Heater-Cathode Leakage

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By THE APPLICATION ENGINEERS
of
THE ADVISORY GROUP
ON ELECTRON TUBES

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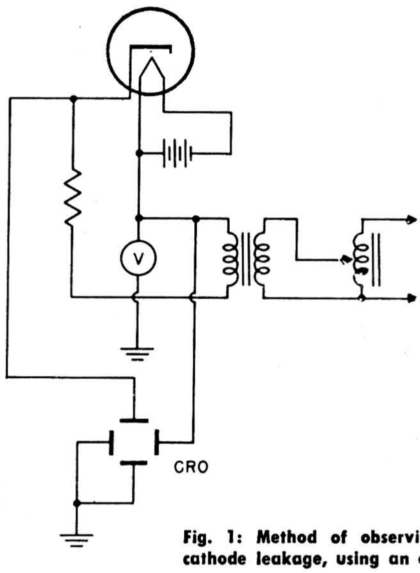

Fig. 1: Method of observing heater-cathode leakage, using an oscilloscope

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Heater-Cathode Leakage

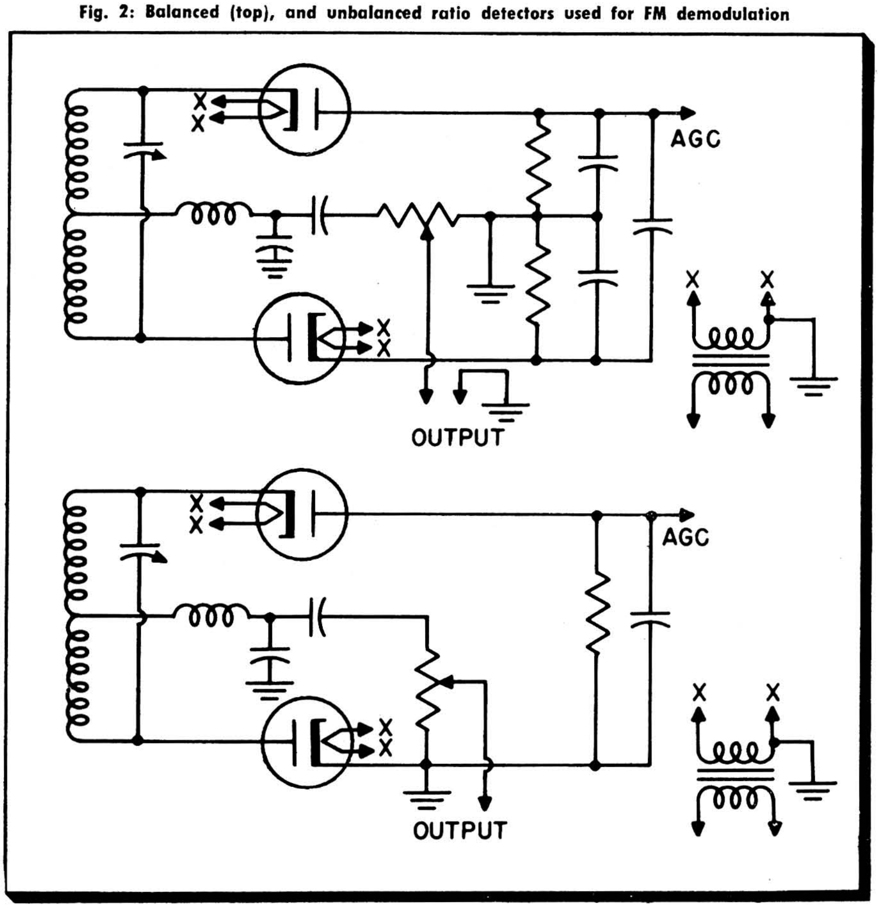
THE oxide coated cathode in an indirectly heated type receiving tube operates in the approximate temp. range of 750 to 875°C and receives its heat from a heater, operating at about 1150 to 1350°C, by both radiation and conduction. The heater is electrically separated from the cathode by a sleeve of insulation material, usually a specially prepared form of aluminum oxide applied to the heater as a coating. The same insulation also separates adjacent heater folds or turns. Any current flow between the heater and the cathode is known as heater-cathode leakage, and should always be considered a detriment, because it may result in the malfunctioning of electronic equipments.

Before specific circuit design problems arising from heater-cathode leakage are discussed it would be well to review some of the physical factors involved in insulating the heater from the cathode of the tube. As previously stated, the insulating material must operate at high temperature and still adhere extremely well to the heater. The coated heater, inserted into the cathode sleeve during the assembly of the tube, and the cathode make physical contact at various places along the outer surface of the insulation and the inner surface of the cathode sleeve. With 100 volts applied between heater and cathode, the voltage gradient in the insulating material can be as high as 50,000 v./in. The coating thickness cannot be materially increased since the thermal expansion of the aluminum oxide is not identical to that of the heater material, and the insulating material or the heater would be subjected to breaking with repeated heater cycling. Increased coating thickness would also greatly prolong the warm-up characteristics of the tube since more mass would have to be heated.

