March 6, 1951 W. C. BROWN ET AL 2,543,887

MAGNETRON POWER SUPPLY CIRCUITS

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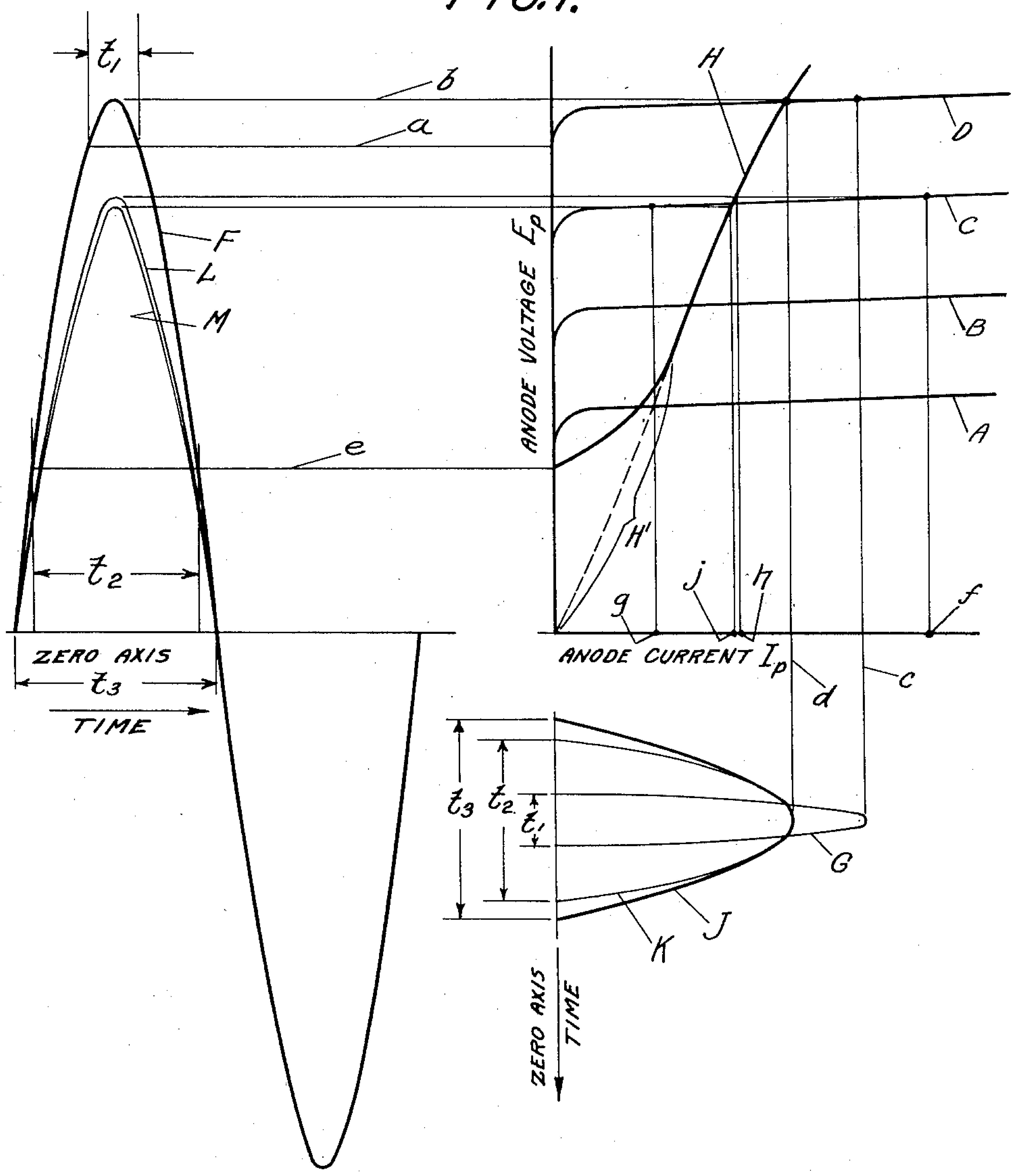
FIG. 1.

