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ANALYSIS AND REDUCTION OF OUTPUT DISTURBANCES RESULTING FROM THE ALTERNATING-CURRENT OPERATION OF THE HEATERS OF INDIRECTLY HEATED CATHODE TRIODES*

BY

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Summary—*This paper discusses the disturbance currents in the output circuits of indirectly heated cathode triodes, introduced by the use of alternating current in the heaters. It indicates that the disturbance currents are introduced into the output circuit by (1) the electric field of the heater, (2) the magnetic field of the heater current, and (3) the resistance between heater and grid and between heater and plate, and the capacitance between heater and grid and heater and plate.*

The outputs due to the electric field between cathode and plate are produced by the "grid" action of the heater and heater leads. The frequency of the output is chiefly that of the heater supply. The outputs are shown to be effectively reduced by electrostatically shielding the heater.

Disturbance currents of the frequency of the heater supply, and of double this frequency are shown to be produced by the magnetic field. The double-frequency component is shown experimentally to be proportional to the square of the heater current. The following means of reducing the magnetic field are discussed: (1) the adoption of a heater geometry which produces a smaller field in the space between the cathode and the plate, (2) the use of a magnetic shield around the heater system, and (3) the use of a lower current, higher voltage heater.

The ways in which disturbance currents are introduced by leakage resistances and capacitances between heater and grid and heater and plate are indicated, and experimental verification is given for the case of resistance between the grid and heater.

Use has been made of this disturbance current analysis in the development of an extremely low disturbance output tube, which is described.

THE advantages to be obtained by operating the cathodes of the vacuum tubes in radio receiving equipment, public address systems, and talking motion picture reproduction systems directly from alternating-current lighting circuits have long been recognized. The use of alternating current for heating the cathodes produces objectionable disturbance currents of the frequencies of the power supply and its harmonics in the output of the amplifying system. These currents enter the system by induction between circuit elements and directly through the vacuum tubes. It has been found practicable to reduce the disturbance currents produced through cir-

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cuit coupling to any desired level by suitable arrangement of the circuit elements and adequate shielding. The disturbance currents originating in the tube have not been reduced to as low levels as required in some audio-frequency amplifying systems.

Prior to the time when the indirectly heated cathode type of tube became available, operation of the cathode on alternating current was necessarily restricted to the filamentary type of tube. By proper selection of filament voltage and current and by the adoption of certain operating conditions for these tubes it was possible to obtain balancing actions which could be made to reduce the disturbance currents in the outputs by very appreciable amounts.[1] The conditions necessary for the best degree of balance vary from tube to tube and are fairly critical with circuit variations, with the result that the optimum conditions of operation are infrequently obtained in the usual circuit. Because of the amount of disturbance introduced, even the best practical design in the filamentary types of tubes does not permit the satisfactory use of alternating current where amplification from relatively low levels is required.

The introduction of the indirectly heated cathode into the vacuum triode made immediately possible a further extension of the direct use of alternating current as the source of the cathode energy. A heater and cathode unit consisting of a hairpin of tungsten wire mounted in a cylindrical insulator of magnesia or its equivalent, with a tightly fitting nickel sleeve surrounding the insulator upon which is deposited the active cathode material, has been generally standardized in triodes for broadcast radio receiver use. The heater element of such a tube can be operated on alternating current in radio-frequency stages without the introduction of fundamental and higher frequency disturbance currents from the heater supply. However, its use in audio-frequency circuits of flat frequency characteristic down to that of the heater supply is, in general, limited to circuits with gain of the order of 50 db following the first tube operated on alternating current. If such a tube employing alternating current for the heater supply is used in amplifiers with flat frequency characteristics of appreciably greater gain, disturbances from the heater supply are too great to be tolerated.

The amplifying units of sound recording and reproducing systems have over-all gains of the order of 100 db. With a system having this amount of gain, it is possible to use alternating-current supply in heating the cathodes of all tubes only by a sacrifice in the frequency characteristic of the amplifier below approximately 150 cycles or by the toleration in the output of a high level of extraneous noise arising

[1] See bibliography, item 8.

from the heater disturbance currents in the tubes of the earlier stages.

The advantages of using alternating current for cathode supply in high quality sound reproduction amplifiers as well as in public address systems, radio broadcast speech input equipment, and other high gain audio-frequency amplifiers, made desirable the study of heater disturbance current levels and an investigation of means of sufficiently reducing them to permit the use of alternating-current heating on all tubes in such systems. In order to make alternating-current cathode heating generally applicable, its disturbances in the plate circuit of the first tube should be of the same order of magnitude as that of resistance and thermionic emission noises. Alternating-current heating could then be applied to any amplifier whose gain was not limited by these fundamental noise sources.

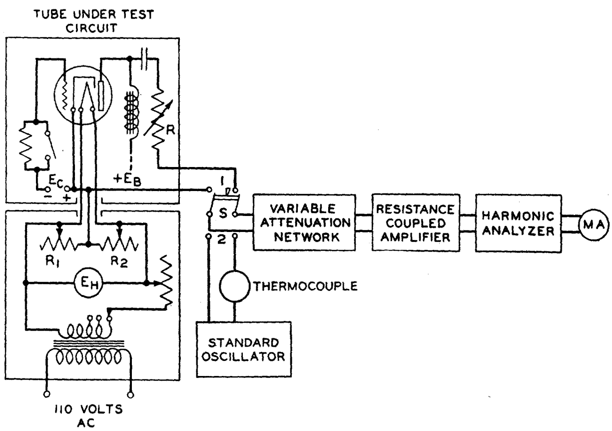

Fig. 1—Schematic diagram of disturbance current measuring circuit.

