Aug. 8, 1961 D. A. WILBUR 2,995,715

MAGNETRON POWER OUTPUT CONTROL

Filed June 3, 1958

Fig. 1.

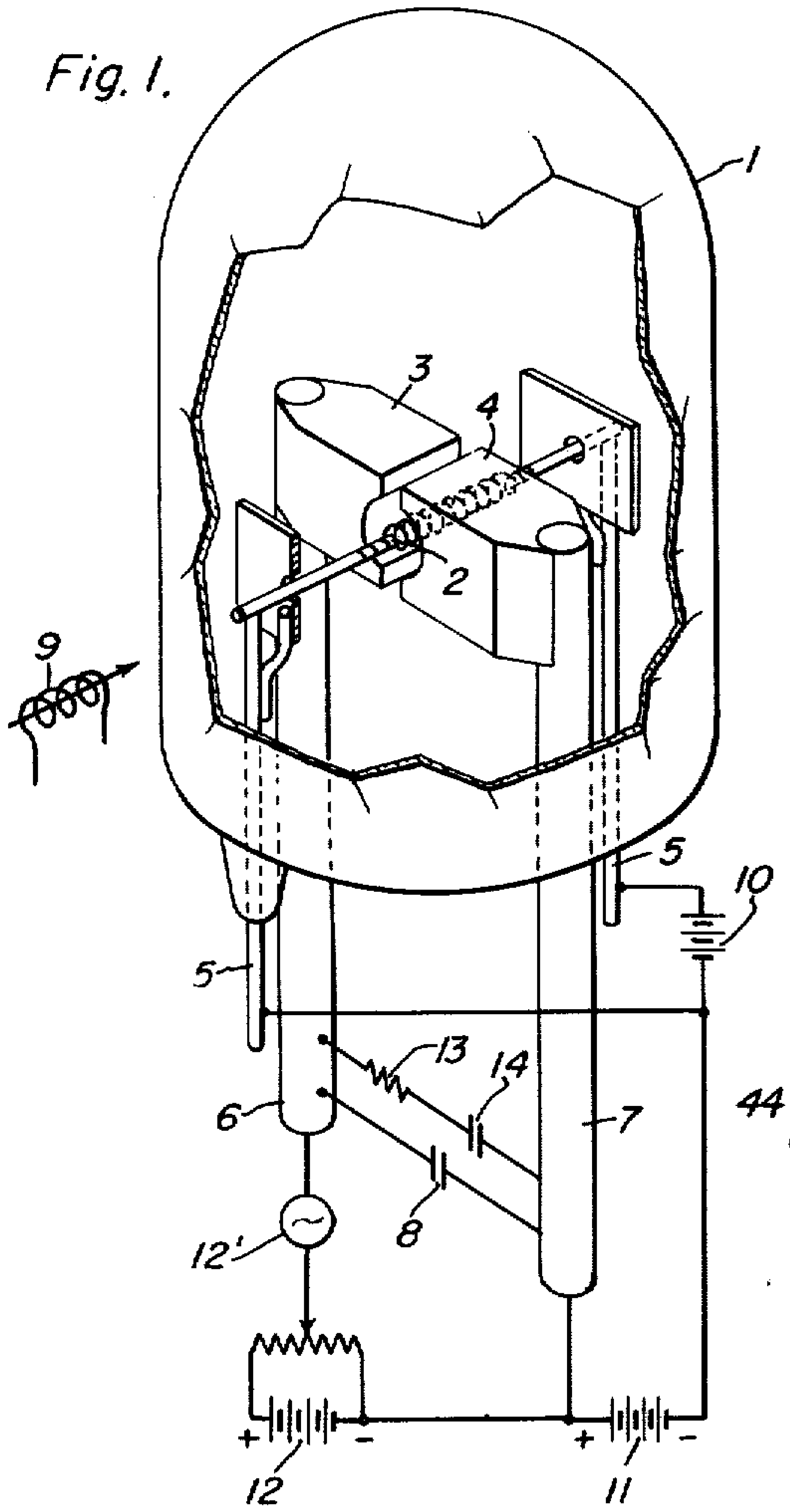


Fig. 3.

