V. H.

LB-861

HEATER-CATHODE LEAKAGE HUM REDUCTION BY MEANS OF A SHIELDED HEATER

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Approved

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Introduction

This bulletin describes an improved heater-cathode structure which utilizes a metallic shield interposed between the heater and cathode to substantially eliminate hum introduced into the cathode circuit by heater-cathode leakage currents and to reduce the hum introduced by heater-cathode capacitive currents. Two techniques are described for the fabrication of tungsten heater-shields. One technique employs a wrapped tungsten shield and, with this construction, the leakage hum currents were essentially eliminated. The capacitive hum currents were reduced to the point where capacitive currents due to the base leads and socket are of major significance. A second technique employs a sintered tungsten shield but the present results indicate the wrapped shield to be superior and more reliable.

General Discussion

The causes of hum in circuits employing vacuum tubes with a-c operated heaters are well known[1,2,3] and the overall hum level in such tubes has been steadily reduced since their introduction. Representative of the best commercial tubes in this respect are the "low-noise" type 1620 and the more recent 5879.[4] Although the hum level in such tubes is very low, still lower hum levels are frequently desired for many applications. Minimum hum levels[5,6] are sometimes achieved by various circuit arrangements and sometimes by selection procedures which are not always convenient for commercial equipment. Furthermore, the hum level varies widely[7] from tube to tube and is subject to random variations depending on the treatment and past history of the tube.

Among the various sources of hum that are closely allied with the design of the vacuum tube are:

1. Leakage resistance between heater and cathode.
2. Capacitance between heater and cathode.
3. Leakage resistance between heater and other tube electrodes.

[1] J. O. McNally, "Analysis and Reduction of Output Disturbances Resulting from the Alternating-Current Operation of the Heaters of Indirectly Heated Cathode Triodes," *Proc. I.R.E.*, Vol. 20, p. 1263; 1932.

[2] M. Benjamin et al, "Modern Receiving Valves: Design and Manufacture", *Jour. I.E.E.* (London), Vol. 80, pp. 419 and 424; 1937.

[3] W. Graffunder, "Uber das Brummen indirekt geheitzter Verstarkerrohren", *Telefunken Rohre*, Vol. 12, p. 46; April 1938.

[4] D. P. Heacock, R. A. Wissolik, "Low-Noise Miniature Pentode for Audio Amplifier Service", *Tele-Tech*, Vol. 10, p. 31; February 1951.

[5] A. F. Dickerson, "Hum Reduction", *Electronics*, Vol. 21, p. 112; December 1948.

[6] L. Fleming, "Controlling Hum in Audio Amplifiers", *Radio and Television News*, p. 55; November 1950.

[7] "Heater-Induced Hum in Audio Amplifier Tubes", *Tele-Tech*, Vol. 10, p. 58; November 1951.

4. Capacitance between heater and other tube electrodes.
5. Deflection of electrons by the magnetic field of heater.
6. Deflection of electrons by the electric field of heater.
7. Electron emission from heater to grid or anode.
8. Mutual inductance between the heater circuit and other electrode circuits.

The major sources of hum in modern tubes are considered to be (1) the leakage resistance between heater and cathode (unless this electrode is grounded) and (2) capacitance between the heater and other tube electrodes (including the cathode). In practice, hum due to capacitance effects is often minimized by returning the cathode to a center tap (sometimes adjustable) on the heater supply circuit. To minimize the hum due to heater-cathode leakage resistance, advantage is taken of the non-linear character of this resistance and the resistance to the flow of hum currents may be made very high by biasing the heater with respect to the cathode. In addition, the cathode resistor often may be bypassed to provide a low impedance path for the leakage currents. However, the demands of various circuitry often make it difficult to apply these practical expedients and, in any event, to achieve a better performance than these expedients afford it seems necessary to consider what may be done at the source.

Of the major sources of hum, the leakage resistance between heater and cathode is considered by many to be the most significant. In any event, the capacitance effects can, in principle, be eliminated by electrostatic shielding. Recent work[8,9] indicates that the heater-cathode leakage currents are due to the thermionic emission of electrons and ions and the magnitude of these currents depends on the impurities in the heater insulation. The tube design to be described here is directed primarily toward eliminating the effects of heater-cathode leakage currents.

Experimental Tube Construction

A metal sleeve inserted between the heater and cathode, insulated from them, and returned to the heater supply circuit will intercept the alternating leakage currents from the heater and thus prevent the flow of such currents in the cathode circuit. Such a sleeve will also reduce the capacitance between heater and cathode and, consequently, the hum arising from this capacitance. This method of reducing the heater-cathode leakage currents was utilized in the experimental tubes to be described, which were assembled from the type 1620 tube parts in order to achieve an excellent basic tube structure. A cage shield was added to improve the shielding in the glass envelopes used.