Measuring Equipment

As a first step in these studies, aparatus was assembled in which the outputs of the frequency of the heater current and its harmonics could be measured separately. The tube, whose disturbance current is to be measured, is placed in a circuit indicated in Fig. 1 as the "tube under test" circuit. The output from the tube is fed through switch *S* into the variable attenuator and hence to the resistance coupled amplifier. The output of this amplifier is applied to the input of the harmonic analyzer which permits the separation and measurement of the fundamental and harmonics of the frequency supplying the cathode power. The analyzer was designed for frequencies between 50 and 350 cycles per second. The frequency of the alternating current used for the cathode supply was approximately 60 cycles per second. The sensitivity of the apparatus was such that a readily readable output was obtained from the analyzer with a current 120 db below 1.0 milliampere (10^{-9} ampere) flowing through a resistance of 600 ohms in the input of the resistance coupled amplifier. In order to evaluate the analyzer readings, a standard oscillator is provided, the known output of which may be fed through the attenuator and amplifier and into the analyzer.

It will be noted that the tube under test obtains its heater power from a transformer, suitable voltage control being obtained by taps and rheostats in the secondary side. The two resistances, R_1 and R_2, shown connected in series across the heater are two 100-ohm decade resistance boxes. Their common point is connected to the common point of the grid and plate circuits. By keeping the sum of the two resistances a constant, a potentiometer is provided by which the cathode can be connected to any potential point along the heater circuit. The position of the common point of the two resistances is indicated by the ratio a/b where a is the resistance between the common point and one side of the heater arbitrarily selected and b is the total resistance of the potentiometer. With a/b either zero or unity, one side of the heater is connected directly to the cathode and the other side varies in potential with respect to the cathode by an amount equal to the heater voltage. With a/b equal to 0.5 the heater is effectively connected to the cathode at its center point and the two heater leads vary in potential with respect to the cathode by equal amounts in opposite phase. In the shunt feed plate circuit the reactance of the choke coil is high and that of the blocking condenser is low compared to the load resistances used. A variable load resistance, R, has been provided and a resistance mounting with a switch, for short-circuiting when desired, has been placed in the grid circuit.

In the assembly of this apparatus in order to prevent pick-up, the heater circuit was separated from the rest of the tube under test circuit by placing each circuit in a copper lined box. To prevent inductive pick-up it was found necessary to place the heater transformer at a distance of several feet from the choke coil in the plate circuit of the tube under test.

The amplifier preceding the harmonic analyzer contained three resistance coupled stages, resistance coupling being used to eliminate the possibility of interference entering through the iron-core coils otherwise necessary. In the harmonic analyzer three tuned circuits discriminate against the unwanted frequencies and the necessary gain is obtained by two shield-grid tubes. A direct-current meter in the plate circuit of a triode operating near the point of plate current cut-off gives a measure of the output. It was found to be necessary to enclose the coil in the first tuned circuit within a magnetic shield in order to reduce sufficiently the interference experienced with other apparatus in operation in and near the laboratory.

Checks were made to note that the modulation in the amplifier was sufficiently small so as not to produce errors in the amounts of harmonics measured. Careful checks were also made to show conclusively that no disturbance currents were being introduced through parts of the circuit other than in the tube itself. In one test the heater of the tube under test was operated on direct current and the outputs of 60 and 120 cycles per second were found to be practically zero. With the heater still operating on direct current, the heater transformer supplied current to a dummy heater in the form of a short length of resistance wire placed as near as possible to the heater terminals of the tube socket; the output of the analyzer continued to remain at zero.

Disturbance Currents in Output of Triodes with Standard Hairpin Heater

The curves of Fig. 2 exhibit typical results of measurements of the fundamental and second harmonic disturbance current outputs as a function of the position of the cathode-heater common point (the a/b ratio) for tubes having an indirectly heated cathode of the usual type of hairpin heater. The measurements were taken with the tubes operating under normal conditions. The plate potential is 135 volts, the grid potential is -6.0 volts and the average plate current is 5.0 milliamperes. The heater voltage is 2.0 volts and the heater current is 1.6 amperes. The measurements were made with a load resistance equal to the plate resistance of the tube and with one or two hundred ohms resistance in the grid circuit. The outputs of fundamental and second harmonic disturbance currents are expressed in decibels below one milliampere. Here 80 db below 1.0 milliampere indicates an output ripple of approximately 1.0 millivolt; 100 db below 1.0 milliampere corresponds to approximately 0.1 millivolt. It will be noted that in most cases the output of fundamental frequency varies with changes in the ratio a/b. Although the minimum level does not occur as regularly at a/b equal to 0.5 as has been observed in tubes having the filamentary type of cathode, there is a general similarity in the relation. The level of second harmonic output is unchanged by variations in a/b. Measurements were also made of the third and fourth harmonic output currents. The level of the third harmonic generated in the tube was so low that it was masked by the presence of third harmonic in the power supply.