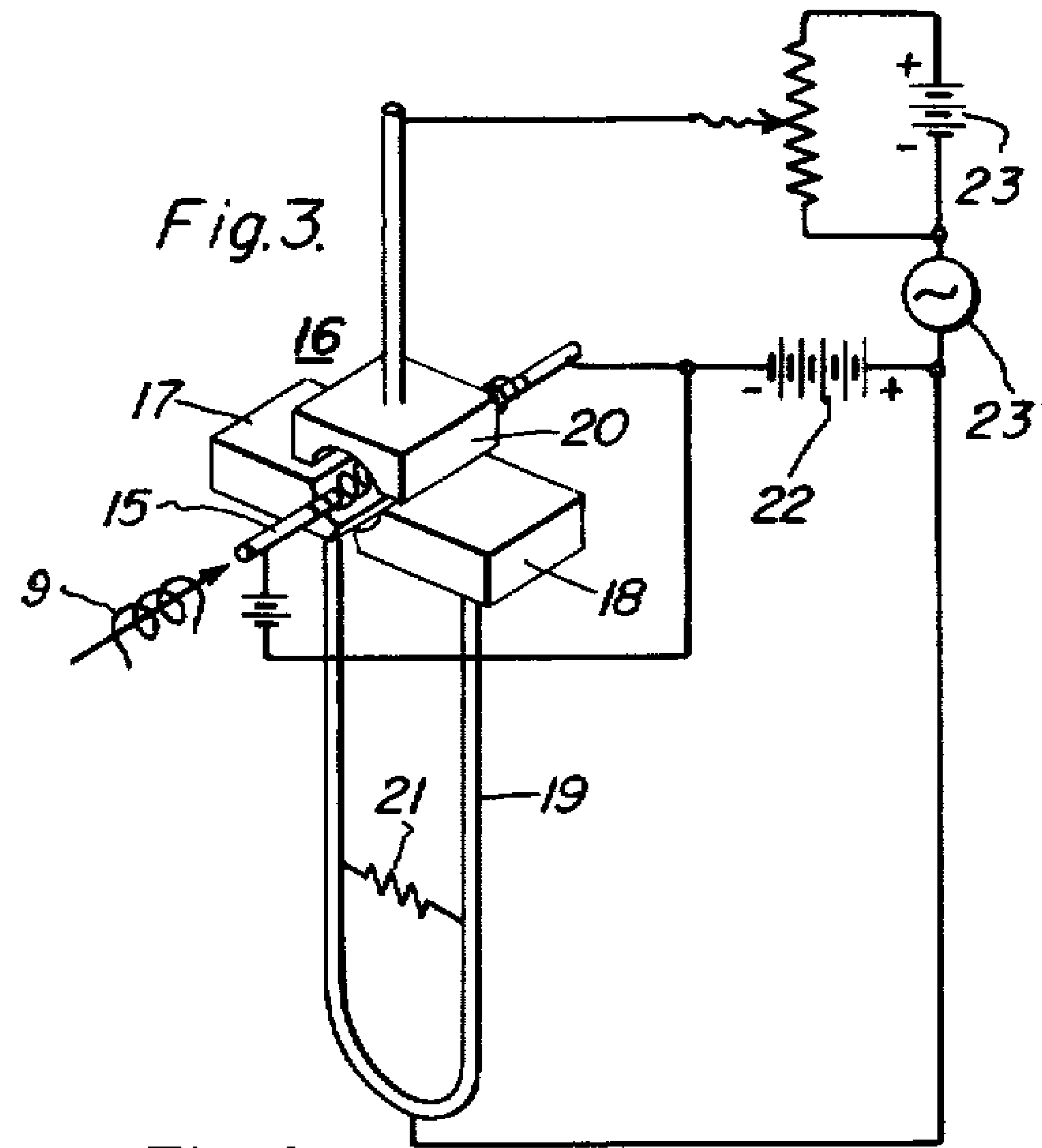


Fig. 4.