Electrical Behavior

Although the aluminum oxide which is used for the heater-to-cathode insulation is an extremely high resistance material, the leakage observed in tubes is not a simple

Fig. 2: Balanced (top), and unbalanced ratio detectors used for FM demodulation



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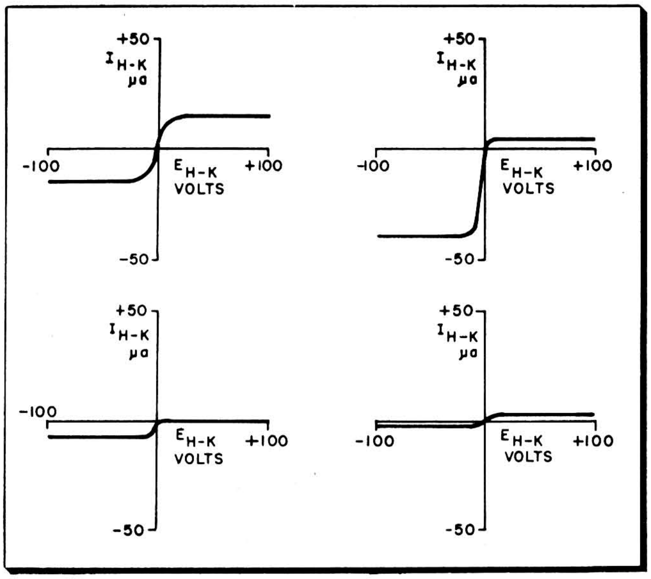


Fig. 3: Leakage with 10-15 v between h & k

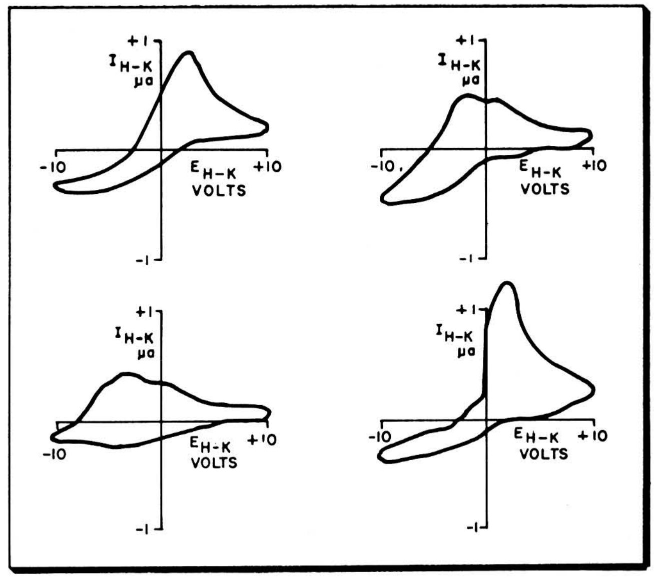


Fig. 4: Leakage with below 10 v between h & k

case of a resistance between the heater and the cathode. Electrons find their way, in both directions, between the heater and the cathode by at least three different methods:

(1) The first type of leakage consists of a straight resistive component of current flow through paths that have a lower resistance than the aluminum oxide. Impurities in very small amounts can cause this type of leakage to occur.

(2) Cracks or fissures in the aluminum oxide can expose bare heater wire having sufficient electron emission at the operating temperature to account for the flow of electrons from the heater to the cathode, if the heater is negative in respect to the cathode. In the same manner, electron emission can take place from the cathode to the heater, when the heater is positive with respect to the cathode, if any emitting material is present on the inner surface of the cathode sleeves.

(3) Although there is controversy as to the exact cause, with arguments ranging from positive ion migration to semi-conductor theories, a third type of heater-cathode leakage may be due to some form of ion migration between the heater and cathode.

Methods of Measurement

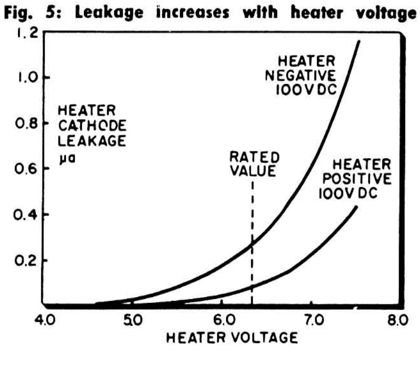
Heater-cathode leakage can be readily observed on an oscilloscope by the method shown in Fig. 1. The use of a dc supply rather than an ac supply for the heaters circumvents the problem of having one half of the heater out of phase with the other half.

