July 6, 1948. J. B. FISK **2,444,435**

FREQUENCY CONTROL OF MAGNETRON OSCILLATORS

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FIG. 1

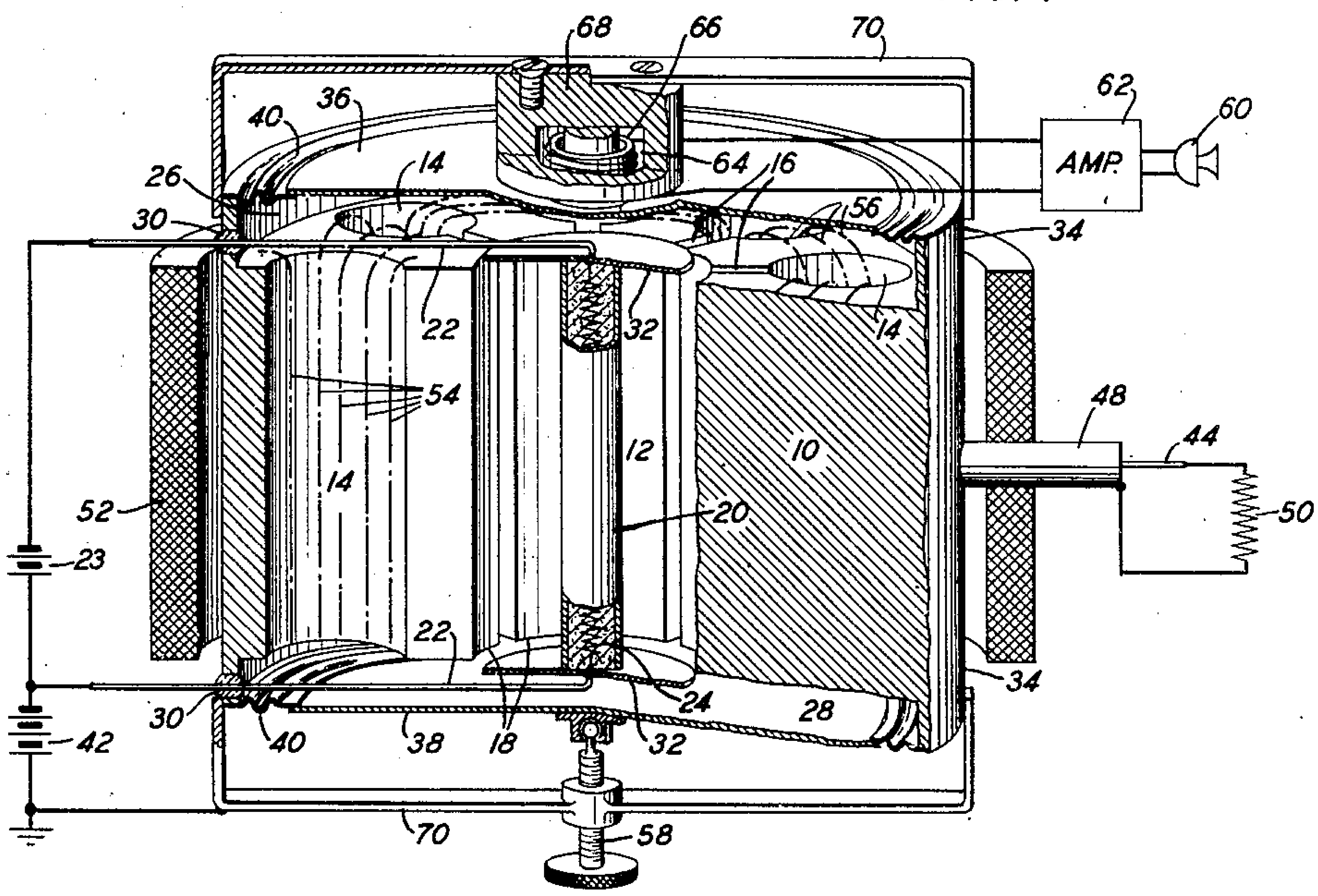

FIG. 2

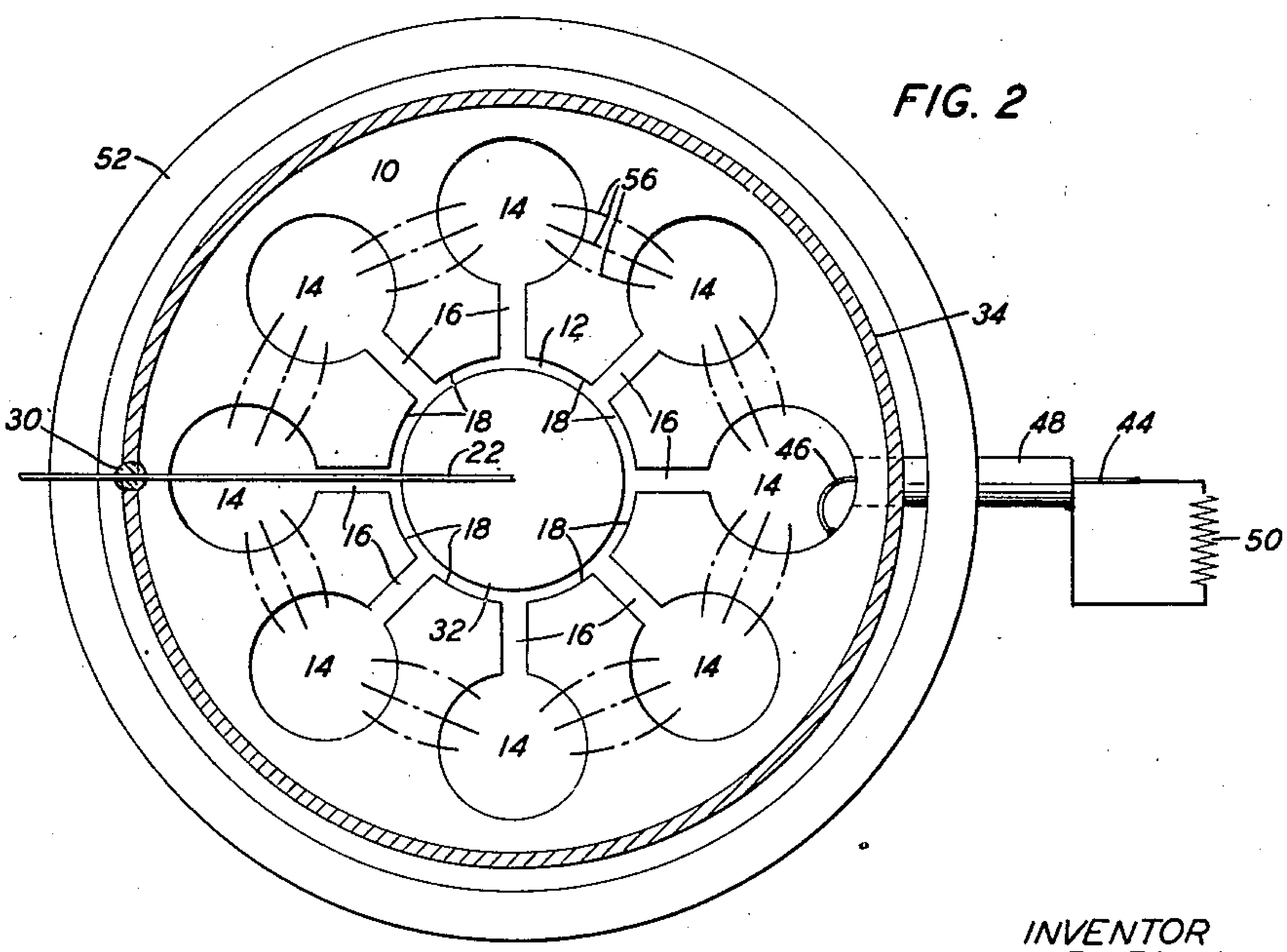

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FIG. 3