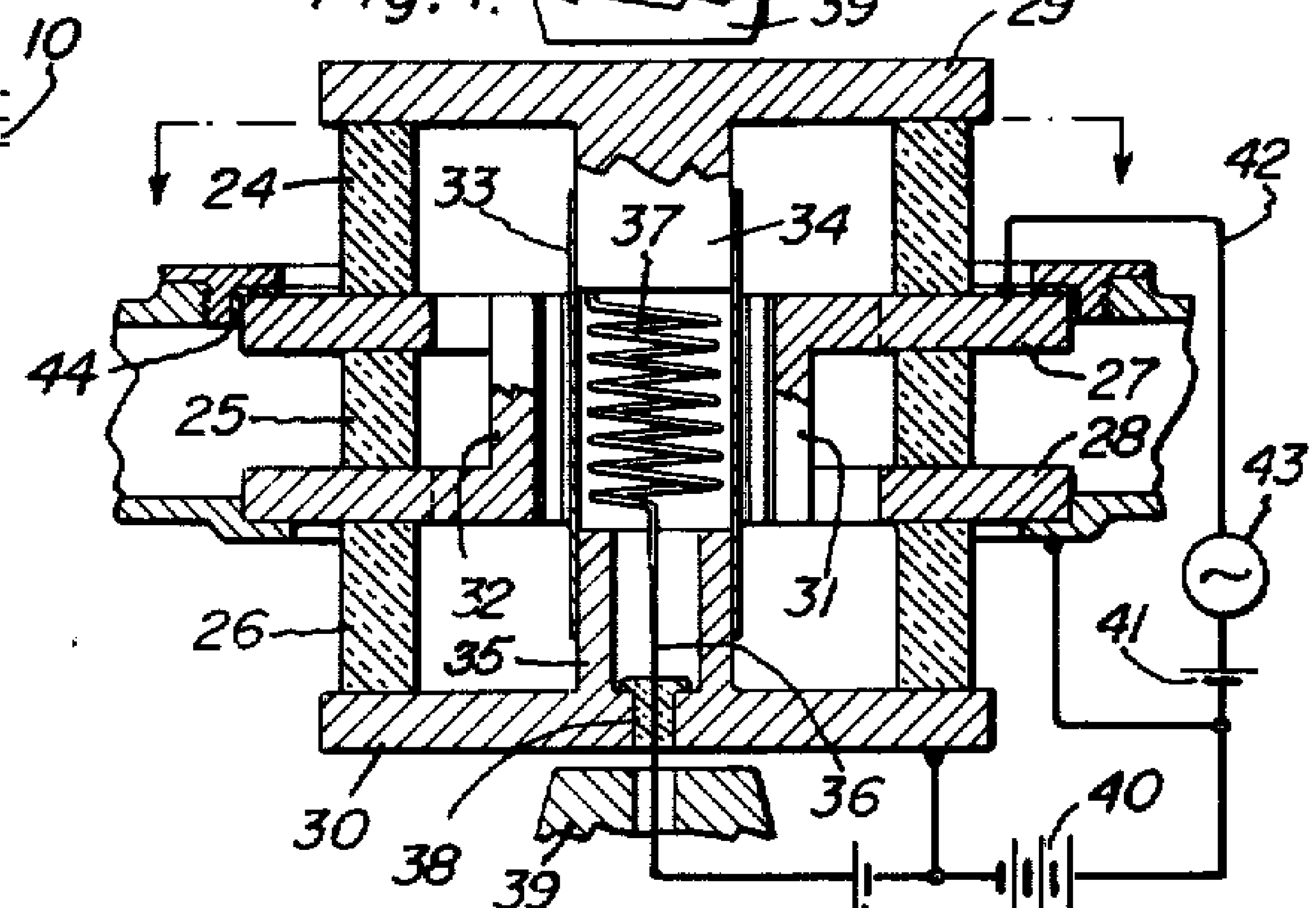


Fig. 2.