Two versions of the cathode-shielded heater structure were tried experimentally. One of these employed a wrapped tungsten sleeve for the shield while the other utilized a sintered tungsten sleeve. The cathode tubing had the same outer diameter as the standard 1620 cathode but was seamless to increase the inside clearance.

The wrapped tungsten construction is shown in Fig. 1a. The 1-mil tungsten sheet was cut to size, about 1-1/16 inches long and about 0.110 inch wide, and formed into a cylinder by wrapping smoothly around a tungsten mandrel 0.029 inch in diameter. This was inserted into

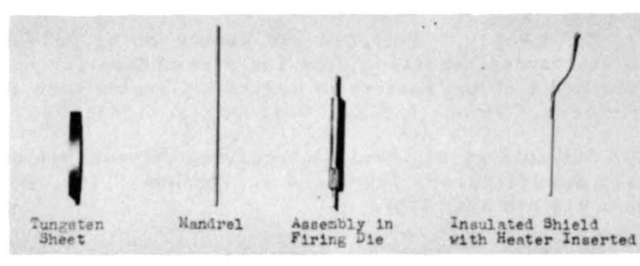

Fig. 1 (a) - Fabrication of wrapped tungsten shield.

a 0.033-inch diameter hole in a cold-rolled steel mandrel. This assembly was hydrogen fired at 1065 degrees C; the steel mandrel was cu

[8] A. R. Shulman, "The Nature of Currents Forming the Basic Component of Valve Hum", *Jour. Tech. Phys.*, U.S.S.R., Vol. 20, p. 1505; 1950. (In Russian). An English abstract is given in Science Abstract, B 3415; 1951.

[9] L. U. Hamvas, C. R. Knight, "Heater-Cathode Current at Low Voltages in Receiving Type Tubes", Report of 11th Annual Conference on Physical Electronics, March, 1951, Massachusetts Institute of Technology.

down to 0.050-inch diameter and the remaining steel was etched away. The resulting sleeve was fired again, the heater inserted, the sleeve sprayed with C-220 (pure alundum) heater insulation to a diameter of 0.039 inch, hydrogen flashed at 1700 degrees C, and assembled in the seamless cathode.

Fig. 1b shows the essential steps in the process of fabricating the sintered tungsten sleeve by powder metallurgy techniques. A 9-mil tungsten core rod was inserted in the heater to give the necessary rigidity and to provide a means of making contact to the sleeve. The assembly was then coated by dipping and brushing with C-267 (alundum and silica) heater insulation, and carefully "drawn" to 0.031-inch diameter through a series of small dies which scraped off the excess wet insulation. This grade of insulation has a relatively high leakage but, after firing at 1700 degrees C, forms a firm substrate for the powdered tungsten. The powdered tungsten was painted to include a core rod contact. The tungsten was sintered and the assembly coated with C-220 insulation spray to a diameter of 0.039 inch. Successful tubes were built using this technique, but some developed cathode-to-heater-shield shorts because of faulty insulation.

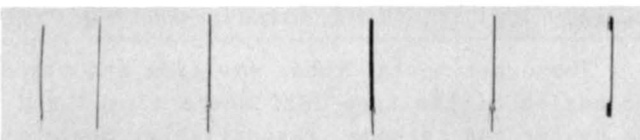

Fig. 1 (b) - Fabrication of powdered tungsten shield.

The completed tubes are shown in the photograph of Fig. 2. The mounts employing the wrapped tungsten cathode-heater structure were enclosed in a hard-glass envelope and molded stem, which gave minimum inter-electrode capacitance when an external shield of silver paint was applied to the envelope. The sintered tungsten cathode-heater structures were mounted in soft-glass envelopes.

Special diodes, constructed to compare cathode temperatures, indicated that the temperature distribution along the cathode was more uniform in the shielded-heater tubes than in the normal 1620, and the temperature was equally as high.

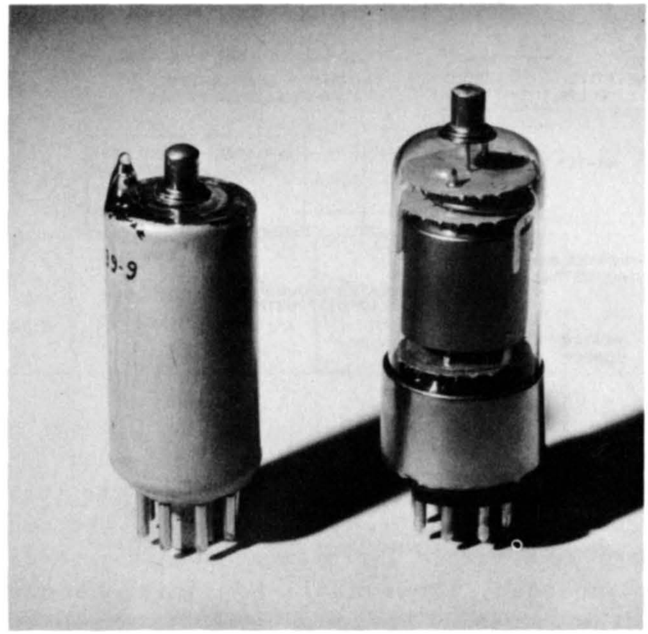

Fig. 2 - Photograph of shielded heater tubes. Hard glass construction is shown at left and the soft glass construction shown at right.