120 db below 1.0 milliampere represented an upper limit for the fourth harmonic output.

Measurements were made of disturbance current outputs as a function of the plate potential, grid potential, and of the impedance into which the tube operates. It was found over a considerable range of these parameters that the magnitude of the disturbance currents was proportional to the amplification obtained in the stage and was

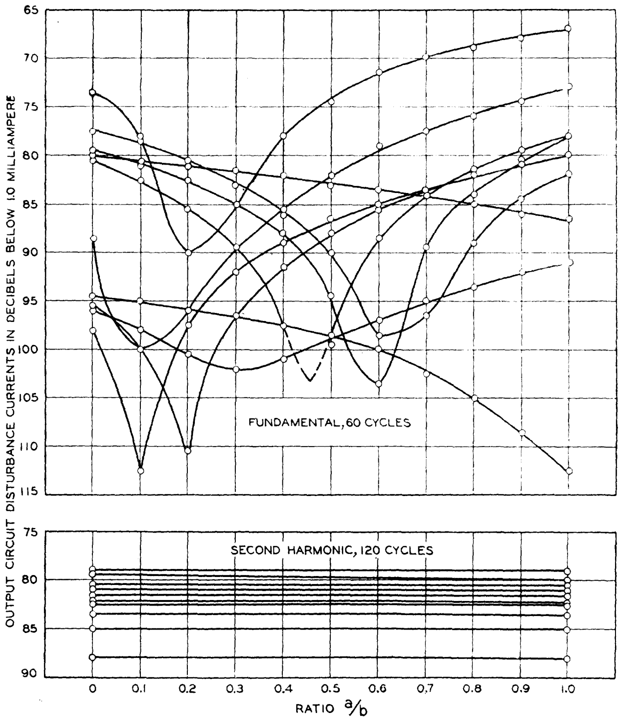

Fig. 2—Disturbance currents in typical indirectly heated cathode triodes used for radio reception.

independent of these operating parameters except as they affect the amount of the stage amplification. The level of the disturbance currents is affected materially by the value of resistance in the grid circuit as will be shown later.

Source of Disturbance Current Pick-up

It may be shown that the disturbance currents are introduced into the output circuit by:

1. Electric field of the heater
2. Magnetic field of the heater current

3. Resistance between heater and grid and between heater and plate, and capacitance between heater and grid, and between heater and plate.

Disturbance Currents Produced by the Electric Field of the Heater

The electric field of the heater element in the space between the cathode and anode will affect the electron current to the plate in precisely the same manner as does the electric field of the control grid. It is to be expected, therefore, that a disturbance current will be found in the plate circuit which is due to the grid action of the heater element.

With one point of the heater circuit connected to the cathode, the electric field of the heater at each point in the cathode-anode space will

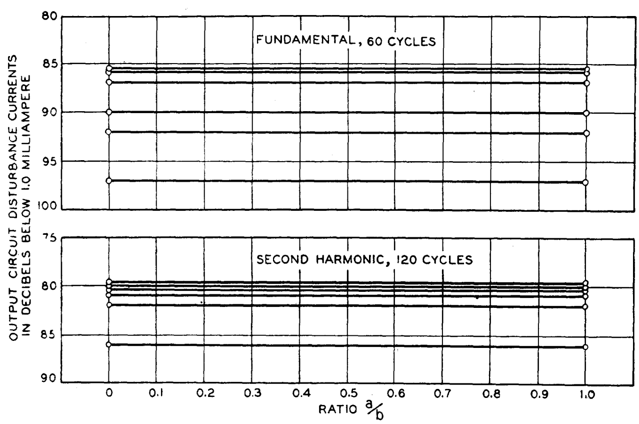

Fig. 3—Disturbance currents in indirectly heated cathode triodes having shields to reduce the electric field of the heater in the cathode-plate space.

be the sum of the fields due to each segment of the heater element. As the common point of the heater and cathode is shifted along the resistance across the heater, the value of the field will change. It would be expected when the common point was located at the symmetry mid-point of the heater circuit that the electric field would have its minimum value.

An examination of the disturbance currents in the output circuit as the common point of the heater and cathode is shifted along the resistance across the heater bears out, in a general way, this expectation. Results on typical standard tubes given in Fig. 2 show that the magnitude of the 60-cycle current in the output circuit does vary with the position of the common point. A definite minimum is shown in most cases. Since in the tubes under test the 60-cycle disturbance current is due to factors in addition to the electric field, the expected characteristic variation of the disturbance current due to shift of the common point is masked to varying degrees in the different tubes.

It should be possible to eliminate substantially the electric field of the heater in the cathode-anode space by adequate shielding of the heater circuit. The nickel sleeve upon which the active material of the cathode is placed acts as such a shield for a portion of the heater circuit. Experimental tubes were constructed in which further shielding was provided. This shielding was made so complete that the electric field of the heater in the cathode-anode space should be substantially zero. The results of disturbance current measurements of six such tubes are shown in Fig. 3. In these tubes there is no variation in the

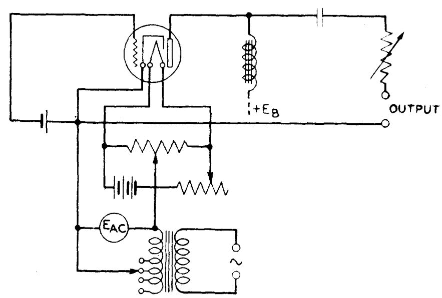

Fig. 4—Circuit for the study of the electrostatic effect in the presence of large disturbance outputs due to the magnetic field.