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MAGNETRON POWER SUPPLY CIRCUITS

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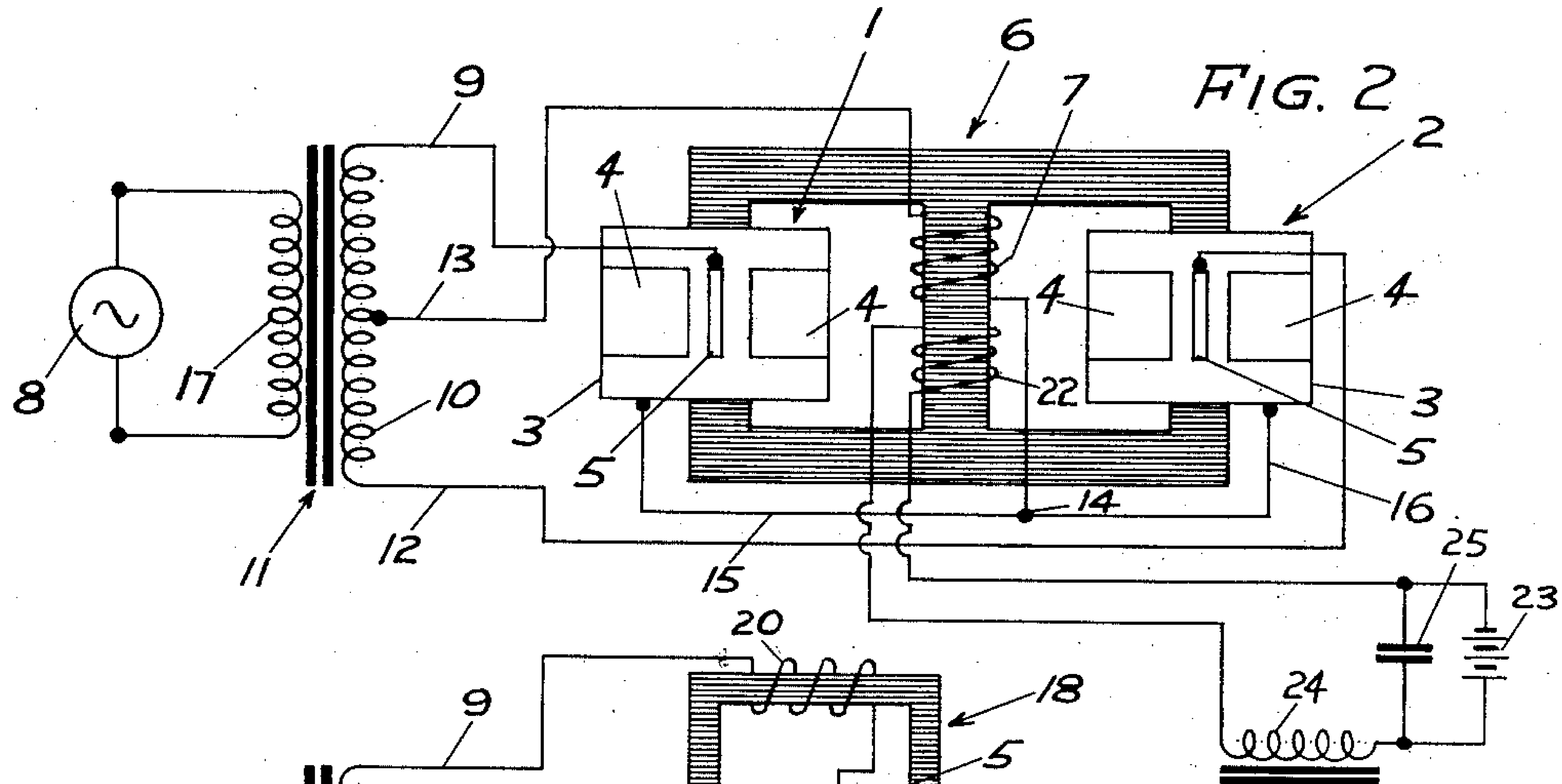


