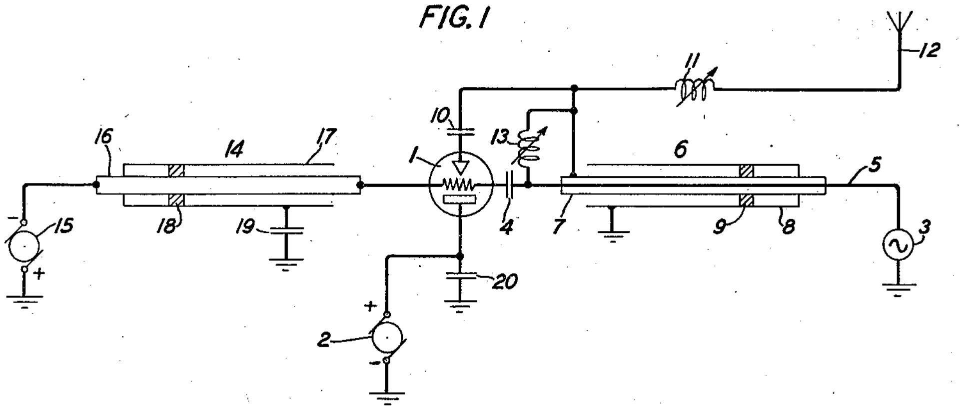
March 16, 1943. W. H. DOHERTY 2,314,132

HIGH FREQUENCY AMPLIFIER

Filed June 21, 1941 2 Sheets-Sheet 1

FIG. 1



INVENTOR
W. H. DOHERTY
BY
B. F. Stoddard
ATTORNEY

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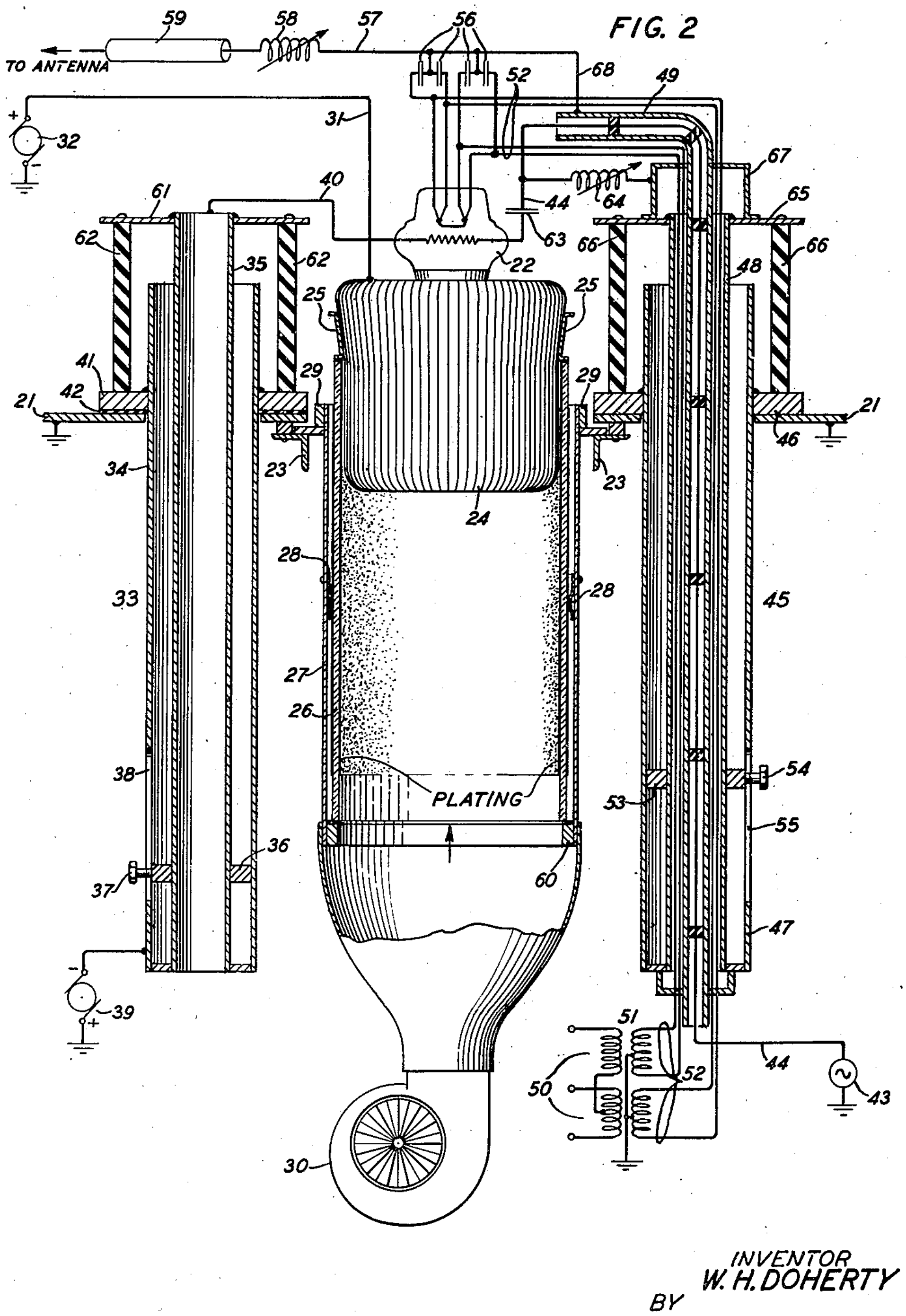
FIG. 2



