HEATER-CATHODE LEAKAGE AS A SOURCE OF HUM

BULLETIN 38-1

BY

COMMERCIAL ENGINEERING DEPARTMENT

TUNG-SOL LAMP WORKS INC.

SUMMARY

THE MECHANISM OF HEATER-CATHODE LEAKAGE CAUSING HUM AND THE NATURE OF THE LEAKAGE ARE EXPLAINED. METHODS OF PREDICTING HUM BY CALCULATION AND MEANS OF REDUCING HUM ARE GIVEN.

 JULY 1, 1938

HEATER–CATHODE LEAKAGE AS A SOURCE OF HUM

Electrical leakage between an AC operated heater and cathode of a vacuum tube can introduce low frequency voltage into audio amplifier circuits and cause objectionable hum when considerable gain follows this part of the circuit. High frequency circuits are also subject to hum, if they allow the low frequency voltage to modulate the signal.

The principal cause of this hum is a minute leakage current which flows between heater and cathode. The flow of this current through the self-biasing resistor or the parallel combination of resistor and by-pass condenser applies a hum voltage between the grid and cathode of the tube. The path taken by the leakage current when one end of the heater is grounded is shown in Fig. 1A. Here, the voltage across the heater, especially that between the high voltage end and ground, causes the current to flow. Series operating conditions, with the heater not at ground, are shown in Fig. 1B. The voltage across the other heaters between the tube and ground adds to the voltage causing leakage current to flow.

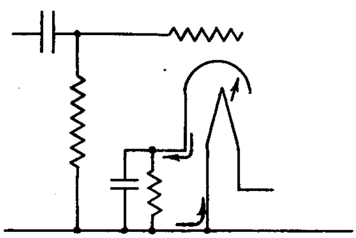

FIG. 1A

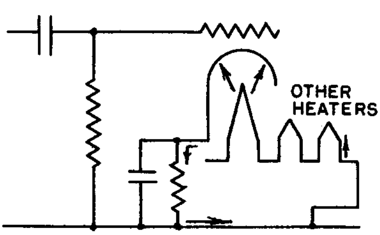

FIG. 1B

Early in 1936, a Tung-Sol electrical engineer found that heater cathode leakage current is essentially a thermionic emission phenomenon and that the flow of current is due to the emission of negative charges (electrons) and positive charges (positive ions) from the insulation coating on the heater to the cathode sleeve. The capacitance between heater and cathode, being of the order of 10 µµf, is too small to constitute a leakage path.

If the heater varies in potential with respect to the other electrodes, the same phenomenon can cause hum, by emission of charges to these electrodes. Hum from this effect occurs most frequently in A.F. amplifiers having a grid bias that is less than the highest voltage between heater and ground. The charges emitted to the grid flow through the grid coupling circuit to ground and the IZ drop in the grid circuit causes the hum voltage. The path of this current is shown in Fig. 2A.

Figure 2B shows the path of emission-current from the heater to the screen grid. In present tube structures this is a minor cause of hum compared to emission to the signal grid.

The heater-cathode leakage current is usually a very distorted wave when the applied voltage is a sine wave. This produces harmonics of the 60 cycle heater voltage at which the loud speaker is highly efficient.

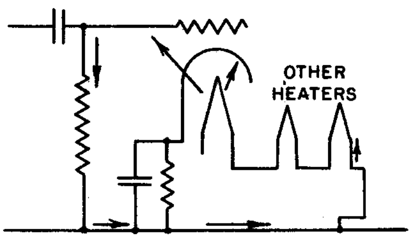

FIG. 2A

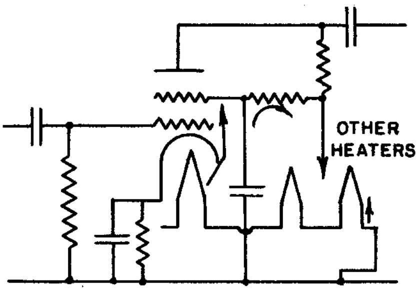

FIG. 2B

Under normal operating conditions, the impedance of the leakage circuit is much greater to DC than to AC. The ratio may be as much as 1000 to 1. This is a result of the fact that with a constant potential (DC) applied between heater and cathode, the current decreases rapidly with time, and when the potential is reversed the current will start at some new high value and again decrease with time. In this report the term leakage current refers to the AC component, unless otherwise specified.