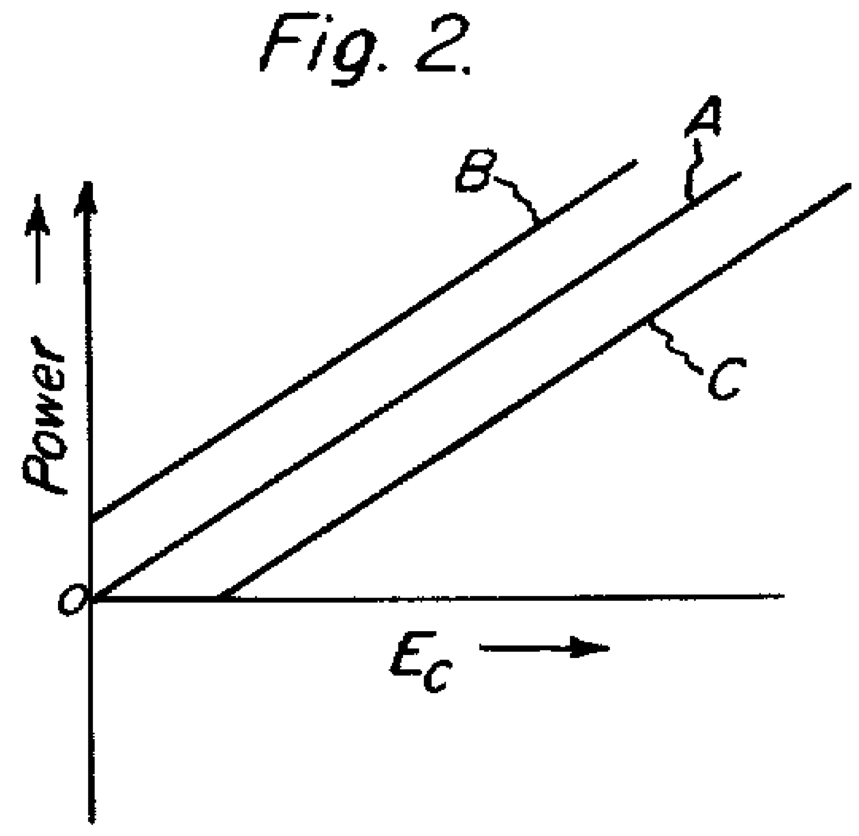
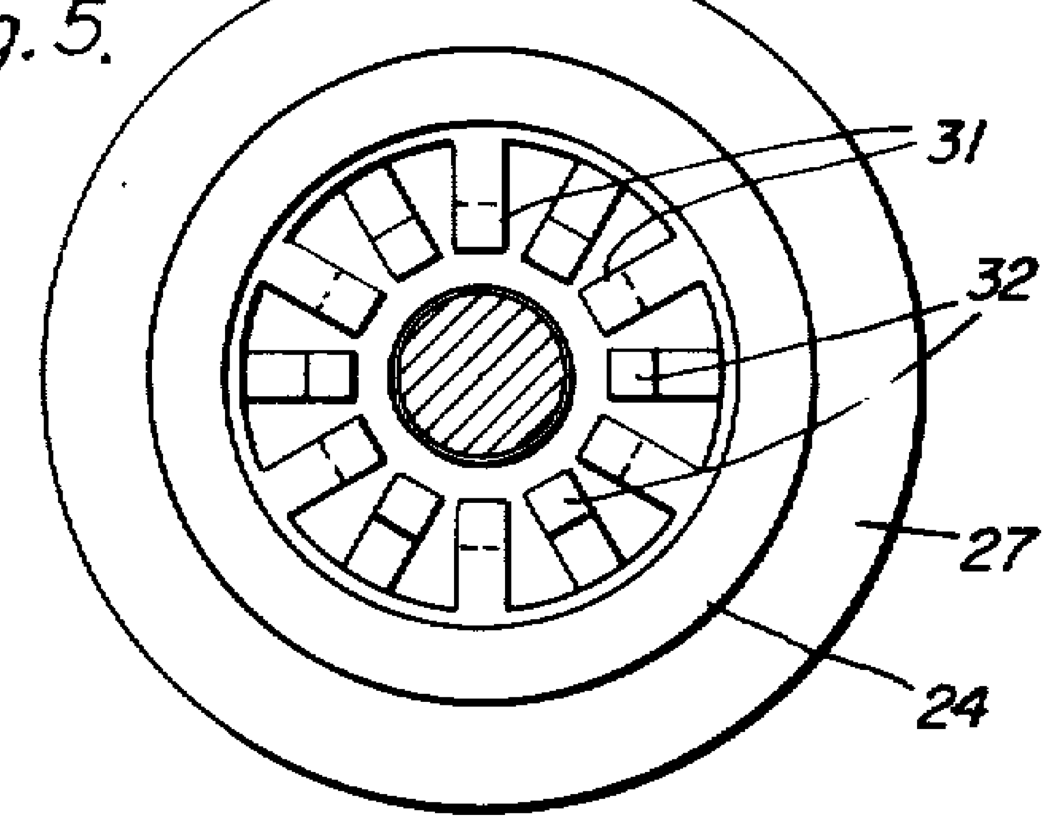


Fig. 5.



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MAGNETRON POWER OUTPUT CONTROL

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8 Claims. (Cl. 332—5)

This invention relates in general to magnetron modulation and has particular reference to means for controlling the power output of magnetron oscillators. This application is a continuation-in-part of my application Serial Number 298,227, filed July 11, 1952, entitled "Magnetron Power Output Control" and assigned to the assignee of this application.

Discharge devices of the magnetron type, particularly of the traveling wave type, have found extensive use as oscillators because of their ability to produce large amounts of high frequency power at relatively high efficiencies. For many applications it is desired to control or amplitude modulate the power output easily and conveniently without changing the magnetic field or the voltage of the direct current power supply. It is furthermore desirable to utilize a control voltage requiring a minimum amount of power from the control voltage source.

It is accordingly a primary object of my invention to control the power output of a magnetron oscillator by an applied control voltage.

It is a further object of my invention to provide a magnetron modulation circuit requiring but a small amount of control power.

It is a further object of my invention to provide a simplified modulation circuit for a magnetron oscillator which does not require variation of either the magnetic or main electric field.

In accordance with my invention, an anode control section comprising one or more segments or vanes of a multi-segment magnetron anode structure is provided with a separate direct current connection and a unidirectional bias or control voltage is connected in series between the control section and the anode voltage source to control the power output in the high frequency resonant circuit. The control section may be a part of the resonant circuit or it may be insulated from the resonant circuit. To the extent the total voltage, i.e., the anode voltage plus the bias voltage, is increased between the control section of the anode and the cathode, the power output of the magnetron is increased. Only a fraction of the energy utilized to accelerate the space charge and thus increase the power output is provided by the control voltage source, however, since the control voltage represents only a fraction of the total voltage impressed on the control section. Loading of the control voltage source is further minimized since very little of the discharge current is collected by the control anode segment or segments despite their higher voltage. Instead, the rotating space charge, which tends to follow equipotential electric field lines, first contacts and is collected by the lower potential segments connected to the power output circuit.