INVENTOR
W. H. DOHERTY
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B. F. Stoddard
ATTORNEY

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HIGH FREQUENCY AMPLIFIER

William H. Doherty, Madison, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

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8 Claims. (Cl. 179—171)

This invention relates to power amplifiers and, more particularly, to improvements to broad-band power amplifiers for operation at high frequencies.

Objects of the invention are to improve the efficiency and operating characteristics of power amplifiers at ultra-high frequencies; to diminish the adverse effects of the electrode capacities in ultra-high frequency amplifiers; to facilitate transmission of currents in a wide frequency range at ultra-high frequencies; and to simplify the neutralization of power amplifiers for ultra-high frequencies.

In the operation of vacuum tube amplifiers at frequencies of the order of 40 megacycles or greater, the efficient delivery of the high frequency energy requires that the connected load should present a resistive impedance of about the same magnitude as the resistance of the space path within the amplifier tube. When the vacuum tube is operated in the customary manner with the cathode at ground potential for radio frequencies, the capacity of the anode to ground acts as a reactive shunt to the load or utilization circuit and, in general, tends to diminish the effective impedance of the connected load circuit. Where large power outputs are required, the anode must have a superficial area large enough to permit the dissipation of a substantial amount of energy and, because of this, its capacity to ground becomes correspondingly large. The low impedance of the capacitive shunt path so provided may be compensated by the provision of a parallel inductance adjusted to resonate with the ground capacity at the operating frequency. However, at ultra-high frequencies the necessary inductance may be so small that it becomes difficult to construct in practical form and, moreover, tends to give rise to an extremely sharp frequency selectivity quite unsuited for broad-band transmission such as is required, for example, in frequency modulation systems.

In accordance with the invention, the effects of the anode capacity of the vacuum tube are substantially diminished by operating the tube with its anode at ground potential for radio frequency currents and by the use of a novel input circuit which permits the high frequency voltage from a grounded source to be applied between the grid and cathode of the amplifier tube and which at the same time provides a high frequency tuning inductance in the output circuit of the amplifier. The grounding of the anode for radio frequency currents effectively removes its direct capacity to ground from the output circuit and leaves as a shunt to the connected load only the relatively small direct capacity which exists between the anode and the cathode. This capacity is very small and its reactance can be readily neutralized without unduly sharpening the selectivity of the amplifier. Modulated high frequency oscillations from a source grounded at one side are led to the grid of the amplifier vacuum tube through the central conductor of a section of coaxial line, the outer conductor, or shield, of which is connected at one end to the vacuum tube cathode and at the other end to ground and is of such length and configuration as to constitute an inductive path of high impedance between the cathode and ground. In amplifiers for use at ultra-high frequencies, the necessary inductance may be obtained most advantageously by constructing the coaxial input circuit line as the inner conductor of another coaxial line of adjustable length and having its outer shield grounded. Other methods such as coiling the input line might also be used, but the triple concentric line construction has the advantage of providing a high degree of electrostatic and electromagnetic shielding.