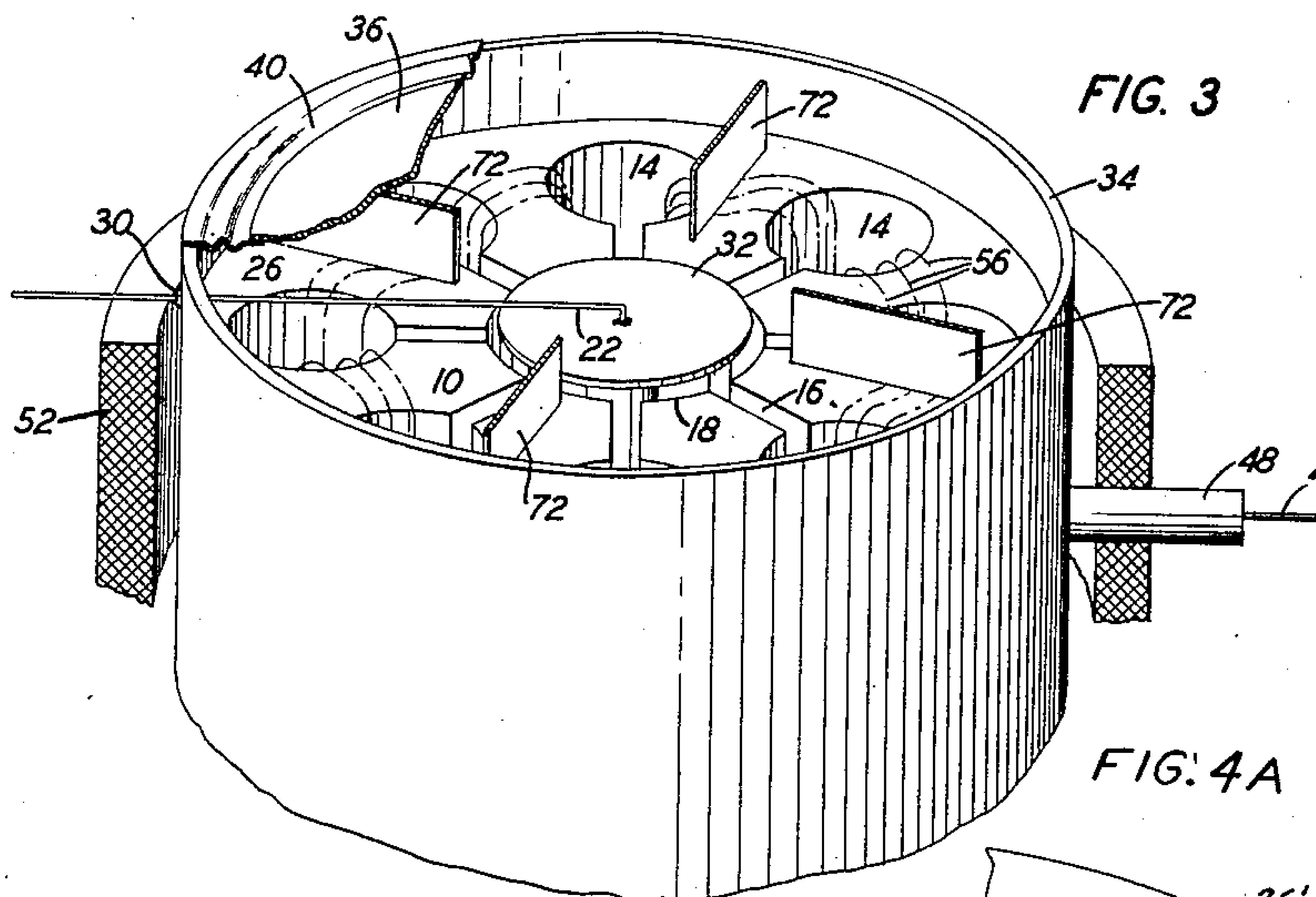


FIG. 4A

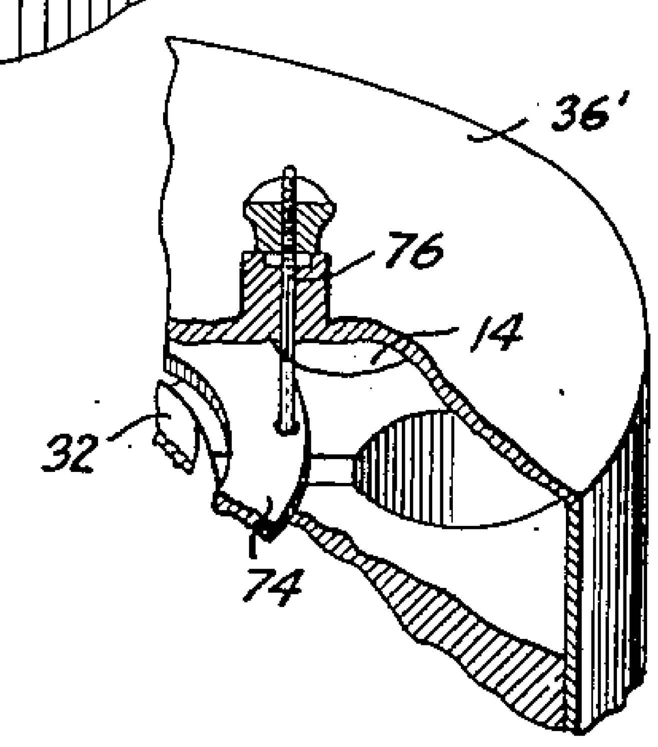
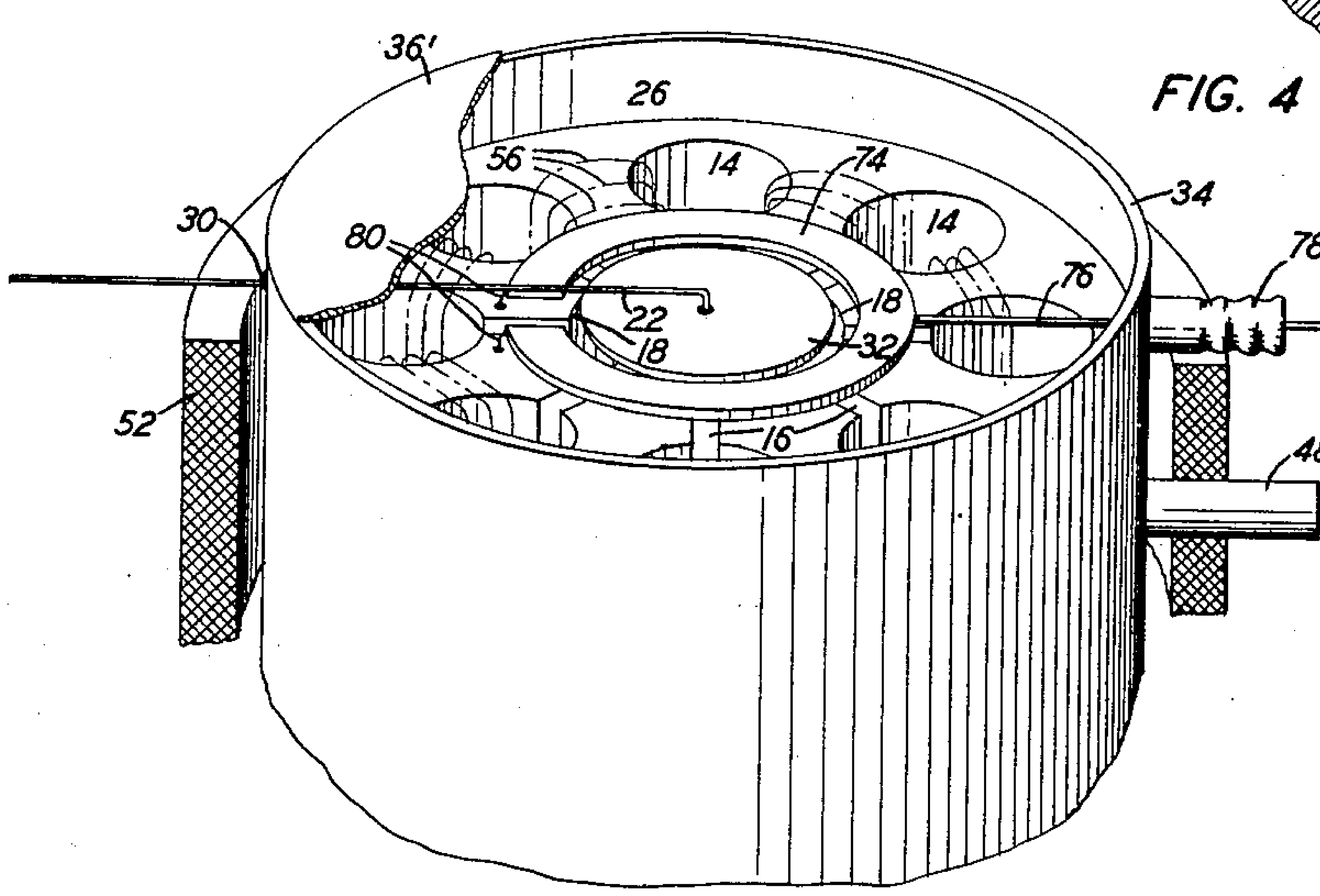