Heater-cathode leakage phenomena can be divided into two categories. The first of these shows saturation with about 10 to 15 v. between heater and cathode and may or may not be symmetrical with respect to voltage polarity, as shown in the waveforms in Fig. 3. The second category of leakage takes place with less than 10 v. between heater and cathode. Leakage of this variety is usually below 1 μa. and is characterized by extremely distorted waveforms as illustrated in Fig. 4.

The above two categories may occur separately or together, and when both exist at the same time, one may mask the other.

The test for heater-to-cathode leakage as specified in MIL-E-1[1] is made by applying rated ac voltage to heaters tested at 35 v. and over and either ac or dc voltage to heaters rated below 35 v., and then reading the current flow between heater and cathode when a direct voltage of 100 vdc is applied between the electrodes. The test is made with two polarities, that is, with the heater both positive and negative with respect to the cathode. One μa. leakage under this test implies a resistance value of 100 megohms, but this resistance value may be deceiving because the current may reach saturation below 15 v. Thus at 10 v. the equivalent resistance may be only 10 megohms. A result of this phenomenon is a relatively poor correlation between the leakage measured at 100 vdc and hum developed across the cathode resistor in actual applications.

Fig. 5: Leakage increases with heater voltage



Effects on Performance

Heater-cathode leakage increases rapidly with heater voltage as shown in Fig. 5, and it may improve or deteriorate with life. Because it is also subject to changing levels during shock and vibration, the MIL-E-1 specifications for "reliable" tubes now call for heater-cathode leakage tests to be made before and after shock and vibration tests.

For purposes of illustrating the effects of heater-cathode leakage upon performance in specific equipments, consider:

(1) A low level Class A amplifier

(2) A multivibrator

(3) An FM demodulator

In the case of the low-level Class A amplifier, the cathode bias resistor is usually unbypassed for purposes of degeneration. In conventional circuitry one side of the heater (6.3-v. type) is at ground potential and the cathode is usually about 2 v. positive above ground potential (See Fig. 6.) The underground side of the heater then swings from −10.9 to +6.9 v. with respect to the cathode. During these excursions, current may flow from the heater to the cathode and from the cathode to the heater, resulting in an ac voltage across the cathode resistor. This ac voltage, which may be highly distorted, is then amplified throughout the whole system, since it effectively changes the bias of the tube.

Methods of attacking this problem are:

H-K Leakage

(a) Adequate bypassing of the cathode resistor for the power-supply frequency.

(b) Use of a heater filament transformer with the center tap grounded. This will reduce the voltage excursions between cathode and heater to -6.5 to $+2.5$ v., with a subsequent reduction in current. A further reduction in current may be realized in this arrangement due to current cancellation because the two halves of the heater are out of phase.

(c) Use of a center-tapped resistor (or a potentiometer) across the heaters with the center tap grounded. The effects will be the same as (b), except a variable resistor (potentiometer) may aid in adjusting to a minimum.

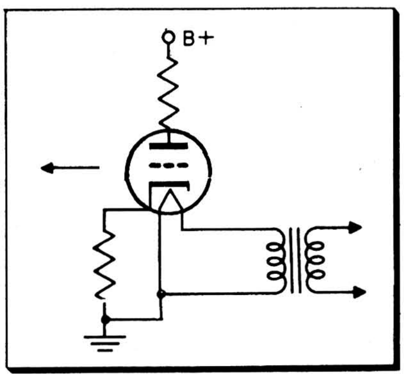


Fig. 6: Class A amp, with grounded heater

(d) Use of dc on the heaters.

(e) Operation of the tube with a dc bias between heater and cathode of approximately 30 v. The bias can be applied in either direction. Operation with this value of bias is beyond the saturation point in the heater-cathode characteristic curves (Fig. 3) Variation in dc potential about the operating point will not introduce a corresponding current change because the current has reached saturation throughout this region.

In the schematic of a low-frequency multivibrator shown in Fig. 7, a variable cathode bias is used in one cathode lead for a fine frequency adjustment for proper synchronization. Because the average cathode current through the tube is low, a high value of resistance is required to provide the proper voltage range. The total resistance is 250k from cathode to ground. In this type of circuit it was noted that:

(a) Some tubes could not be synchronized within the range of the hold control.

(b) Operation at elevated line voltage caused the circuit to go out of the range of the hold control.

(c) The circuit went out of range of the hold control during life.