With respect to the direct current voltages for energizing the vacuum tube electrodes, the amplifier circuit of the invention is so arranged that the cathode is at ground potential and the anode at a high positive potential. This is the reverse of the conditions with respect to the high frequency potentials and is advantaegous in that it simplifies the insulation of the circuits for furnishing heating current to the vacuum tube cathodes. In accordance with one feature of the invention, the cathode heating current leads are run through a shielded line contiguous with the shielded high frequency input line and cooperating therewith to provide the desired anode-cathode inductance. In the preferred practical form, the shield of the high frequency input line is made in the form of two concentric tubes connected together electrically at both ends and at intermediate points if desired and separated from each other just enough to provide space between them for the cathode current leads. By virtue of this arrangement, the ground capacities of the heating current circuits and transformers are kept out of the high frequency circuits and their deleterious effects on the operating efficiency of the amplifier are avoided. Since the cathode is at ground potential for direct current voltages, the insulating of the supply leads becomes very simple.

Another feature of the invention is the use of a grounded coaxial line section for the neutralization of the interelectrode capacity between the grid and plate of the vacuum tube. Neutralization is effected by means of an inductance connected between the grid and anode of the tube in the manner shown in H. W. Nichols Patent 1,325,879, granted December 23, 1919. The neutralizing inductance is provided by an adjustable length of short-circuited coaxial line, the inner conductor of which is connected to the grid and the outer shield of which is grounded for radio frequencies. Since the anode is at ground potential for radio frequencies, the inclusion of the line element does not add any capacity in shunt to the output circuit.

These and other features of the invention are explained more fully in connection with the following detailed description of the invention with reference to the drawings in which:

Fig. 1 is a simplified schematic circuit diagram showing the application of the principles of the invention to a high-frequency amplifier; and

Fig. 2 is a combined cross-sectional view and schematic circuit diagram of a complete ultra-high frequency, broad-band power amplifier in accordance with the invention.

In Fig. 1 a high-frequency amplifier stage of a radio transmitter is shown to include a triode amplifier tube 1 which is provided with a source of anode current 2. As Fig. 1 is a schematic diagram, certain elements of the energizing circuits have been omitted for the sake of clarity. These would include a high impedance path between the cathode and ground to complete the space current circuit and also circuits for supplying heating current to the cathode. The energizing circuits in a typical amplifier of the invention are shown in detail in Fig. 2. A source 3 of high-frequency input oscillations is connected through a condenser 4 to the control grid of tube 1 by a conductor 5 carried through the inner conductor 7 of a coaxial line section 6. The lead 5 and the hollow conductor 7 form a shielded transmission line supplying the input oscillations from source 3 to the grid of tube 1, and isolating the grid circuit from the anode circuit.

The hollow conductor 7 and the surrounding shield 8 form the coaxial line 6. At the left-hand end, this line is open-circuited and is connected to the anode and cathode, the inner conductor 7 being connected to the cathode through the blocking condenser 10 and the grounded outer conductor 8 being connected to the anode through the blocking condenser 20. The right-hand end of the line 6 is short-circuited by a slider 9 which may be moved along the conductors 7 and 8 to vary the effective length of the line and therefore its reactance. This provides a method of tuning the anode circuit.

An output load, or utilization circuit, extends from the cathode of tube 1 through a blocking condenser 10 and a variable inductance 11 to an antenna 12. A small adjustable inductance 13 is connected across the terminals of the input line between the grid and the cathode for the purpose of increasing the voltage impressed on the control grid of tube 1.

A neutralizing inductance constituted by a section of short-circuited coaxial line 14 of adjustable length is provided for eliminating the feedback effect of the grid-to-plate capacity. This coaxial line section 14 comprises two tubes 16 and 17. The line 14 is open-circuited at its right-hand end, and is short-circuited at its left-hand end by a sliding member 18, the position of which may be adjusted to vary the effective length of the line. The inner conductor 16 is connected to the grid of the tube 1. The outer conductor 17 is grounded through the blocking condenser 19 and consequently is connected to the anode of tube 1 for radio frequencies by virtue of the grounding of the anode through the blocking condenser 20. So long as the neutralizing line is less than one quarter wave-length at the operating frequency, its reactance will be inductive and may be adjusted to the correct value necessary for neutralization by adjustment of the sliding member 18.