FIG. 4



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FREQUENCY CONTROL OF MAGNETRON OSCILLATORS

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Application May 1, 1942, Serial No. 441,405

12 Claims. (Cl. 179—171.5)

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This invention relates to electron discharge devices and particularly to those devices termed magnetrons in which high frequency oscillations are produced by the curvilinear orbital motions of electric charges under the joint influence of electric and magnetic fields.

An object of the invention is to provide a simple and effective means for adjusting the frequency of oscillation of a magnetron.

A related object is to enable the oscillation frequency of a magnetron to be modulated in accordance with a signal.

In the development of the magnetron art, an important step which was taken in an effort to obtain higher oscillation frequencies than were possible with the original continuous anode surface, was to subdivide the anode into two halves and connect tuning elements, for example inductance and capacity elements, between them. This practice was then further extended by subdividing the anode surface into four, six, eight, etc. separate surfaces, alternate ones being conductively connected together. In all of these arrangements tuning was a comparatively simple matter, being accomplished simply by adjustment of the inductance and capacitance elements, which were normally mounted externally of the magnetron proper, to desired values.

Further efforts to extend the oscillation frequency of magnetrons to higher values were impeded by the limitations inherent in the lumped tuning elements. Accordingly, the art turned to a modified structure such as shown, for example, in Samuel Patent 2,063,342, December 8, 1936, in which the external lumped tuning elements are replaced by cavity resonators disposed within the envelope and close to the discharge or interaction space itself, being coupled thereto by way of openings or channels. The discharge space and the tuning cavities may indeed be machined from a single solid mass which may be mounted within a cylindrical shell and between flat end plates. This departure, though it permits a considerable increase in operating frequency, suffers from the disadvantage that any minute error in the dimensions of the resonators or the channels which interconnect them with the discharge space causes a corresponding error in the oscillation frequency which can be corrected only by remachining the anode structure.