The operation just described in which the space charge becomes bunched and makes several excursions past the anode gaps in synchronism with the high frequency wave on the anode structure is characteristic of magnetron devices and systems which have become known as traveling wave type magnetrons. In these systems energy is transferred from the space charge to the anode structure by the motion of the bunches past the anode gaps. In magnetron oscillators of the negative resistance type the operation is essentially non-synchronous and the energy transfer is accomplished by the collection of electrons on the anode surface which complete the excursion from

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the cathode to the anode in a fraction of a cycle at the frequency of operation.

The features of the invention which I believe to be novel are set forth with particularity in the appended claims. My invention itself, however, both as to its organization and method of operation together with further objects and advantages thereof may best be understood by the following description taken in connection with the accompanying drawing in which—

FIG. 1 represents magnetron apparatus embodying my invention;

FIG. 2 is a set of power output characteristic curves;

FIG. 3 is a semi-schematic view of magnetron apparatus representing a modification of my invention;

FIG. 4 is an elevational view in section of an interdigital magnetron system embodying my invention; and

FIG. 5 is a sectional view taken along the line 5—5 of FIG. 4.

Referring now to FIG. 1 of the drawing an electron discharge device of the magnetron type is shown having an evacuated envelope **1** which is suitably made of glass and within which are mounted a cathode **2** and anode segments **3** and **4**. These segments define between them a cylindrical space charge chamber coaxial with the cathode and are representative of the usual anode segment array of a conventional magnetron of the split-anode or multi-vane type. The cathode **2**, which may suitably take the form of a helix of tungsten wire having a thermionic emissive coating thereon, such as barium oxide, is supported at its ends by conductors **5** sealed through the base of the envelope **1** to provide external terminals. The anode segments **3** and **4** are respectively supported by parallel conductors **6** and **7** which are also sealed through the envelope base.

The parallel conductors **6** and **7** are capacitively terminated at their external ends to define a resonant output circuit. Its frequency is governed by the spacing and length of the conductors **6** and **7**, the capacitance of the terminating capacitor **8** connected across their ends being sufficiently large to present substantially zero impedance at the resonant frequency. The anode segments **3** and **4** are thus isolated for application of different direct current potentials.

In operation a magnetic field is provided in the space charge chamber in coaxial relationship therewith, the means for producing the field being schematically indicated as a solenoid **9** although, of course, magnet means may be substituted. A suitable source of heater voltage conventionally represented as a battery **10** is connected between the cathode terminals **5** to provide the proper cathode operating temperature for emission of the electrons constituting the magnetron space charge.

Unlike conventional magnetrons, however, and in accordance with my invention, all of the anode segments of the anode arrangement, in this case the two segments **3** and **4**, are not operated at the same unidirectional voltage with respect to the cathode. While both segments are connected in circuit to the positive terminal of the anode voltage supply **11**, conventionally represented as a battery having its negative terminal connected to the cathode, an additional voltage is connected in circuit with segment **3**. This added signal is supplied from an additional unidirectional control voltage source **12** connected in series with source **11** with its positive terminal connected to conductor **6** of the output circuit and its negative terminal connected to the positive terminal of voltage source **11**. Segment **3** accordingly serves as the control electrode of the anode array.

The direct current isolation of the anode segments **3** and **4** must be maintained for operation of the magnetron according to my invention and accordingly the output load, schematically represented as a resistor **13**, is connected across the resonant circuit conductors **6** and **7** through the direct current blocking or isolating capacitor **14**.

While the desired modulation of the control voltage may actually be provided by a source **12′** of alternating signal voltage superimposed on a positive bias voltage, it is important, for proper operation, that the instantaneous applied control section total voltage should at all times be at least as high as the anode voltage from the source **11**. The significance of this requirement for maintaining the control characteristics generally desired is analogous to the desirability of preventing the grid current in a conventional triode. In the triode the control electrode should be negative with respect to the cathode; in the present invention the control section should be positive with respect to the anode. Accordingly, it is significant that the additional voltage supplied from the control voltage source **12** is not connected between the cathode and all of the anode segments coupled to the output circuit.