60-cycle current as the position of the common point is shifted. It, therefore, seems reasonable to conclude that the disturbance currents due to the electric field are substantially eliminated.

The disturbance currents in these specially shielded tubes were due mainly to the magnetic effect of the heater current. In order to get a somewhat better indication of the adequacy of the shielding, an experiment was performed in which the magnetic effect of the heater current was eliminated. The cathode was heated by direct current and a variable alternating voltage was applied between the heater and cathode. The circuit arrangement is shown in Fig. 4. In this experiment the electric field of the heater was different from that when the heater was operated on alternating current. In this case the entire heater circuit was, of course, at one alternating potential with respect to the cathode. However, the adequacy of shielding can well be tested in this manner. In Fig. 5 are given such measurements on the shielded tubes of Fig. 3 and on unshielded tubes that are similar to them in all resects except for the shielding. It will be seen that the shielding has reduced the level of the 60-cycle disturbance current by approximately 40 db.

In our discussion of the electric field disturbance current we have so far limited ourselves to the 60-cycle current. It will be noted that in the

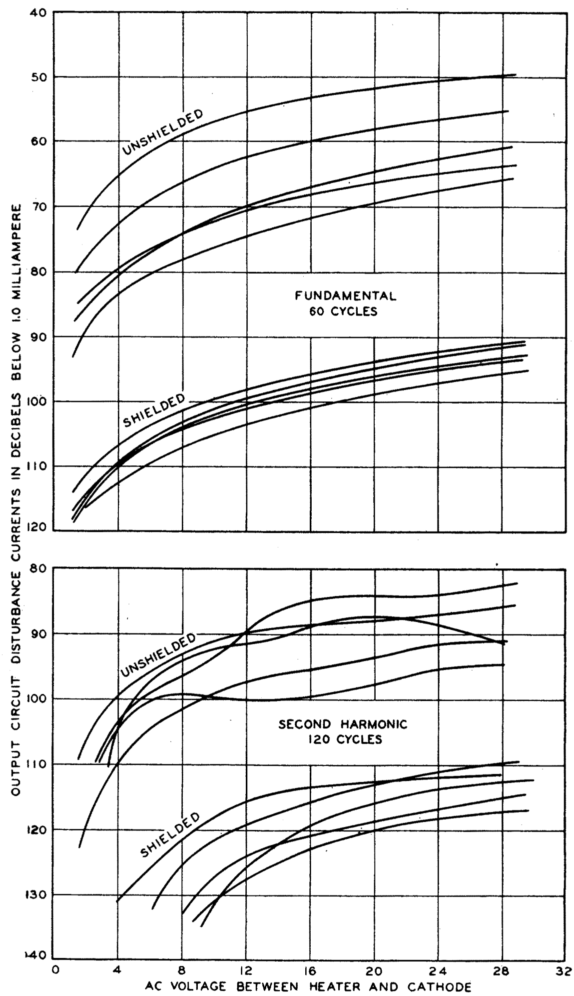

Fig. 5—Disturbance current measurements on shielded and unshielded tubes with the circuit of Fig. 4.

data of Fig. 5, second harmonic disturbance currents are presented and that their absolute value is shifted approximately 30 db by the shielding. While the data given for typical tubes in Fig. 2 do not indicate any variation in the second harmonic current with the position of the common point, we have observed a number of cases of standard heater type tubes where such a variation was present. The evidence from such standard tubes, as well as the data given in Fig. 5, indicates clearly that second harmonic disturbance currents may be due to the electric field effect. The presence of such second harmonic currents is to be expected from fundamental considerations. The grid action of the heater circuit varies in a nonlinear way as the effective voltage of the heater system is changed with respect to the cathode. This nonlinearity of the grid action would be expected to produce second harmonic components in precisely the same manner as they are produced in the familiar case of μ modulation with the standard control grid.

These experiments have indicated the presence of disturbance currents due to the electric field of the heater and have roughly established their magnitude in the case of tubes of standard construction. The substantial elimination of disturbance currents due to the electric field of the heater by adequate shielding of the heater circuit in the experimental tubes, has indicated a possible means of controlling the level of disturbance currents due to the electric field of the heater in the design of standard tubes.

Disturbance Currents Produced by the Magnetic Field of the Heater Current

The magnetic field of the heater current in the space between the cathode and anode will affect the electron current to the plate. The electrons will be deflected by the magnetic field according to the magnetic field force relations.[2] The deflection of electrons by this field causes a double-frequency change in the electron space charge condition which results in a second harmonic component of disturbance current in the anode circuit. Due to asymmetries in the space charge system, the two changes in space charge per cycle of the heater current are not equal. The inequality in the two changes will produce a disturbance current in the plate circuit of the same frequency as that of the heater current.