The present invention is based upon the discovery that in a magnetron of this type the cavity resonators, though geometrically separate, are electromagnetically intercoupled, inasmuch as some of the high frequency magnetic flux lines

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which link any one cavity bend over at the ends of the structure to link other cavities, thus providing a mutual impedance coupling between the cavities of each pair of adjacent cavities. They are also capacitively intercoupled, inasmuch as high frequency lines of electric force from one part of the end plate may terminate on the anode structure between two adjacent cavities while other lines of opposite sign may lead from another part of the end plate to another part of the anode structure between another two adjacent cavities. The magnitude of this mutual impedance as compared with the self impedance of each cavity depends in a complex manner on all the cavity deminsions. It depends, in addition, on the cross section of the mutual flux path between cavities, which path is bounded on one side by the anode structure and on the other by the end plate of the magnetron. When oscillations take place in the simplest mode in which the high frequency potentials of alternate anode surfaces are in phase, it appears that an increase in the separation distance between the end plate and the anode structure increases the cross section of this end space flux path and so increases the magnetic coupling between adjacent cavities. At the same time it reduces the plate-to-anode capacitance and so increases the capacitive coupling. Likewise a reduction in the separation distance reduces the magnetic flux path cross section and increases the plate-to-anode capacitance and so reduces both the magnetic and the capacitive coupling. Similar though not identical effects are present when the oscillations are in some other mode. As long as the intercavity coupling is greater than a critical value, increases and reductions in the coupling produce corresponding alterations in the resonant frequency of the magnetron, in accordance with principles which are well known in the coupled circuit art. See, for example, chapter 3 of "High Frequency Alternating Currents" by McIlwain and Brainerd, 1931 edition. Thus the recognition of the presence of substantial amounts of coupling between adjacent cavities, inductive, capacitive or both, leads to a simple and efficient tuning or frequency-modulating system for magnetrons, comprising a movable end plate and means for adjusting its position to produce a desired oscillation frequency or for reciprocating it in dependence on a signal to produce frequency-modulated oscillations.

The change in inductive and capacitive coupling for a given amount of end plate movement may be increased in accordance with a further feature of the invention by the provision of conducting semipartitions or curtain walls which extend part-way between the anode block and the end plate at certain selected points and partly close off the mutual flux path, thus reducing both the inductive and the capacitive coupling for certain cavities without substantially modifying it for others. With this arrangement, a small amount of end plate movement produces a large percentage change in the coupling between certain of the cavities without greatly affecting the coupling between others.

In accordance with a modification of the invention, an additional electrode may be mounted within the end space of the magnetron, preferably parallel with the end plate and close to but separated from the ends of the anode spaces. For example, it may be a horseshoe shaped conductor of sheet metal, mounted at its mid-point on a control rod which extends to the outside of the device. Movement of this control rod, producing axial movement of the horseshoe shaped conductor, causes an alteration of the capacitance which exists between each anode space and the movable member. With this construction a conductor entering the side of the magnetron for applying a potential to an internal electrode such as the cathode or heater, may conveniently be placed between the open opposed ends of said horseshoe shaped member.

The invention will be fully understood from the following description of a preferred embodiment thereof taken in conjunction with the appended drawings, in which:

Fig. 1 is a broken perspective view of a cavity-tuned solid-anode magnetron provided with movable end plates;

Fig. 2 is a plan view of Fig. 1;

Fig. 3 is a broken perspective view of a modification of Fig. 1; and

Fig. 4 is a broken perspective view of a cavity-tuned solid-anode magnetron provided with means for varying the capacitive interanode coupling, Fig. 4A being a fragmentary view of the same to illustrate an alternative means for varying the coupling.

Referring now to Figs. 1 and 2, the body of the magnetron may comprise a comparatively massive block **10** of conductive material, such as copper, into which are cut as by drilling a central discharge space **12** and a plurality of resonant cavities **14** surrounding the same and symmetrically disposed about it. Each of the cavities **14** opens into the discharge space **12** through a channel **16** which serves as a coupling means between the energy of movement of the electrons in the discharge space **12** and the electromagnetic fields within the cavities **14**. The cylindrical surfaces **18** between channels serve as anode surfaces. A central cathode, for example, an elongated cylindrical element **20** whose surface is rendered electron emissive by suitable treatment, may be mounted centrally in the discharge space **12** and supported in place as by conductive rods **22**. To bring it to a state of electron emissiveness, heat may be applied thereto as by a heating element **24**, which may be embedded in ceramic material within the cathode **20** and electrically connected to one end thereof. The heater element **24** may be supplied with current from any suitable source, for example a battery **23**, by way of the cathode supports **22**, which enter the upper and lower end spaces **26**, **28**, by way of insulating seals **30**. Under certain conditions, the operating temperature of the cathode may be maintained after the apparatus has been well started merely by bombardment thereof by electrons which originate on the cathode surface, travel part way through curvilinear paths into the discharge space, and return at high velocities to the cathode. To minimize high frequency power losses over the heater leads **22**, the latter may, if desired, be tuned as by short-circuited coaxial lines in accordance with known techniques.

The cathode may be provided with end discs **32** to maintain space charge conditions within the discharge space at desired values and reduce losses due to the escape of working electrons into the end spaces of the device.

The anode block is preferably mounted centrally in a cylindrical shell or casing **34** of conductive material, such as copper, and connected thereto. If preferred, anode block **10** and the shell **34** may be machined from a single solid mass. In either case the shell may be closed at the ends by end plates **36**, **38** which are preferably of light construction, the closure being completed by flexible metal bellows or elastic ribbons **40**. These end plates **36**, **38**, with the ends of the anode block **10**, define the end spaces **26**, **28** of the device. Operating voltage may be applied between the cathode **20** and the anode surfaces **18** from a suitable source, for example a battery **42**, whose negative terminal is connected to the cathode **20** and whose positive terminal is connected to the anode casing **34** which, since it is external to the cathode and liable to be touched by the hands of an attendant, may be connected to ground. If desired, a varying voltage, e. g. a succession of pulses or a low frequency signal voltage of any desired type, may be applied to the anode **10** to effect modulation of the oscillations.