As is well known in magnetron operation, the electronic space charge is acted upon by the radial electric field and the axial magnetic field in the space charge member so that it assumes an average angular velocity about the cathode in a given direction. Assuming the usual π mode excitation of a traveling wave magnetron oscillator, the electrons traversing a gap between adjacent segments at an interval when they are in phase with a fringing alternating electric field between the segments established by the initial excitation of the tuned circuits reinforce the oscillations by giving up part of their kinetic energy to the alternating electric field. Upon losing some of their energy the electrons move toward the anode to regain energy and thus eventually are collected on the anode after an excusion past a number of gaps and usually after a substantial number of revolutions in the interaction space. In this way the space charge envelope is distorted to assume a spoke-shaped form, each spoke corresponding to a region of in-phase electrons having an average angular velocity synchronous with the high frequency electric field of the anode assembly. Since this average angular velocity is dependent upon the ratio of the radial electric field to the axial magnetic field within the space charge chamber an increase in the radial electric field tends to increase the average velocity above synchronism, thus cause a greater interchange of energy from the electrons to the high frequency fields.

Accordingly, upon the addition of the control voltage to the anode voltage on the control segment **3**, the space charge spoke passing under the control anode segment **3** is accelerated and tends to exceed the synchronous frequency. As a result, more energy is transferred to the high frequency alternating fields and the power delivered to the load **13** and **14** increases. Moreover, since the rotating space charge tends to follow equipotential lines most of the electrons of the space charge spokes which have given up their energy or a portion of their energy to the fringing fields between the anode segments are ultimately collected on the segment having the lower potential. Accordingly, most of the collected electron current flows from the cathode through the output segment **4** and returns to the anode voltage source **11** without loading the source **12** of control voltage. As the control voltage is increased the distortion of the static electric field equipotential lines is increased, and hence the loading of the control voltage by collection current increases very little with power output.

As may be noted from FIG. 2, the power output, which in this case is the power dissipated in the resistor **13**, increases linearly with the increase of the positive control voltage Ec superimposed on the anode supply. Curve A, which shows zero power output when the control voltage from source **12** is zero, is obtained when the voltage of the anode supply **11** is just sufficiently high to initiate oscillation. The voltage of the anode supply **11** is adjusted as desired to determine the control voltage at which zero power is obtained, the magnitude of the superimposed control voltage determining the maximum power level. Linear curves B and C of FIG. 2 illustrate this effect.

Since the control voltage from sources **12** and **12′** is also normally but a small fraction of the anode voltage from source **11**, the increased energy imparted to the space charge spokes passing under the control electrodes is derived mainly from the anode voltage source **11**.

Referring now to FIG. 3, a power amplifier utilizing a neutral anode segment as the control electrode is illustrated. The magnetron comprises an elongated cathode **15** surrounded by an anode assembly **16** which defines a cylindrical space charge chamber coaxial with the cathode. Only three anode segments are employed in the embodiment illustrated, two of these segments **17** and **18** being the output segments to which a tuned output circuit **19** is connected. These output segments each subtend an angle of approximately 90° to the space charge chamber axis, thus corresponding in width with the vanes of a conventional four-vane magnetron. The third segment **20** subtends an angle of almost 180° and is normally employed as a neutral element in a magnetron oscillator, being coupled only to a neutral point, so far as high frequencies are concerned, of the resonant output circuit **19**. This anode segment, called a neutrode, maintains the radial electric field in the space charge chamber, and is profitably employed to replace a plurality—in this case two—of the anode output segments. Since the positioning of a full array of anode segments is often difficult, particularly where a large number of segments are desired for higher frequency operation, a neutrode may replace all but one or a few pairs of high frequency coupled segments. A further discussion of the advantages of the magnetron neutrode construction and an explanation of its operation is presented in my Patent No. 2,462,698, issued February 22, 1949, and assigned to the assignee of the present invention.

As further shown in FIG. 3, the tuned output circuit **19**, to which the output anode segments **17** and **18** are connected, is a resonant loop comprising a section of parallel conductor transmission lines short-circuited at one end. An output load **21**, schematically represented as a resistor, is suitably connected across the parallel conductors at a point where a standing wave voltage exists. The midpoint of the loop, which is its high frequency neutral point, is connected to the positive terminal of the anode voltage supply **23** whose negative terminal is connected to the cathode. The neutrode **20**, since it is designed to be neutral so far as the output frequencies are concerned is not coupled to a tuned circuit but is connected directly to a positive tap on a control voltage source **23** whose negative terminal is connected to the positive terminal of the anode voltage supply **22**. The control voltage source corresponds to the signal source **12** of FIG. 1. Modulation of the power output may be accomplished by mechanical movement of the tap or preferably by a source of alternating signal voltage **23′** having an amplitude less than the magnitude of the direct current voltage **23**.