Performance

The tubes were tested by measuring the hum voltage developed across the cathode resistor in the circuit of Fig. 3. For these measurements, the tube elements other than the cathode, heater, and heater shield were placed at a negative potential in order to avoid hum components due to other sources. Tests were made for both leakage and capacitance hum. For the leakage test, the capacitance hum was balanced out by adjusting the variable ground return on the heater for minimum 60-cycle hum while the heater was biased 40 volts positive (the condition for minimum leakage). The effectiveness of the shield was checked by operating with the heater shield grounded and ungrounded. The leakage tests were run by varying the heater bias and recording the leakage current hum components for 60, 120, 180, and 240 cycles using their r-m-s sum as a measure of the leakage current. Fig. 4 compares the results with and without the shield grounded, for the wrapped tungsten sleeve construction. The hum level is smaller than the circuit noise in the grounded-shield case, despite the fact that the General Radio Wave Analyzer used as a detector had only a 4-cycle noise bandwidth.

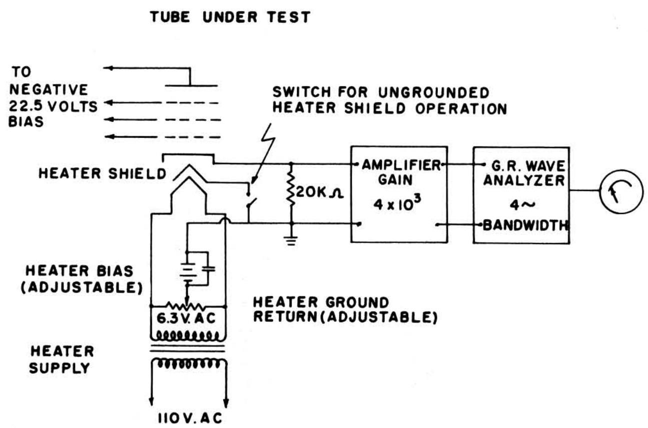

Fig. 3 - Test circuit.

Fig. 5 shows the performance of the tubes with the powdered tungsten shields. Although there is a marked improvement when the shield is grounded, the overall hum level is much higher, and the bias has some effect on the hum. This is perhaps due to the inferior heater insulation used in this tube and perhaps to a somewhat higher unbalance in the capacitance hum.

The grounded heater-shield in the experimental structures reduced the heater-cathode capacitance to about 0.125 μμf from about 4 μμf for the type 1620 structure. The hum due to the flow of capacitance currents will be much reduced in the case of the experimental tubes. An approximate measure of the capacitive hum currents was obtained by biasing the heater 40 volts positive to minimize leakage currents and observing the magnitude of the 60-cycle hum component when alternate sides of the heater were grounded. These measurements are tabulated below along with a computed effective capacitance which assumes that the observed currents were entirely capacitive and include the effect of tube, socket, and wiring capacitances.

The experimental tubes employed the standard basing of the type 1620 where pins 7 and 8 are heater and cathode, respectively. Since the adjacent pin capacitance on a conventional socket is 0.37 μμf, the socket capacitance becomes a major source of capacitive hum in the