In operation the cathode and heater leads **22** will be maintained at potentials which are highly negative with respect to the anode block **10** and the end plates **36**, **38**, which define the end spaces through which the heater leads **22** reach the cathode **20** and the heater **24**. To avoid asymmetry of the electromagnetic fields within the end spaces **26**, **28** due to the presence of the low potential cathode and heater leads and also to prevent high frequency induction therein and consequent power loss, these leads **22** are preferably brought into the end spaces in the plane of the axis of one of the tuning cavities. Thus the mutual flux lines emerging from this cavity pass to one side or the other of the leads **22** in such a way that only a negligible quantity of the flux links the leads. By this expedient coupling between the leads and the electromagnetic field in the end spaces **26**, **28** may be reduced to a negligible value.

High frequency energy may be withdrawn from the apparatus when the latter is in a state of oscillation in any known manner, for example, by way of a conductor **44** which extends through the wall of the casing **34** and through the outermost portion of the anode block **10**, to terminate within one of the tuning cavities **14** in a loop **46**, disposed to link a portion of the high frequency magnetic flux within the tuning cavity. This energy thus delivered to the coupling loop **46** may be withdrawn as through a coaxial line **48** and fed to a suitable energy receiver, schematically indicated by a resistance element **50**. An axial magnetic field may be provided in any desired manner, for example by a coil **52**, which surrounds the casing **34** and is supplied with steady current from a suitable source.

Consideration of Figs. 1 and 2 reveals that of the magnetic flux lines 54 which thread each cavity 14, some of these lines 56 may rise through one cavity 14 to its upper extremity, bend over, travel part way through the end space 26 of the apparatus and in turn pass downward through an adjacent cavity 14. Thus these flux lines 56 are common or mutual to adjacent cavities 14 and serve to couple the cavities together.

Additionally, lines of electric force lead by way of the end plates 36, 38 from one side of each cavity 14 to the other, especially about the channels 16 which couple the cavities 14 to the central discharge space 12, since it is here that the high frequency voltage between adjacent anode surfaces 18 is greatest. Indeed, were it not for these mutual electric and magnetic fluxes and the consequent coupling afforded thereby, each of the cavity resonators 14 would oscillate at its own frequency with a consequent reduction in the efficacy of the apparatus as a source of controlled high frequency energy. On the other hand, when the cavity resonators 14 are coupled together in this way, especially when the coupling exceeds a certain critical value well known in the theory and practice of coupled circuits, the system as a whole oscillates at one of several discrete frequencies which are by no means identical with the resonant frequency of a single cavity 14 taken by itself. The oscillations are maintained by the movements of the electrons within the discharge space 12. The exact value of each of these discrete frequencies of oscillation depends on the amount of coupling between the separate cavity resonators.

In accordance with the invention, therefore, the frequency of oscillation may be altered, adjusted, or varied in any desired manner simply by altering the amount of the mutual magnetic flux which is common to two or more adjacent cavities, or by altering the electric flux which passes from one anode partition to the next one by way of the end plates 36, 38. Alteration of the magnetic coupling may be accomplished in accordance with the invention simply by altering the cross section of the mutual flux path. To this end, provision is made for moving either of the magnetron end plates 36, 38 toward or away from the anode block 10. Moving them toward the anode block 10 evidently reduces the magnetic flux path cross section and therefore the intercavity magnetic coupling. Moving them away from the anode block increases the cross section and therefore the intercavity magnetic coupling correspondingly. Movement of the end plates 36, 38 effects an alteration in the interanode electric flux and therefore in the coupling, in like manner. As the end plates approach the anode block 10 the capacitance from each anode surface 18 to its neighbors by way of the end plate 36, 38 is increased, and vice versa. The effect of such increases and reductions of coupling is to raise some of the possible frequencies of oscillation and lower others in accordance with principles known in the art of coupled circuits. Thus, depending on which one of the available oscillation frequencies is employed, the oscillation frequency may be either increased or reduced in a substantial amount by movement of either of the end plates.

When oscillations of the simplest mode are in progress, it appears that an inward movement of either of the end plates 36, 38, for example, which reduces the intercavity magnetic flux and therefore the magnetic coupling at the same time increases the interanode capacitance and therefore reduces the capacitive reactance and the corresponding coupling. Similarly, an outward movement of the end plates increases both types of coupling. Thus each end plate movement affects both types of coupling alike, and therefore gives rise to cumulative variations in the oscillation frequency. Whether the result be to increase the oscillation frequency or to reduce it depends on whether the oscillation frequency of the coupled system as a whole be higher or lower than the resonant frequencies of the individual cavities.