In addition to the function of the line 14 for neutralization, the inner conductor 16 is used to supply grid biasing voltage from the source 15 to the grid of tube 1.

As both of the blocking condensers 19 and 20 have one side grounded, any stray capacities introduced by these condensers do not result in any lowered shunt reactances in either the grid or anode circuits of the amplifier.

In Fig. 2, a grounded horizontal shelf 21, constituting a ground plane of restricted area, is employed for supporting an assembly including an amplifier tube 22 by means of rails 23 attached to the shelf 21. The amplifier tube 22 includes a control grid, two cathodes, and an anode 24 having a large superficial surface, external to the envelope of the tube, which is equipped with a cooling fin assembly for forced air cooling. A flanged strip 25 of electrically conductive material surrounds part of the upper portion of the anode 24 and is electrically connected thereto. The lower portion of the anode 24 is inserted into the upper portion of a glass cylinder 26 which is silver-plated on both sides to form a by-pass condenser, corresponding to the condenser 20 in Fig. 1, through which the anode is grounded for alternating current. It is to be noted that the outer plating ends a short distance from both the top and bottom edges of the cylinder 26 whereas the inner plating extends over the top edge of the cylinder 26 and ends a short distance from the bottom edge. The anode 24 is electrically connected to the inner plating of the cylindrical condenser 26 by means of the flanged strip 25 resting on the top edge of the cylinder 26.

The glass cylinder 26 is protected by a surrounding metal shell 27 and is supported at its lower end by a flange 60 on the inner surface of the shell 27. The shell 27 is electrically connected to the outer plating of the cylindrical condenser 26 by a plurality of spring fingers 28 distributed around the inner circumference of the shell 27. The metal shell 27 is provided with a flange 29 at its upper end which rests upon the rails 23 thereby electrically connecting the cylindrical condenser 26 to the grounded shelf 21 and supporting the tube assembly.

An air blower 30 for providing forced air-cooling of the large external fin assembly of the anode 24 is connected to the bottom of the metal shell 27 together with the cylindrical condenser 26 serve as a duct for confining the air stream to the proper path. A conductor 31 extends from the top portion of the anode 24 to a high voltage source 32 for supplying anode current. This is shown as a direct current generator but obviously may be a rectifier.

In order to neutralize the interelectrode capacity between the grid and the anode for the purpose of preventing spurious oscillations, the circuit employs a neutralizing inductance in the form of an adjustable length of short-circuited coaxial line 33. This line is composed of an outer tubular conductor 34 and an inner tubular conductor 35 connected together electrically at their bottom ends. The effective length of the coaxial line section 33 can be varied by adjusting the position of a movable short-circuiting slider, or bridging connector, 36. Control member 37 attached to the slider and extending through a narrow longitudinal slot 38 in the outer tube permits the position of the slider to be adjusted as required.

The inner conductor 35 is connected to the control grid of tube 22 by a conductor 40 which extends from the top of tube 35 to the grid. The line section 33 is supported from the grounded shelf 21 by means of a flange 41 sweated onto the outer tube 34. The flange 41 rests upon a mica ring 42 on the top surface of the shelf 21. The flange 41, the mica ring 42, and the grounded shelf 21 together form a blocking condenser, corresponding to the condenser 19 in Fig. 1, through which the outer conductor 34 is connected to ground. The inner tubular conductor 35 is supported by means of a disk 61 sweated thereto and mounted upon insulating pillars 62 resting upon the flange 41.

A direct current source 39 has one terminal grounded and the other (negative) terminal connected to the junction of the conductors 34 and 35 so that grid biasing voltage is supplied through the conductor 35 to the grid of tube 22.