In order to observe the effect of the magnetic field on the disturbance current output, experimental tubes were constructed with the cathode arrangement shown in Fig. 6. In this arrangement a hairpin heater of the usual type is mounted in a two-hole insulator. A platinum cylinder is placed over the outside of the insulator and is welded to the upper end of the hairpin heater. An electrical connection from the bottom end of this cylinder is made through a lead wire in the press. A second cylindrical insulator fits tightly over the platinum cylinder and the nickel sleeve coated with the thermionically active material

[2] See bibliography, item 10.

is placed on the outside of this insulator. The cathode unit is mounted in a structure having electrical characteristics and electrostatic shields identical with those of the group from which the data of Fig. 3 were taken.

The cathode can be heated to an operating temperature by two different heater systems. In the first system, voltage is applied across the terminals of the hairpin and the platinum cylinder plays no part as a heater unit. In the second system, the two terminals of the hairpin are connected together and the heater voltage is applied across the

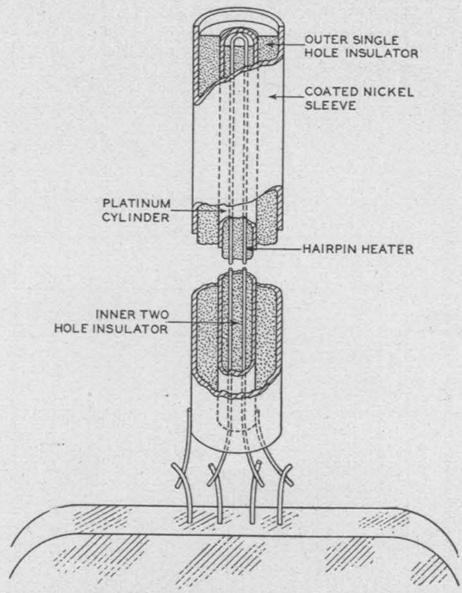

Fig. 6—Experimental heater arrangement for the study of the magnetic effect.

cylinder in series with the two heater legs connected in parallel. Platinum was used in the current cylinder, since it was the most convenient metal that would withstand the necessary temperatures during pumping. The computed magnetic field intensity in the space between the cathode and anode for the second system is approximately one-fourth of that of the first. Due to the fact the platinum cylinder was formed from sheets of insufficient width, the cylinder was not complete, and the field, therefore, was not reduced by the computed amount.

The disturbance current outputs for a number of such tubes were measured with both heater systems and the current due to the electric field was found to be substantially eliminated by the electrostatic shield. The fundamental output is produced by assymmetries that are random and no exact relation between the magnetic field and the fundamental is predictable. In the tubes measured, the fundamental decreased a maximum of 22 db and increased in one tube as much as 9.5 db in changing from the first to the second heater system. Similar measurements made on the second harmonic output indicated a decrease in level in all tubes ranging from 11 to 15.5 db. If the current cylinder had been complete, the reduction would have been approximately 22 db.

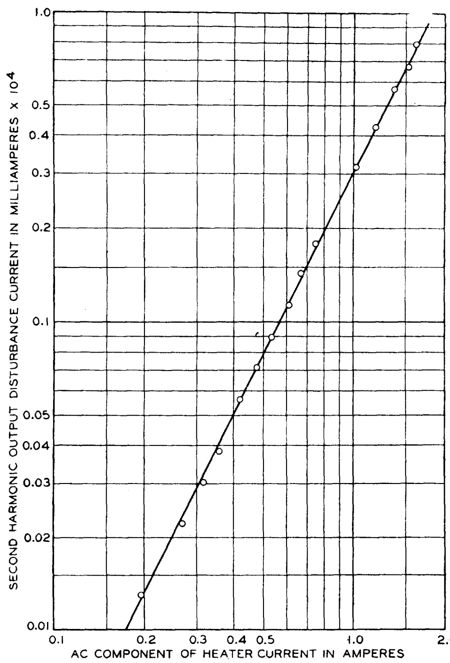

Fig. 7—Second harmonic output disturbance current produced by the magnetic field as a function of the alternating-current component in the heater.

From fundamental considerations it is expected that the second harmonic current would be proportional to the square of the magnetic field. An experimental verification of this square law has been obtained. The heater of one of the tubes, from which the data of Fig. 3 were obtained, having a cathode sheath and an electrostatic shield, was operated on a combination of alternating and direct current.

The alternating-current component was varied from the normal heater current of 1.6 amperes to approximately 0.2 ampere. The direct-current component was adjusted so that at each point the total effective heater current was 1.6 amperes. In Fig. 7 the second harmonic disturbance current in the output circuit is plotted as a function of the alternating component of the heater current. It will be observed that on the log-log coördinate system the points fall along a straight line whose slope is approximately two.

It is evident that in order to reduce the disturbance currents due to the magnetic field of the heater current it is necessary to reduce the magnetic field. Three general methods for this reduction suggest themselves.

1. The selection of a heater element of such geometry that the magnetic field in the space between cathode and anode is decreased.
2. The placing of a magnetic shield around the heater system.
3. Obtaining the necessary heating power for the cathode with a higher voltage and lower current heater unit.

The simplest form of heater is a single wire coaxial with the cathode cylinder. The magnetic field at the surface of the cathode is inversely proportional to the radius of the cathode cylinder. To decrease the magnetic field of such a heater the radius of the cathode is increased. For a given cathode area an increase in its radius necessitates a corresponding decrease in its length. Heat losses from conduction at the two ends and uniformity of cathode temperature determine the maximum practicable diameter. Some flexibility in design is permitted by spiraling the heater. Employing a spiral diameter sufficiently small compared to that of the cathode, the field at the cathode surface is substantially the same as that due to a straight conductor in the axis of the cylinder. The optimum practicable heater of this type offers less possibility in the reduction of the magnetic field than any of the other heater arrangements considered.