Thus it may be seen that, as in the case of FIG. 1, a radial electric field is impressed between the cathode **15** and the anode assembly **16** with the field intensity under the control neutrode **20** being capable of being increased above that supplied by the anode voltage source **22** due to the super-position of a control voltage. As previously discussed, when a suitable axial magnetic field is supplied in the space charge chamber, the addition of the control voltage to the anode supply voltage provides additional velocity to the rotating space charge to produce a greater power output. Since the radial electric field is distorted from symmetry due to the unbalance caused by the control voltage, the electronic current from the cathode accompanying the increased power output is collected by the output anode segments **17** and **18** which are at a lower

D.-C. potential and loading of the control voltage source is avoided.

It should be understood, of course, that the specific discharge device illustrated in FIG. 1 is by way of example only, as other traveling wave magnetrons may be suitably operated in apparatus embodying my invention so long as the control and power output portions of the anode system are isolated for direct current or low frequency voltages. Greater numbers of vanes or segments may be employed, and for the higher frequency ranges the resonant output circuit may be entirely contained within the device envelope.

In FIGS. 4 and 5 I have shown my invention embodied in an interdigital type magnetron which may be manufactured readily with a substantial number of vanes and is, accordingly, suited to higher frequency operation. As illustrated in FIGS. 4 and 5 the magnetron device includes a generally cylindrical envelope made up of hollow cylindrical insulators **24**, **25** and **26** preferably of ceramic material, a pair of annular anode terminals **27** and **28** and a pair of disk-like end caps **29** and **30**. The insulator **25** mutually spaces the anode terminals **27** and **28** while the insulator **24** separates end terminal **29** from anode terminal **27** and insulator **26** spaces end terminal **30** from the anode terminal **28**. As will be readily appreciated the metal terminals and insulating spacers are suitably bonded together during fabrication of the device to form a vacuum tight envelope. The high frequency or anode structure is provided by two sets of anode sections **31** and **32** supported in a cylindrical array with the sections of each set alternately arranged and with the sections of one set supported from anode terminal **27** and the sections of the other set supported from the anode terminal **28**.

A generally cylindrical emitting cathode sleeve **33** is supported centrally within the array of anode sections from the end caps **29** and **30** by means of conducting posts **34** and **35**. As will be readily appreciated the cathode is preferably coated with a suitable oxide emission enhancing coating and provides a source of electrons within the interaction space defined between the array of anode sections **31**, **32** and the cathode **33**. The supporting post **35** is made hollow to provide for the passage of a heater supply conductor **36** which is connected to one end of a spiral heater **37** supported within the cathode cylinder, the other terminal of the heater being connected with the cathode support **34**. Conductor **36** is sealed through the end cap **30** by an insulator **38** and connected with one terminal of a suitable heater supply voltage source **36'**, the other terminal of which is connected to the cathode terminal **30**. A generally axial magnetic field in the interaction space is produced by suitable means which has been illustrated schematically by the pole pieces **39**.

In accordance with an important aspect of the present invention and in accordance with principles already discussed in this application, one set of anode segments **31** is maintained at a positive voltage with respect to the anode segments **32**. As illustrated in the drawing, the anode terminal **28** with which the anode segments **32** are connected is maintained at a positive direct current voltage by means of a battery **40** connected between the cathode terminal **30** and the anode terminal **28**. The anode segments **31** are maintained at a positive voltage with respect to the anode sections **32** by a biasing battery **41** connected between anode terminal **28** and the anode terminal **27** through a circuit including conductor **42** and also an alternating modulating voltage **43**. As previously discussed, this voltage is of an amplitude smaller than the magnitude of the direct current voltage **41** so that the anode or control anode segments **31** are always positive with respect to the remaining anode sections **32**.

The output circuit for the magnetron device may be in the form of a generally rectangular wave guide suitably apertured to receive the anode terminals **27** and **28**. In order to maintain the direct current isolation required for biasing of the anode segments **31** with respect to the anode segments **32** the high frequency connection between the anode terminal **27** and the upper wall of the wave guide is completed through a dielectric washer **44** to provide a bypass capacitor.

The operation and advantages of my invention as applied to the embodiment of FIGS. 4 and 5 are believed to be understood from the earlier discussion in the application. It is to be noted that the control of modulating voltage is only a small portion of the total voltage of the control anode segments **31** and, accordingly, only a small amount of control power is required. Also, due to the movement of the space charge outward toward the structure as the energy is absorbed from the electrons the majority of the electrons are collected, not on the higher voltage anode segments but on the intermediate lower voltage anode segments **32**. Thus, dissipation of power in the control circuit is kept at a minimum and effective control or modulation of the output power is readily accomplished.

