending upon the magnitude of the grid voltage, V2 may have low output, or may even be driven to a near cut-off state. When the plate voltage of V2 rises to a positive value, it will conduct in a normal manner. This assumes that a minimum of grid-to-ground capacitance exists. In this case, the tube with back emission, V1, will operate normally while V2 will not. If both tubes have equal amounts of back emission, the output from each tube would be low. In this case, it might appear as though the tubes were poor for emission.

The foregoing discussion of developed grid voltage pertains to conditions involving a minimum external grid circuit capacitance. Under these conditions, the instantaneous grid voltage, at the time the plate swings positive, is only that due to the contact potential bias. The presence of even a small amount of capacity produces a time constant that causes the grid to assume a negative voltage level in excess of the contact potential level during the positive excursion of the plate.

One circuit has been noted in which the operating bias is obtained from the plate back emission in the grid circuit by adding capacity directly to ground across the grid resistor. This obviously led to difficulties, since tubes with no back emission would contribute to run-away conditions while those with high values would be too insensitive to operate properly.

MINIMIZING THE EFFECTS OF BACK EMISSION

To minimize the effects of back emission the external grid resistance should be as low as possible, since the negative voltage developed on the grid is proportional to this resistance. Another method of alleviating the situation is to insert series diodes in the plate circuits, connected to allow current flow in the conventional direction only. This makes it nearly impossible for current to flow in the reverse direction. A third method of minimizing back emission currents is to employ triodes when practical since the major portion of the back emission measured in a typical triode-connected pentode is from the screen grid.

In addition, receiving type vacuum tubes should be conservatively operated when employed in applications utilizing AC plate voltages. Low AC plate voltage, plate current and dissipations, within practical limitations, will contribute to more reliable operation.

The application of good heat transfer techniques, principally involving a good thermal bond from the tube to a heat sink, will tend to minimize bulb temperatures as much as practical, consistent with tube dissipations and ambient operating temperatures. This will further minimize back emission and further enhance the reliability of such applications.

CONCLUSION

The operation of receiving type vacuum tubes with ac plate supply voltages is an unusual type of service. Tube properties which adversely affect performance in ac applications are not generally controlled in production. To obtain the most reliable performance from ordinary vacuum tubes operated under such conditions the following operational rules should be adhered to: (a) keep bulb temperature down by good cooling techniques, (b) keep peak voltages down — negative peak may be removed by use of series diode, (c) keep peak currents down, (d) use low values of external grid resistance, (e) use protective cathode resistors, (f) keep plate and screen dissipation low, and (g) use triodes if at all possible.