The hairpin type heater is probably the simplest form in which partial neutralization of magnetic field is obtained by the form given to the heater. In this unit the magnetic field produced by one leg is neutralized in part by that of the other leg. In this type of heater the maximum field at the surface of the cathode is proportional to $c/(r^2-c^2)$, where c is one-half the distance between the legs of the heater wires, and r is the cathode radius. As c is decreased and r increased, the magnetic field is reduced. The mechanical difficulties in making the twin-bore insulator and increased tendency for its fusion as c is decreased place definite limits on this dimension. The same considerations hold in determining the optimum value of r that hold in the single-wire heater. For the low voltage heaters commonly used in radio receiving tubes the optimum arrangement results in a reduction in second harmonic output due to the magnetic effect of approximately 10 db over that obtained with the optimum single coaxial heater. The tubes on which data were given in Fig. 2 have a hairpin heater corresponding approximately to this optimum design.

A heater composed of two concentric conductors carrying the same current in opposite directions will give substantially no magnetic field at the surface of the cathode. This ideal heater can be approached in a closely wound spiral with a single wire return in its axis. Two spirals of the same diameter with their windings interlaced also give a very small magnetic field at the surface of the cathode. Experimental tubes having heaters of optimum practicable design of these two types have been made. The results obtained indicated some improvement in the second harmonic output produced by the magnetic field over levels noted in comparable hairpin heater structure. The improvement was of the order of 15 db. There are serious manufacturing and quality control difficulties with such heater units.

The magnetic field in the space between cathode and anode for the hairpin type of heater can be reduced by surrounding the heater unit with a magnetic shield. Considerable portions of the shield must operate at a temperature of approximately 750 degrees C. It is necessary to find a material which will maintain a high permeability at this temperature. Nickel loses its magnetic properties at approximately 340 degrees C and iron loses its magnetic properties at approximately 750 degrees C. The magnetic properties of cobalt are satisfactory at 750 degrees C, but it is difficult to work cobalt down to the required dimensions. An alloy of iron and cobalt that would maintain a high permeability at a temperature well in excess of the operating temperature of the cathode was prepared.

Experimental tubes with heaters of the hairpin type and having a magnetic shield of this material placed between the insulator and the cathode nickel sleeve were constructed. The second harmonic disturbance current due to the magnetic field was approximately 20 db less in tubes with the magnetic shield than in identical tubes with no shield.

The magnetic field is proportional to the heater current. A reduction in magnetic field can, therefore, be obtained by the use of a heater in which the current component of the power is small and the voltage component correspondingly large. Halving the heater current and retaining the same heater and cathode geometry reduces the second harmonic magnetic component to one-fourth or by approximately 12 db.

An increase in heater voltage raises the level of the electric field components of disturbance current. This must be taken into account in the consideration of heater unit design.

Disturbance Currents Produced by Resistance and Capacitance Between Heater and Grid and Heater and Plate

Heater circuit voltages are introduced into the grid circuit and into the plate circuit through resistance and capacitance between the heater and each of these elements. A circuit diagram is shown in Fig. 8a which indicates the circuit paths. For simplicity, one side of the heater is shown connected to the cathode and the resistances and capacitances from the heater to the other elements are connected to the opposite side of the heater. The grid-heater circuit is shown schematically in Fig. 8b. The heater voltage is indicated as a generator from

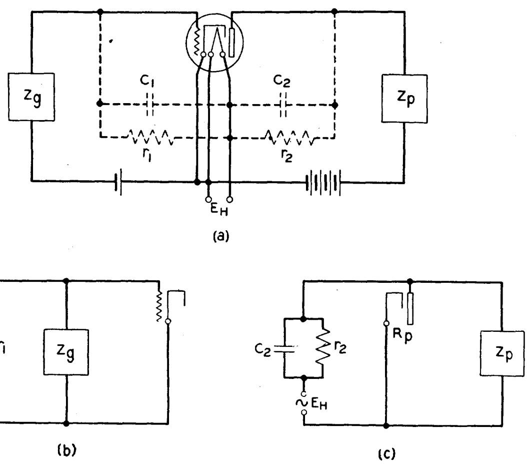

Fig. 8—Diagrams of disturbance current circuits between heater and grid and heater and plate.

which current flows through the grid circuit impedance, Z_g, and through the resistance in parallel with the capacitance between the grid and the heater. The voltage drop across Z_g is applied directly across the grid and cathode so that this voltage amplified will appear in the plate circuit.

The plate-heater circuit is shown schematically in Fig. 8c. The heater voltage is again shown as a generator. It will be noted that in this circuit Z_p is in parallel with the output resistance of the tube, R_p, and that the disturbance voltage is not amplified.

In the usual case the heater will be connected to the cathode at some point other than the end, which makes it necessary to consider two driving voltages and two sets of resistances and capacitances between heater and grid and plate.