The radio-frequency input, cathode heating supply, and anode-cathode circuit tuning are provided by means of a compound coaxial line 45. This line comprises an outer cylindrical conductor 47, an intermediate cylindrical conductor 48 and an inner cylindrical conductor 49. The outer conductor 47 is supported by means of a flange 46 sweated to the exterior of conductor 47 and in turn supported by the shelf 21. The intermediate conductor 48 is supported by a flange 65 sweated to its exterior and supported by insulating pillars 66 which have their lower ends mounted on the flange 46. The inner conductor 49 is supported at its upper end by a collar 67 secured to its outer surface and to the flange 65. This construction also forms an electrical connection between the conductors 48 and 49. At the lower end of the line section 45, all of the tubular conductors 47, 48 and 49 are mechanically and electrically connected together as shown. The conductors 48 and 49 may also be electrically connected together at other points along their length, if desired.

The outer conductor 47 and the intermediate conductor 48 form a short-circuited coaxial line of adjustable length for tuning the anode-cathode circuit. For this purpose, there is provided a slider 53 having secured thereto a control member 54 which is adapted for movement along a path of travel determined by a narrow longitudinal slot 55 in the outer tubular conductor 47. The slider 53 electrically connects together the conductors 47 and 48 and by its adjustment the effective length of the coaxial line and, consequently, the value of its effective inductance may be controlled.

Since the upper end of the outer conductor 47 is grounded to the shelf 21, it is connected to the anode of tube 22 for radio frequencies through the condenser formed by the platings on the glass cylinder 26. The intermediate conductor 48 is connected at its upper end to the cathode through flange 65, collar 67, upper end of conductor 49, lead 68 and by-pass condensers 56.

The inner conductor 49 forms a shield for a radio frequency input lead 44. At the upper end, the lead 44 is connected to the grid of the tube 22 through the blocking condenser 63. At its lower end the lead 44 is connected to a radio frequency source 43 of radio frequency oscillations which may be modulated and which it is desired to amplify. The shielded line formed by the lead 44 and the tubular conductor 49 isolates the input to the amplifier from all extraneous high frequencies including the amplifier output. A variable inductance coil 64 connected between the grid terminal of lead 44 and the shielding conductor 49 provides a termination for the line to give an optimum input voltage to the control grid.

The space between the inner conductor 49 and the intermediate conductor 48 provides a shield for bringing in the leads 52 supplying heating current to the cathode of the tube 22. In this way, the heating circuit is isolated from the high frequency circuits of the amplifier and the deleterious effects of the stray capacities of the heating current transformer and leads on the operation of the amplifier avoided.

The cathode of the tube 22 is connected in a two-phase circuit and heating current is supplied thereto through the leads 52 from a Scott-connected transformer 51, the primary of which is connected to a three-phase alternating current line 50.

The output of the amplifier is taken between the cathode and the grounded anode. The connection from the cathode is taken through four condensers 56, one pair of condensers 56 being connected in parallel with one pair of cathode leads 52 and the other pair of condensers 56 being connected in parallel with the other pair of cathode leads 52. The cathode lead continues from condensers 56 along conductor 57, through a variable inductance coil 58, and then through a shielded line 59 to a load circuit, such as an antenna.

What is claimed is:

1. A high frequency amplifier comprising a vacuum tube having an anode, a cathode, and a control grid, a by-pass condenser for high frequencies connecting said anode to ground, a coaxial line section comprising at least three coaxial conductors, an adjustable high frequency tuning reactance connected between said cathode and ground, said reactance being constituted by at least two conductors of said line section, means for adjusting the effective length and reactance of said two conductors, and a signal input circuit connected between said control grid and ground, said input circuit including another coaxial conductor of said line section.

2. A high frequency amplifier comprising a vacuum tube including an anode, a cathode, and a control grid, said anode having a large superficial area, a by-pass condenser for high frequencies connecting said anode to ground, a load circuit capacitatively connected to the cathode, a coaxial line section comprising an inner conductor surounded by two concentric tubular conductors, an adjustable high frequency tuning reactance connected between said cathode and ground, said reactance being constituted by said two concentric tubular conductors, means for adjusting the effective length and reactance of said two concentric tubular conductors, and a signal input circuit connected between said control grid and ground, said input circuit including the inner conductor of said line section.