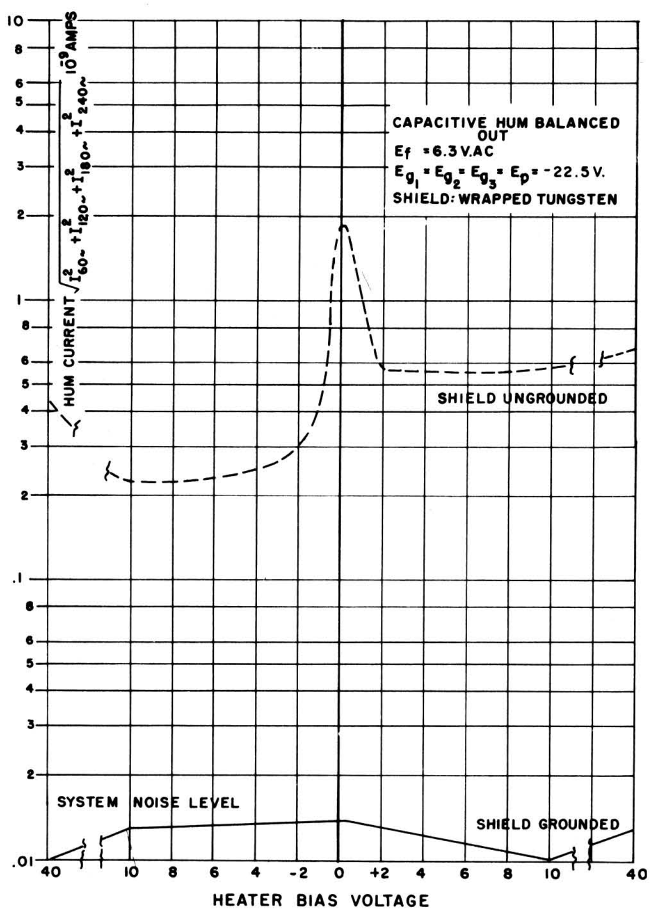

Fig. 4 - Variation of leakage hum current with heater bias for wrapped-tungsten shielded-heater tube.

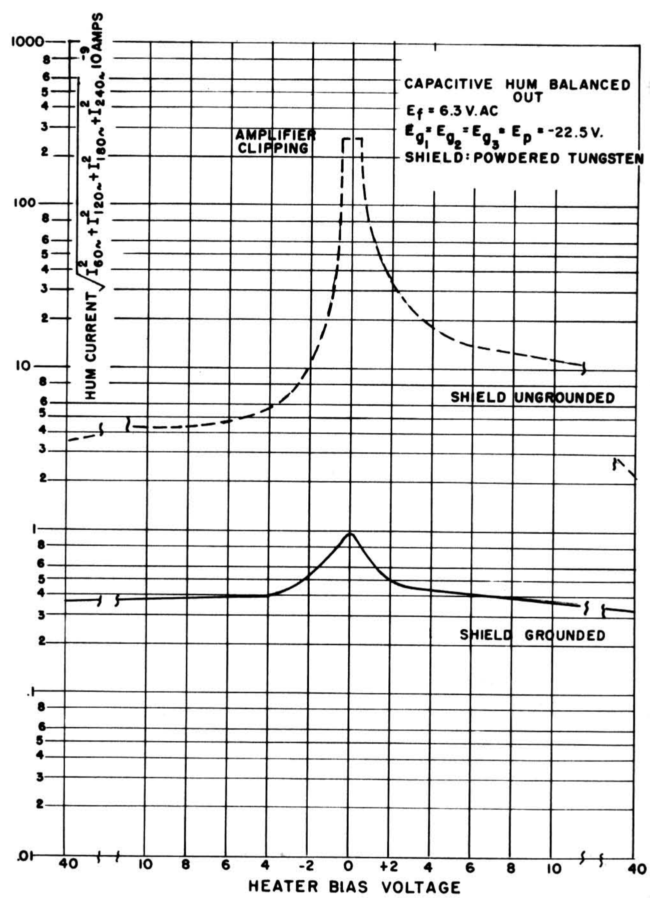

Fig. 5 - Variation of leakage hum current with heater bias for sintered-tungsten shielded-heater tube.

experimental tubes. A revised basing, in which the heater and cathode pins would be separated by a grounded lead, would reduce this capacitance to only 0.05 μμf.

Table

Tube	Hum Current Pin 7 Grounded (10^{-9} amp)	Hum Current Pin 2 Grounded (10^{-9} amp)	Effective Capacitance Pin 7 Grounded (μμf)	Effective Capacitance Pin 2 Grounded (μμf)
Type 1620	5.65	7.38	2.4	3.1
Shielded Heater (wrapped)	0.30	1.61	0.13	0.68
Shielded Heater (Sintered)	0.59	2.95	0.25	1.24

Conclusions

The addition of a grounded shield between heater and cathode is a means to eliminate hum due to leakage and heater-cathode capacitance. Furthermore, this method of hum reduction lends itself to a definitive control of the hum level, independent of the variations due to heater-cathode bias, aging, etc. The wrapped-tungsten-sleeve type construction was found to be more reliable than the sintered-powder technique and has a faster heating time. For further reduction of capacitance hum, than in the present tests, it would probably be necessary to reorient the base pin positions so that a grounded pin would be placed between the heater and cathode. Although the performance of the tubes with respect to other sources of hum was not measured, there is no reason why these should differ from those for the standard type 1620.

While the construction described in this bulletin accomplishes the desired result of reducing hum, this construction is costly. For most conventional applications, the improvement in hum would not be commensurate with the increased cost. This would limit the use of this construction to those applications where hum elimination is necessary irrespective of cost.

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