An experimental tube was constructed with extremely high insulation and the capacitance between grid and heater was made negligible by bringing the grid lead out of the top of the tube and by having no grid support in the stem press. A resistance of 1000 ohms was placed in the grid circuit and resistances varying in value from 30,000 ohms to 90 megohms were connected from one side of the heater to the grid. The cathode was connected to the opposite side of the heater. Fundamental output disturbance currents were measured for the different values of grid-heater resistance. The results of these measurements are given in Fig. 9. This current was also computed from the relation

$$\frac{E_H Z_g}{r_1 + Z_g} \cdot \frac{\mu}{R_p + Z_p}.$$

It will be seen that the experimental points lie substantially on the computed line which give concrete experimental verification of the circuit relations indicated in Fig. 8.

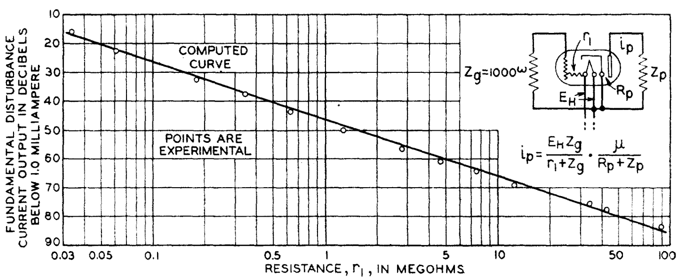

Fig. 9—Fundamental disturbance output current as a function of the grid-to-heater resistance.

A Tube with Extremely Low Level of Disturbance Currents in the Output Circuit

These studies of disturbance currents produced in the output circuit by alternating current in the heater element have been used as a background for the design of a tube with a sufficiently low level of disturbance currents in the output circuit to be satisfactory for use in all voice frequency amplifying systems.

In order to get the required low level of the disturbance currents due to the magnetic field, a low current, high voltage heater was adopted. This heater is a fine wire wound as a close spiral and shaped in the form of a hairpin. It is mounted in a twin bore insulator. The voltage across the heater is 10 volts and current is 0.3 ampere.

To obtain sufficiently low disturbance currents due to the electric field, substantially complete shielding of the heater circuit from the glass press to the top of the hairpin is employed. This shielding is obtained by suitable extensions of each end of the cathode cylinder. The shielding arrangement can be seen in the photograph, Fig. 10.

The capacitance between the heater and grid is materially decreased by the complete shielding of the heater system above the press, and by making the connection for the grid through the top of the bulb. No grid support wires enter the stem press, the grid being supported

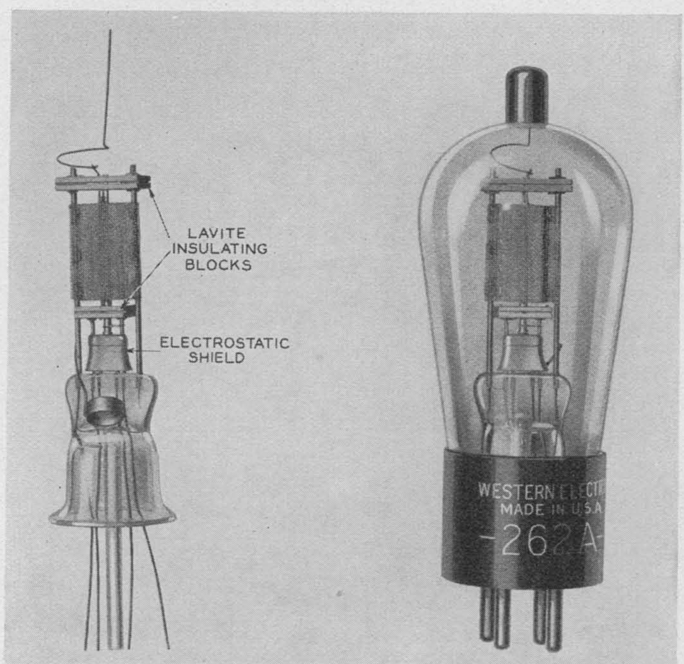

Fig. 10—No. 262A mount and completed tube.

at top and bottom by the lavite insulators shown in Fig. 10. The lead through the top of the bulb is terminated in a cap as is common practice with the control grid in shield-grid tubes. The direct grid-to-heater capacitance has been reduced to approximately 1/1000 of the value common in indirectly heated cathode tubes used in radio reception. No special precautions have been necessary in reducing the heater-to-plate capacity, although some reduction is effected by the heater shielding. This capacity is approximately 1.0 $\mu\mu$f.

The electrostatic shield covering the heater leads effectively prevents the deposit of metal vaporized during the pumping process, and of material vaporized from the cathode during life, from forming a leakage path on the stem press between plate and heater leads. With the tube elements at operating temperature, the resistance between heater and plate is maintained at a value greater than 100 megohms. With the grid removed entirely from the stem press, the insulation between grid and heater is considerably greater than 100,000 megohms.