The characteristics of the leakage vary greatly, as the current may consist of the emission of negative charges only, positive charges only or a combination of both. The leakage is usually unstable and will increase or decrease with use as illustrated in Fig. 3.

The impedance of the internal leakage circuit is always much greater than any external impedance across which hum voltage is developed. Therefore, in practical cases, the hum voltage varies directly with the impedance of the circuit through which the leakage current flows, and can be calculated

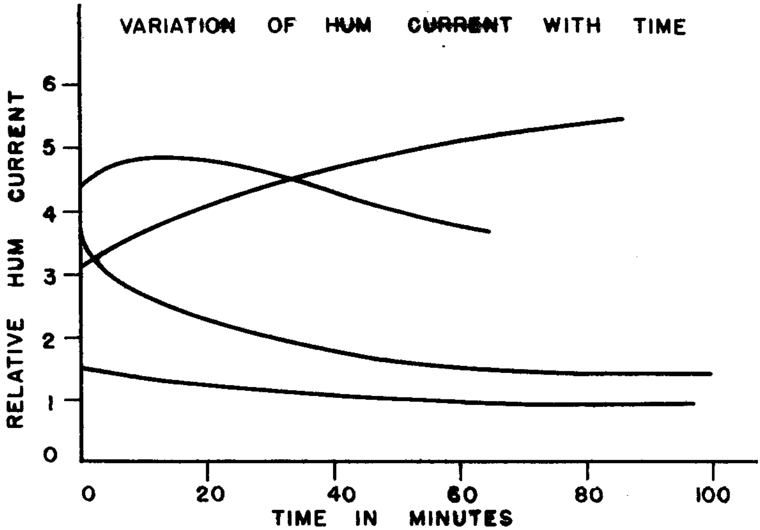

FIG. 3

from the short circuit leakage current.

The leakage current varies from 0 to about 3 microamperes of AC for 6.3 volt heaters operated at normal voltage and no external voltage in the heater cathode circuit. The product of this current multiplied by the 60 cycle impedance of the cathode biasing circuit is the hum voltage. As an example, assume the leakage current of a type 6F5 tube is 2 microamperes, and it is operated as an amplifier with a 3000 ohm cathode bias resistor, by-passed with a 0.1 µf condenser. The 60 cycle impedance is nearly 3000 ohms and the IZ drop or hum is 6.0 millivolts. With a 5 µf by-pass condenser, the 60 cycle impedance is 520 ohms and the hum voltage is then 1.0 millivolt. If the full input signal to the tube is 0.1 volt, the leakage hum in the latter case is 40 db down. The hum will be down 60 db if the leakage current is 0.2 microamperes.

The effect, on hum, of additional alternating voltage between heater and ground is determined by use of Fig. 4. The leakage current varies as the cube root of the entire voltage in the circuit. Part of this voltage is internal, depending on heater voltage and leakage characteristics and the remainder is the alternating voltage between heater and cathode. The internal voltage varies between tubes, and to properly rate the leakage of a tube it is necessary to give the leakage current without external alternating voltage as well as the additional external alternating voltage necessary to cause the current to double. Each curve of Fig.4 is labeled for the voltage that will double the current. The average for most tubes is 25 volts. Tak-