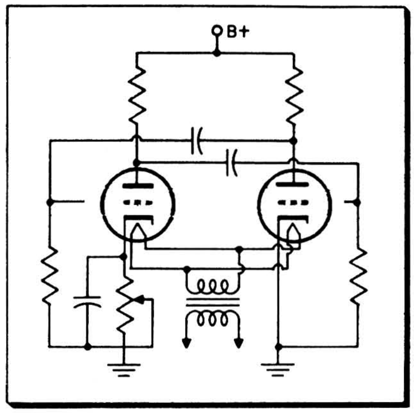


Fig. 7: Multivibrator, using variable bias

The trouble in all three cases was due to heater-cathode leakage forming the equivalent of a shunt resistor across the cathode resistor and lowering the effective cathode bias resistance. The solution to the problem was to change the method of obtaining the bias voltage to that shown in Fig. 8. Use of a voltage divider of low impedance effectively lowers the value of resistance between the cathode and ground so that the shunt resistance caused by the heater-cathode leakage is insignificant. The bypass capacitor can be eliminated in this method of obtaining bias.

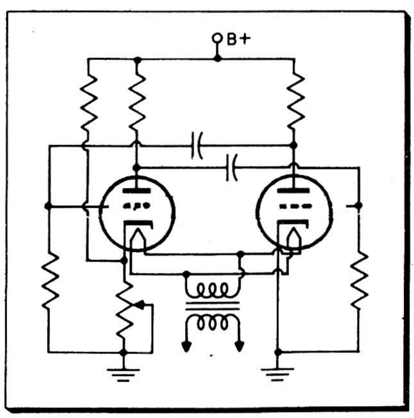


Fig. 8: Voltage divider bias lowers leakage

The schematic diagram for two arrangements of ratio detectors used for FM demodulation is shown in Fig. 2. The two arrangements show a so-called "balanced" circuit and an "unbalanced" circuit. In the balanced arrangement, both cathodes are at a positive potential with respect to ground and the heater-cathode leakage current drawn by the cathodes develops hum in the output at the supply frequency.

In the unbalanced arrangement one cathode is directly on ground. At least a 2 to 1 improvement in hum output is realized by using the unbalanced system. The unbalanced system has the further advantage of recovering twice the AGC voltage.

Other examples of degraded circuit operation due to heater-cathode leakage can, of course, be cited. In general, circuits involving high voltages between heater and cathode should be carefully examined for the effects of heater-cathode leakage. In the same manner, tubes using large cathode resistors should be examined to make sure that the required circuit operation is compatible with MIL-E-1 specifications. Some general rules that can be used concerning the order of magnitude of leakage follow:

(1) The magnitude of heater-cathode leakage shows little difference with regard to heater-cathode polarity when an adequate cross section of the industry's product is examined.

(2) Tubes with higher-wattage heaters tend to have more heater-cathode leakage than those with lower-wattage heaters, as is illustrated in the following tabulation:

Type	E_h Volts	I_h Amps	Heater Power Watts	Max H-K Leakage μamps
5899	6.3	0.15	0.95	5
6100/6C4WA	6.3	0.15	0.95	10
5670	6.3	0.175	1.1	10
5725/6AS6W	6.3	0.175	1.1	10
5750/6BE6W	6.3	0.3	1.9	10
5726/6AL5W	6.3	0.3	1.9	10
5902	6.3	0.45	2.8	15
5727/2D21W	6.3	0.6	3.8	15
6005/6AQ5W	6.3	0.45	2.8	50
6098/6AR6WA	6.3	1.2	7.5	75

(3) Higher heater voltage versions of tubes usually have more heater-cathode leakage than their lower voltage counterpart.

(4) Greater reliability can always be obtained by avoiding the use of heater-cathode voltages approaching the maximum ratings.

NOTES:

1. MIL-E-1B, paragraph 4.10.15 Heater-cathode leakage. "The rated heater voltage shall be applied; for heaters having a rating of less than 35 v., either ac or dc voltage may be used; for heaters having a rating of 35 v. or greater, only ac heater voltage shall be used. 100 v. dc in series with a micro-ammeter shall be applied between the highest numbered heater pin and the cathode. If ac heater-cathode potential is specified, the heater voltage shall be phased to subtract from this heater-cathode potential. The current shall be determined for both negative and positive polarities between heater and cathode, except for rectifiers or rectifier sections of multiunit tubes, in which the measurements shall be made with the heater at a negative potential with respect to the cathode. The absolute value(s) of the leakage current measured shall not exceed the limit specified. All other tube elements, except those internally connected, shall be electrically isolated from the heater during this test. A resistor of not more than 1000 ohms/v. of heater-cathode potential shall be used in this measurement in series with heater-cathode."

2. Since the preparation of this paper, reports have been received that operation of heater at $+135$ volts with respect to the cathode resulted in less leakage development than at $+50$ volts. This result is based on limited tests with one manufacturer's type 5751WA.