Such movement, and therefore such frequency alteration, may be accomplished either for precise frequency adjustment, for example by a thumbscrew 58, arranged to be turned manually to move the plate 38 or it may be accomplished in accordance with a signal by which it is desired to effect a frequency modulation of the magnetron output. Thus, voice signals, for example, fed into the transmitter 60 and amplified by the amplifier 62 are passed to a coil 64 wound on a form 66 fixed to the end plate 36 and lying within the field of a permanent magnet 68. Voice frequency currents passing through the coil 64 cause forces to be exerted which reciprocate the end plate 36 inward and outward and therefore modulate the oscillation frequency in accordance with the voice signals. The magnet 68 and the screw 58 may be supported as by brackets 70 fixed to the casing 34.

In case it be desired to employ metal bellows 40 of such light material that it would be liable to injury by atmospheric pressure, this result may easily be avoided as by enclosing the whole magnetron in an evacuated envelope.

Any other suitable construction which serves to expand and contract the mutual flux path cross section and increase or reduce the electric flux path length may also be employed. Furthermore, such variation of either or both of these fluxes operates to vary the oscillation frequency in any mode, though just what this alteration may be is generally not easy to predict in the case of complex modal oscillations.

Fig. 3 shows a modification of the apparatus of Figs. 1 and 2. It is in the main the same as that described above, and like parts are designated by like reference numerals. It differs by the addition of curtain-like conducting plates 72 which are mounted on the end plates 36, 38 in planes midway between adjacent cavities 14 and extend toward the anode block 10. Such plates increase the change in the mutual magnetic flux for a given axial movement of the end plates 36, 38. Thus, if when in the undisplaced position the edges of the curtains 72 are separated from the anode block 10 by a distance of 2 millimeters, then an end plate movement of only 1 millimeter reduces the mutual flux path by approximately 50 per cent and, consequently, produces a greater change in the oscillation frequency than can be produced with the apparatus of Figs. 1 and 2. Any projection which extends from the end plates into the end space in a region in which flux density is high will operate in much the same way as the partitions to increase the effect of end plate movements.

Fig. 4 shows another modification in which the externally controlled coupling is principally the mutual capacitance between adjacent anode surfaces 18. The structure is in many respects similar to those of Figs. 1, 2, and 3 and like parts are designated by like reference characters. Instead, however, of being movable the end plates **36′**, **38′** are fixed and there is provided internally of the end space defined by the anode block **10** and the end plate **36′** an annular member **74** of sheet metal or other light-weight conducting material. The inner diameter is of the same order as the diameter of the discharge space **12** and its width is of the same order as the depth of the slots **16** which couple the cavities **14** to the discharge space **12**. It thus provides substantial capacitive coupling between adjacent anode surfaces **18** without substantially affecting the intercavity magnetic flux. This interanode capacity may be altered by axial movement of the ring-like member **74** by any suitable means. For example, it may be mounted on a rod **76** which extends outwardly of the end space **26** through a flexible seal **78** for lateral movement as indicated in Fig. 4. If preferred, the control rod **76** may be mounted axially and brought out through the end plate **36′**. Its movements may be imparted by an adjusting screw or the like for manual adjustment or by other means such as shown in Fig. 1 for rapid movements in accordance with a modulating signal. Fig. 4A illustrates this alternative using an adjusting screw for an axial movement of said ring-like member **74**. For convenience of reference the same reference numerals are used as in Fig. 4 to indicate similar elements.

The capacity adjusting member **74** may be a complete ring or it may have the shape of a fork as shown. Its two ends may be directly connected to the anode block as at **80**. While the coupling change is slightly less than with a complete ring for a given movement, the difference is more than compensated by the advantage offered by the space between the tines of the fork, which space serves as a convenient passage for the upper heater lead **22**.

Various modifications of the arrangements hereinabove described will suggest themselves to those skilled in the art, for varying the oscillation frequency of a magnetron by a controlled variation of the intercavity or interanode couplings.

What is claimed is:

1. In a high frequency magnetron device having a plurality of spaced anode surfaces interconnected by a like plurality of open-ended cavity resonators, and in which adjacent anode surfaces and cavities are intercoupled by high frequency electromagnetic fields existing in a region adjacent the open ends of said resonators, a conductive member disposed adjacent said open resonator ends and in a plane substantially perpendicular to the axes of said resonators and means for varying the position of said member to vary said fields and the coupling provided by said fields.

2. In a high frequency magnetron device having a plurality of spaced anode surfaces interconnected by a like plurality of open-ended cavity resonators, an end plate of conductive material disposed in a plane substantially perpendicular to the axes of said resonators and defining with the open ends of said resonators a region in which there exist high frequency electromagnetic fields intercoupling said resonators, and means for varying the position of said end plate to vary said coupling fields.