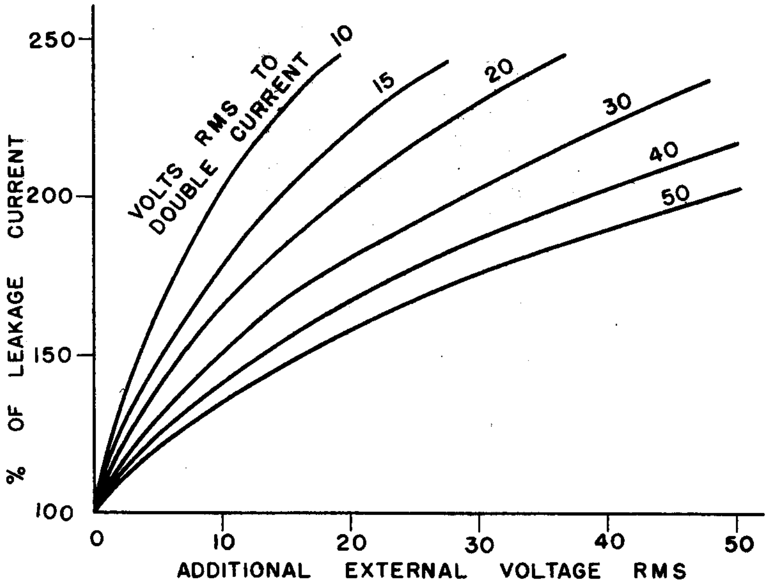

FIG. 4

ing this value to apply to the 6F5 in the above example, the increase of hum by raising the heater 3 tubes or 18.9 volts RMS above ground, is determined from Fig. 4. Interpolate between the 20 and 30 volt lines for 25 volts at the 18.9 point on the "Additional External Voltage" scale. Reading the "% Leakage Current" scale, the hum is found to be 185% of its previous value.

The leakage current increases rapidly with temperature, as does all thermionic emission phenomena. Fig. 5 is a graph of leakage current against heater voltage. Fig. 6 is a graph of the same data, expressing hum in terms of db. A 6% increase in heater voltage approximately doubles hum, or a 1% change in heater voltage causes the hum to change about 1 db when the hum in the amplifier is due entirely to heater cathode leakage.

The instantaneous leakage current, measured with continuous voltage, saturates as the potential between heater and cathode increases. This characteristic makes it possible to reduce the hum in any tube to a very

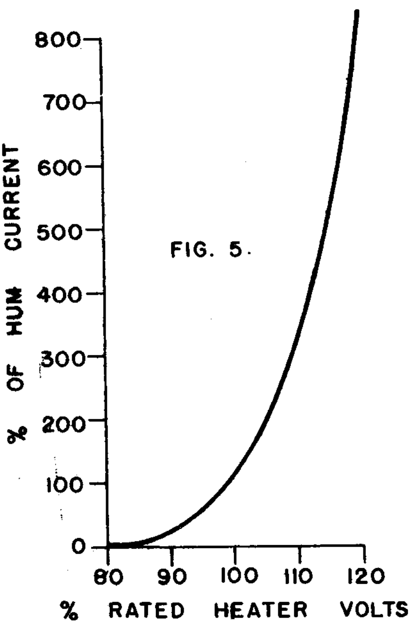

FIG. 5.

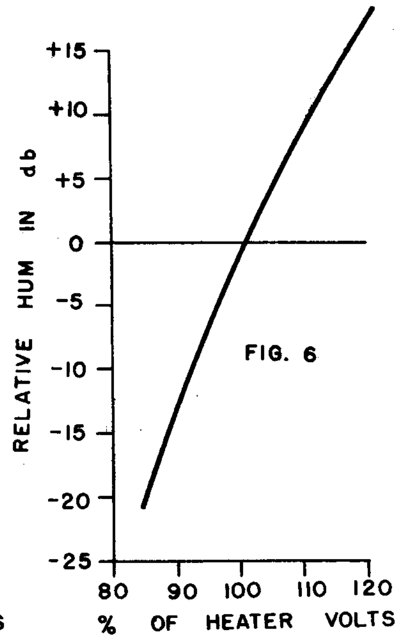

FIG. 6

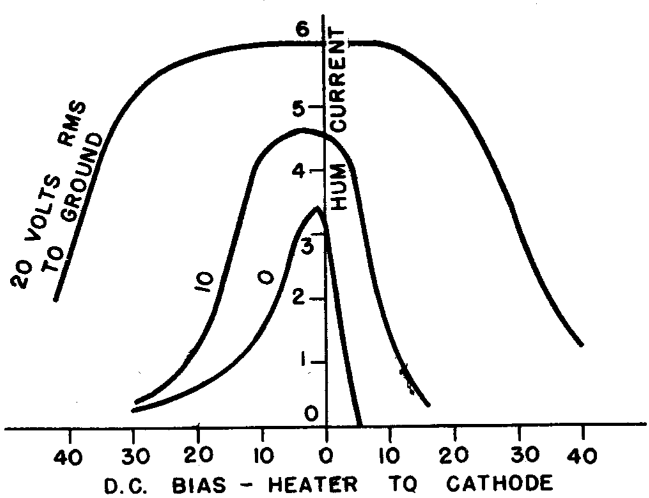

FIG. 7

small value by biasing the heater with respect to the cathode so that the net potential between the two never reverses. The effect of bias on hum is shown for several cases in Fig. 7. Hum reaches a maximum with a small bias (sometimes positive, sometimes negative) between cathode and heater. Fig. 8 shows circuits using bias to reduce hum.