While I have shown particular embodiments of my invention, it will, of course, be understood that numerous modifiactions may be made by those skilled in the art without actually departing from the invention. I, therefore, aim in the appended claims to cover all such equivalent variations as come within the true spirit and scope of the foregoing disclosure.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. A magnetron system including a magnetron of the traveling wave type having a plurality of anode segments surrounding a centrally disposed cathode, means for applying a unidirectional voltage between said cathode and one of said plurality of anode segments to maintain said segment at a fixed positive potential with respect to said cathode and means for impressing an adjustable voltage to said one of said anode segments positive with respect to another of said anode segments to control the power output of said magnetron system.

2. A magnetron system including a magnetron of the traveling wave type having a plurality of anode segments surrounding the centrally disposed cathode, means for applying a unidirectional voltage between said cathode and one of said plurality of anode segments to maintain said segment at a fixed positive potential with respect to said cathode and means for impressing a variable magnitude modulating voltage to said one of said anode segments positive with respect to another of said anode segments to control the power output of said magnetron system.

3. A magnetron system including a magnetron of the traveling wave type having a plurality of anode segments surrounding the centrally disposed cathode, and means for impressing a direct current voltage component of fixed magnitude and an alternating current modulating voltage having a maximum amplitude less than the magnitude of said direct current voltage component between said one of said anode segments and another of said segments to control the power output of said magnetron system and means for impressing a direct potential of magnitude less than the minimum value of the sum of said voltages to said other of said anode segments.

4. A magnetron system including a magnetron device of the traveling wave type including a cathode, a pair of mutually insulated anode terminals, an array of anode segments surrounding a centrally disposed cathode with alternate segments connected with a different one of said pair of mutually insulated anode terminals, means for applying a unidirectional voltage of fixed magnitude between said cathode and one of said anode terminals, means for impressing a unidirectional voltage of adjustable magnitude between said one of said anode terminals and said cathode to control the power output of said magnetron system and means for impressing a direct po-

tential to the other anode terminal of lesser magnitude than the minimum sum of said voltages.

5. A magnetron system including a magnetron device of the traveling wave type including a pair of mutually insulated anode terminals, a cathode, a generally cylindrical array of anode segments surrounding said cathode with alternate segments connected respectively with a different one of said anode terminals, means for impressing a unidirectional voltage of fixed magnitude between said cathode and the anode segments connected with one of said anode terminals and means impressing a unidirectional but variable amplitude component of modulating voltage having a minimum value of magnitude greater than said voltage of fixed magnitude between the anode segments connected with one of said anode terminals and the anode segments connected with the other of said anode terminals to control the power output of said magnetron system.

6. A magnetron discharge device of a type having a plurality of anode segments surrounding a centrally disposed cathode in a cylindrical array coaxial therewith, said anode segments cooperating with said cathode to define a substantially annular space charge region, a resonant output circuit coupled to selected segments of said plurality of segments, means for maintaining said selected segments at a positive operating potential with respect to said cathode, and means for controlling the power in said output circuit comprising means for impressing a positive voltage larger than said operating potential between said cathode and one of said anode segments other than said selected segments.

7. An oscillator for producing high frequency energy comprising a magnetron discharge device of the type having an anode including a plurality of output segments and a control segment surrounding a centrally disposed cathode in a cylindrical array coaxial therewith, said anode segments cooperating with said cathode to provide a substantially annular space charge region, an output circuit coupled to said output segments, means for connecting a source of direct current voltage between said output segments and said cathode to maintain said output group of anode segments at a positive operating potential with respect to said cathode, and means for connecting a source of unidirectional control voltage in cumulative series between said control segment and said direct current voltage source to maintain said control segment at a potential greater than said operating potential segment in order to control the magnetron power output.

8. A high frequency magnetron oscillator comprising a magnetron discharge device of the type having a plurality of anode segments surrounding a centrally disposed elongated cathode to define a cylindrical space charge chamber coaxial therewith, one of said anode segments subtending a substantially greater angle with respect to said space charge chamber axis than the other segments of said plurality of segments, an output circuit connected to said other segments tuned to the desired output frequency, means for supplying a positive potential with respect to said cathode to said other segments through a high frequency neutral point of said output circuit and to said one segment, and means for increasing the potential applied to said one segment above the potential applied to said other segments for increasing the power in said output circuit.

References Cited in the file of this patent

UNITED STATES PATENTS

2,220,968	Link	Nov. 12, 1940
2,292,073	Hansell	Aug. 4, 1942
2,810,095	Peters	Oct. 15, 1957

FOREIGN PATENTS

736,507	Germany	May 13, 1943
851,554	France	Jan. 11, 1940

OTHER REFERENCES

Kilgore: "Magnetron Oscillators," August 1936, IRE Proceedings, pp. 1140–1147 relied on.