3. In a high frequency magnetron device having a plurality of spaced anode surfaces interconnected by a like plurality of open-ended cavity resonators, an end plate of conductive material disposed in a plane substantially perpendicular to the axes of said resonators and defining with the open ends of said resonators a path for high frequency magnetic flux linking adjacent ones of said resonators, said flux providing inductive coupling between said cavities, and means for varying the position of said path-defining end plate to vary said coupling.

4. In a high frequency magnetron device having a central discharge space and a plurality of frequency-determining cavity resonators disposed about said discharge space, each of said resonators being coupled to said discharge space by way of an opening, means, independent of said openings, for coupling each of said resonators to an adjacent one of said resonators, and means for varying the amount of said coupling.

5. In an electromagnetic oscillation device for generating high frequency electromagnetic energy, the combination which comprises an evacuated envelope, a plurality of like anode surfaces mounted within said envelope and symmetrically disposed with respect to an axis of symmetry and defining a discharge space, a plurality of symmetrically disposed open-ended cavity resonators, each connecting adjacent members of said plurality of anode surfaces, said resonators being so disposed with respect to each other that when said device is in operation under the joint influence of applied electric and magnetic fields, high frequency magnetic flux lines link adjacent open cavity resonator ends, and means for altering at will the cross section of said mutual flux path.

6. A high frequency magnetron device having anode surfaces defining a central discharge space, a plurality of frequency-determining cavity resonators disposed about said discharge space, and an end plate defining an end space, each of said resonators being coupled to said discharge space by way of an opening and being coupled to said end space by way of another opening, said end space providing a path for high frequency magnetic flux linking adjacent ones of said resonators, the amount of said flux being determined, at least in part, by the cross section of said end space path, and means for varying the cross section of said path.

7. A high frequency magnetron device having anode surfaces defining a central discharge space, a plurality of open-ended frequency-determining cavity resonators disposed about said discharge space, an end plate which with the ends of said resonators defines an end space providing a path for mutual magnetic flux linking adjacent ones of said resonators and serving as means for intercoupling said resonators, and means for varying the amount of said mutual flux.

8. In a high frequency magnetron device having a plurality of spaced anode surfaces interconnected by a like plurality of open-ended cavity resonators, said resonators being intercoupled by high frequency electromagnetic fields existing in a region adjacent the open ends of said resonators, a plate-like member of conductive material disposed adjacent said open resonator ends in a plane substantially perpendicular to the axes of said resonators, a curtain-like semipartition attached to said plate-like member in a plane substantially parallel to said axes and substantially midway between two adjacent resonators, and means for imparting axial movement to said plate-like member and said curtain-like member.

9. A magnetron comprising a linear cathode, a cylindrical anode symmetrically disposed about said cathode and defining a discharge space,

means for producing a magnetic field in the vicinity of and parallel to said cathode, said anode having a plurality of substantially cylindrical grooved portions in its inner wall forming inductances and having portions between said grooved portions forming capacitances with each other, said inductances and capacitances forming circuits resonant at frequencies close to the frequency at which the magnetron is intended to oscillate, means external to said discharge space providing couplings between said resonant circuits, said couplings being such as to determine, at least in part, the oscillation frequency of the magnetron, and means providing an axial movement of said external means for varying said intercircuit couplings to vary said oscillation frequency.

10. A high-frequency magnetron device comprising an anode member having an axially extending space therein and a plurality of resonator cavities disposed about and opening into said space, the openings from said cavities into said space serving to couple said cavities to said space, said member also having an end space enclosed therein into which the adjacent ends of said first named space and of said cavities all open, affording coupling means for said cavities additional to said first named openings, said spaces forming a continuous chamber, a cathode in said chamber, and means in said end space axially adjustable in position to vary the amount of said coupling.

11. A high frequency electrical oscillator of the magnetron type comprising a substantially cylindrical anode of conducting material having therein a plurality of electromagnetically coupled resonator cavities each of which opens into a central space within said anode, said central space and resonator cavities opening at their ends into common end spaces enclosed within said anode, members of conducting material joined to said anode at both ends and providing therewith a substantially complete conducting envelope enclosing said resonator cavities and the chamber

formed by said spaces, at least one of said members being movably joined to said anode by a flexible conductive element to facilitate axial movement of said member, thereby altering the dimensions of the end space associated therewith, means for axially moving one of said end plates in accordance with a modulating signal, means for adjusting the position of the other of said end plates to a desired fixed position.

12. In a high frequency magnetron device having a plurality of spaced anode surfaces symmetrically disposed about a central discharge space and interconnected by a like plurality of frequency determining cavity resonators, said device having an end plate of conductive material defining an end space in which there exists a high frequency electromagnetic field intercoupling said surfaces, a horseshoe shaped conductive member within said end space, juxtaposed with at least two of said anode surfaces to provide a frequency-determining capacitance between each of said last-named anode surfaces and said member, means for axially moving said member to alter its separation from said surfaces and so vary the oscillation frequency of said device, a cathode in said discharge space, a conductor entering said end space through the wall of said device and insulated therefrom, for applying potential to said cathode, said conductor lying in a plane substantially midway between the tips of said horseshoe shaped conductor.

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