Heater-cathode hum is seldom of any importance in 25 volt power output tubes, such as type 43. The hum voltage is too small for any noticeable output and is less than the hum introduced into the circuit by a common negative lead of an electrolytic condenser. The important source of hum in this type is emission from heater to signal grid.

OPERATING CONDITIONS TO MINIMIZE HEATER-CATHODE HUM

Heaters should not be operated above rated voltage, as hum doubles with a 6% increase in heater voltage.

If self-biasing circuits are used, the 60 cycle impedance should be as low as possible. This is attained by the use of low cathode resistance and high capacity by-pass condensers and is particularly important in the early stages of a high gain A.F. amplifier. Use of fixed-bias avoids this source of hum.

Tubes having comparatively small leakage, used as biased detectors, frequently hum as the cathode resistor is necessarily high and practical conditions require a small by-pass condenser. The most satisfactory method of avoiding this difficulty is to arrange the circuit to ground the cathode of the detector.

In series heater operation, the tube most critical to hum should be placed nearest ground. This is usually the detector tube in AC-DC receivers. The next tube to be given the preferred position near ground is the converter, as this avoids modulation hum (not caused by heater cathode leakage).

When a transformer is used, hum will be reduced by grounding the center of the heater winding.

Hum can be reduced to a negligible value by use of sufficient bias between heater and cathode to prevent the net voltage reversing. This condition occurs in infinite impedance detectors and certain cathode loaded circuits. See Fig. 8.

Hum, resulting from emission of charges from the heater to other electrodes, is reduced by decreasing heater temperature, by keeping the impedance of the electrode circuits low and by keeping the electrodes constantly biased with respect to the heater.

Balancing or bucking hum in a radio receiver is sometimes resorted to in minimizing total hum. Heater cathode leakage should not be given a part in hum balancing systems as it is too variable.

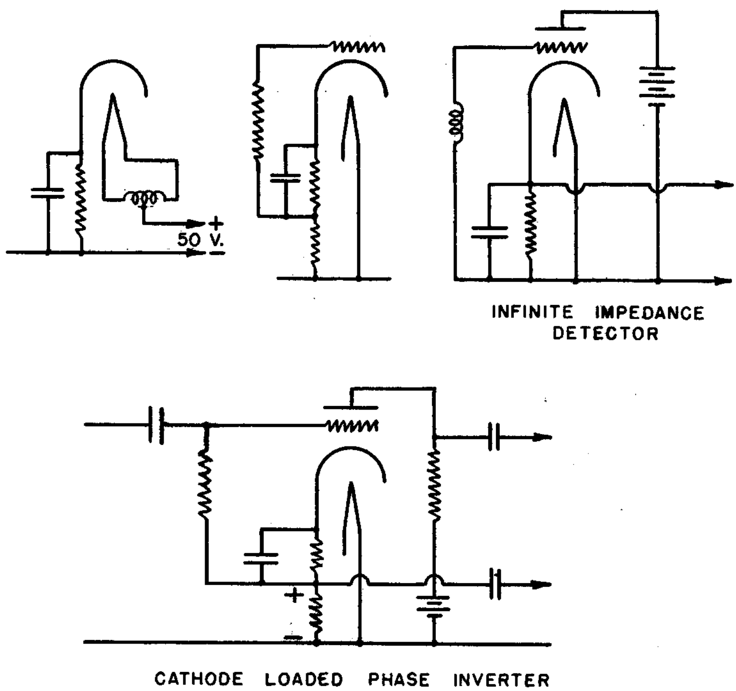

FIG. 8

The two following test methods have been found useful in checking sources of hum:

To test for leakage hum use a 30 µf condenser or a battery whose voltage is equal to the cathode bias. Connect the condenser or battery across the cathode biasing circuit, making the cathode positive, and note the effect on hum. A noticeable reduction of hum indicates the source is heater-cathode leakage.

To test for hum caused by emission from heater to grid, first disconnect the coupling from the orevious tube. If hum is not diminished, continue the test by grounding the grid. Disapoearance of hum indicates emission from heater to grid.

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