3. A high frequency amplifier comprising a vacuum tube having an anode, a cathode, and a control grid, said vacuum tube being characterized in that its anode-cathode direct capacity is small compared with its anode to ground capacity, a by-pass condenser connecting said anode to ground, a load circuit capacitatively connected to the cathode, a coaxial line section comprising an inner conductor and a pair of concentric shielding conductors and an outer concentric conductor, an adjustable high frequency tuning reactance connected between said cathode and ground, said reactance being constituted by one of the shielding conductors of said line section together with said outer concentric conductor, a signal input circuit connected between said control grid and ground, said input circuit including the inner conductor of said line section, and a cathode heating circuit including a grounded source of heating current and leads connecting said source and said cathode, said leads traversing the space between said concentric shielding conductors.

4. A high frequency thermionic amplifier having at least one thermionic tube having input, cathode, and anode electrodes, a ground connection, an anode circuit connected between said anode and ground, said anode circuit including a capacitor of substantially zero impedance at high frequencies, a coaxial line, having at least four concentric conductors, an input circuit connected to said input electrode and comprising the inner conductor of said coaxial line, an adjustable output tuning inductance comprising two of the other conductors of said coaxial line with means for connecting one of these conductors to the cathode and means for connecting the other of these conductors to ground for raising the input-cathode potential to a high value above ground.

5. In an amplifier according to claim 1, means for neutralizing the effect of the grid-anode capacity of the vacuum tube at the operating frequency of the amplifier, said means comprising a second section of coaxial line adjustably short-circuited at one end and having its outer conductor grounded for radio frequencies, the inner conductor of said line being connected at its open-circuit end to the control grid of the vacuum tube, and the length of said line being less than one quarter wave length at the operating frequency of the amplifier.

6. A high frequency amplifier comprising a vacuum tube having an anode, a cathode, and a control grid, a by-pass condenser for connecting the anode to ground for high frequencies, a coaxial line comprising a solid conductor surrounded by at least two concentric tubular conductors, an adjustable high frequency tuning reactance connected between the cathode and ground, said reactance being constituted by two of the concentric tubular conductors, means for adjusting the effective length and reactance of said tubular conductors, and a signal input circuit connected between said control grid and ground, said input circuit including the solid conductor of the coaxial line.

7. A high frequency amplifier comprising a vacuum tube having an anode, a cathode, and a control grid, a by-pass condenser for connecting the anode to ground for high frequencies, a coaxial line comprising a solid conductor surrounded by at least two concentric tubular conductors, an adjustable high frequency tuning reactance connected between the cathode and ground, said reactance being constituted by two of the concentric tubular conductors, an adjustably located bridging conductor for short-circuiting said tubular conductors for adjusting their effective length and reactance, a signal input circuit connected between said control grid and ground, said input circuit including the solid conductor of the coaxial line, means including a second coaxial line having an effective length of less than one-quarter wave-length at the operating frequency of the amplifier for neutralizing the effects of the grid-anode capacity of the vacuum tube at the operating frequency of the amplifier, said second coaxial line being short-circuited at one end and having its outer conductor grounded for radio frequencies, means for connecting the open-circuit end of the inner conductor of said second coaxial line to the control grid of the vacuum tube, and a second adjustably located bridging conductor for adjusting the effective length and the reactance of the second coaxial line.

8. A grounded anode power amplifier for amplifying high frequency currents, said amplifier comprising a thermionic tube having an anode, a cathode, and a control electrode, an anode-cathode circuit, a ground connection, a circuit extending from the anode to the ground connection and having substantially zero impedance at high frequencies, a load circuit, a plurality of condensers for connecting said load circuit to the cathode of the vacuum tube, a coaxial line having a plurality of conductors, means for connecting one of the conductors of said coaxial line to the control electrode for providing a high frequency supply line to the control electrode, means for connecting an end of a second conductor of the coaxial line to the cathode, means for connecting a third conductor of the coaxial line to ground, and means for adjusting the effective length of said second and third conductors for providing an adjustable high frequency tuning reactance in the cathode-anode circuit at the operating frequency of the amplifier.

WILLIAM H. DOHERTY.