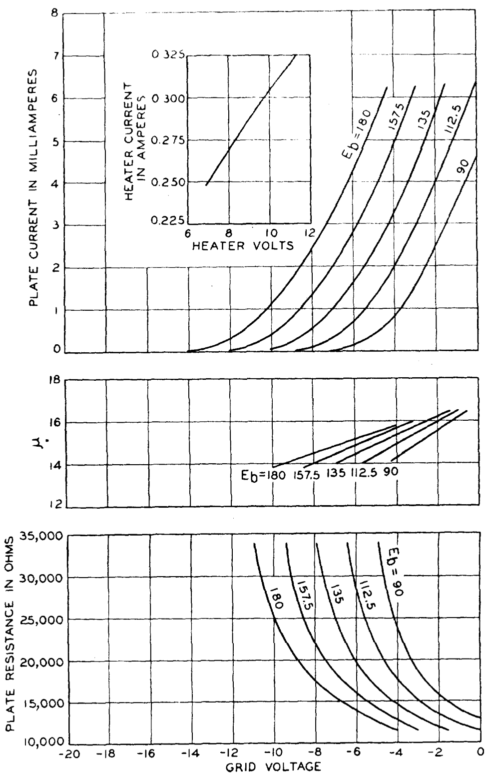

Fig. 11—Electrical characteristics of the No. 262A tube.

When 2.0 megohms are inserted and taken out of the grid circuit, with the cathode connected to the mid-point of the heater circuit, the average change in fundamental output for a representative number of tubes is less than 1.0 db. For the same cathode-to-heater connection the corresponding increase in fundamental output was 25 db for similar tubes in which the grid lead was taken through the stem to the usual prong in a standard five prong base.

The electrical characteristics of the tube are given in Fig. 11. The tube is normally used with a plate potential of 135 volts and a grid bias of -4.5 volts. Under these conditions the plate current is 3.0

milliamperes, the output impedance 15,000 ohms, and the amplification factor 15. The tube is satisfactory for use with a plate potential of 180 volts and a plate current of 10.0 milliamperes. The tube has been given the Western Electric code number 262A. The mount and the completed tube are shown in Fig. 10. Distribution curves of disturbance currents in the output for typical tubes under normal conditions of operation are shown in Fig. 12. The input resistance used here is less than 100 ohms. These data indicate that for $a/b=0.5$, the level of fundamental disturbance current for all tubes is lower than 95 db below 1.0 milliampere (0.27 millivolt), and the level of second harmonic disturbance current for all tubes is lower than 105 db below 1.0 milliampere (0.084 millivolt).

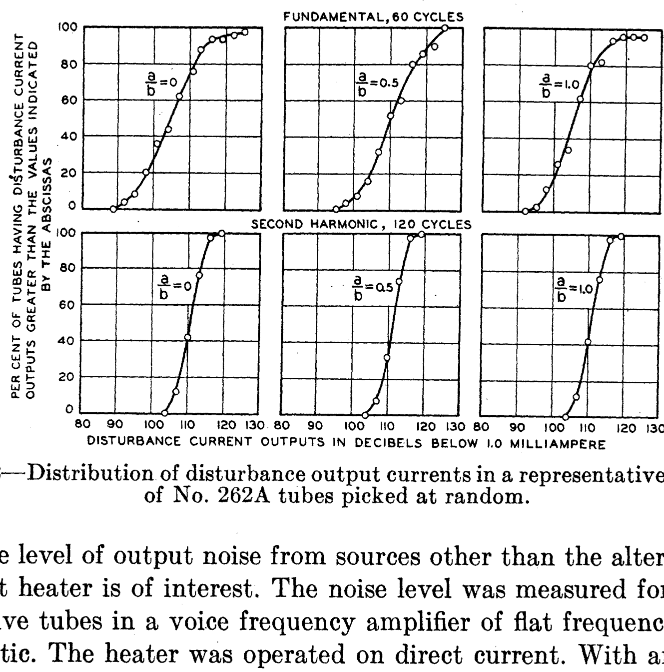

Fig. 12—Distribution of disturbance output currents in a representative number of No. 262A tubes picked at random.

The level of output noise from sources other than the alternating-current heater is of interest. The noise level was measured for representative tubes in a voice frequency amplifier of flat frequency characteristic. The heater was operated on direct current. With an input resistance of less than 100 ohms, the noise level in the output circuit varies between 118 and 127 db below 1.0 milliampere. This noise is principally due to the shot effect from the cathode. With 2 megohms in the grid circuit, the noise level in the output circuit is approximately 105 db below 1.0 milliampere. This noise is substantially all due to the resistance noise of the grid circuit.

In order to obtain a sufficiently high resistance between grid and cathode and grid and plate, and to maintain this value throughout life, special lavite blocks at the two ends are used for mounting the tube elements. These blocks are shown in Fig. 10. They are so designed that there is not a continuous path between any two of the tube elements on the side of the blocks facing the tube elements. This makes it impossible to obtain leakage paths from vaporized metal or material from the cathode.

It is essential that a tube for use in the first stages of a high gain voice frequency amplifier have the lowest microphonic response characteristic possible. In applications which subject the tube to mechanical shock, with even the best possible cushioning and shielding, microphonic disturbance currents may be introduced. Every precaution has been taken in the detailed mechanical design of this tube to make microphonic pick-up a minimum. The top and bottom insulators essential to the maintenance of high resistance have been a material structural aid in reducing microphonic noise levels.

Equipment has been developed in which tubes can be given reproducible mechanical shocks and the microphonic noise currents in the output circuit measured.[3] In this measuring apparatus the microphonic output levels from the No. 262A tube are approximately 20 db lower than from the standard 2.0-volt heater type of tube for radio reception and approximately 10 db better than specially designed filamentary tubes for low microphonic noise level, such as the Western Electric No. 264A tube.

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