FIG. 2

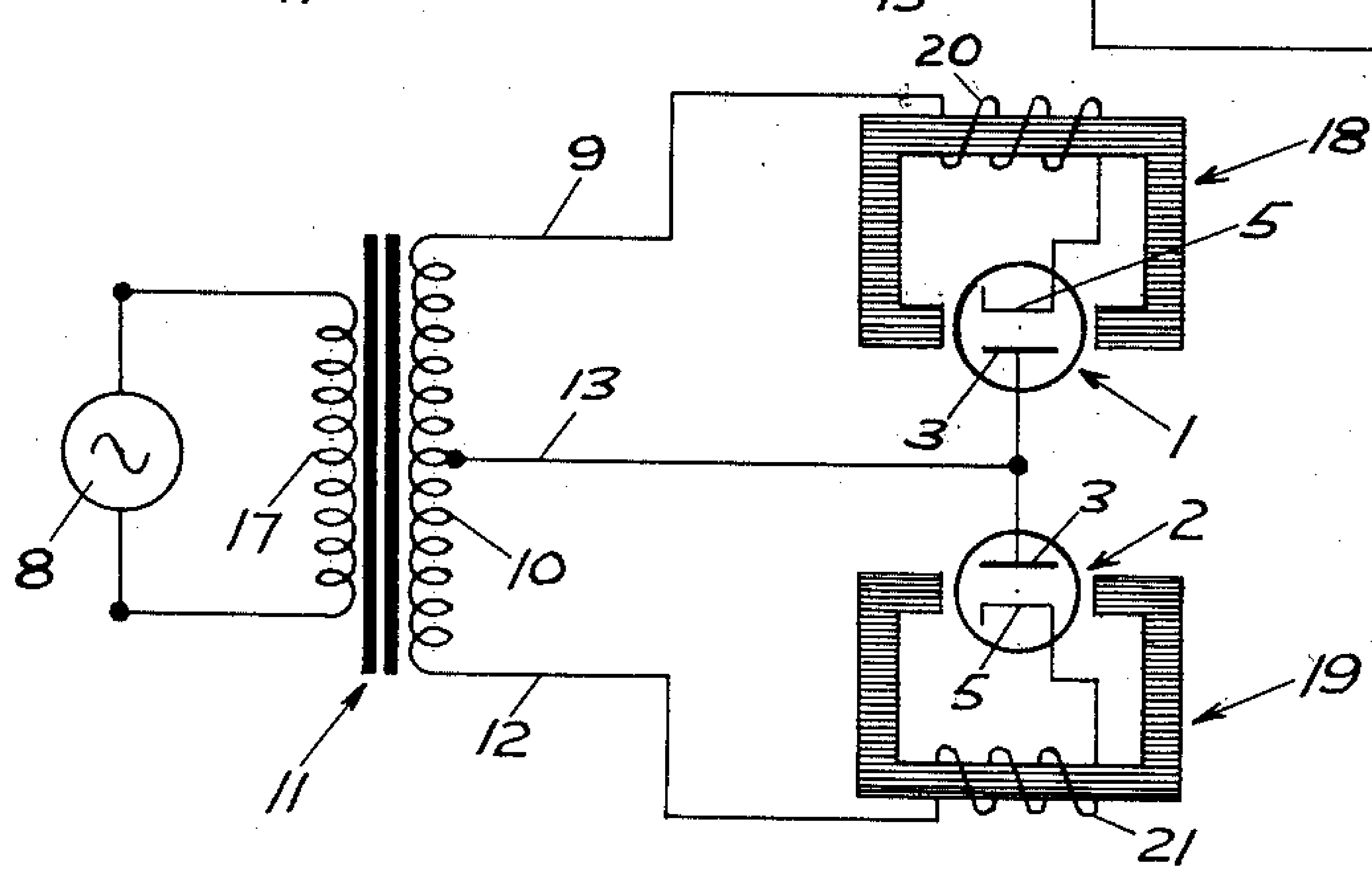


FIG. 3

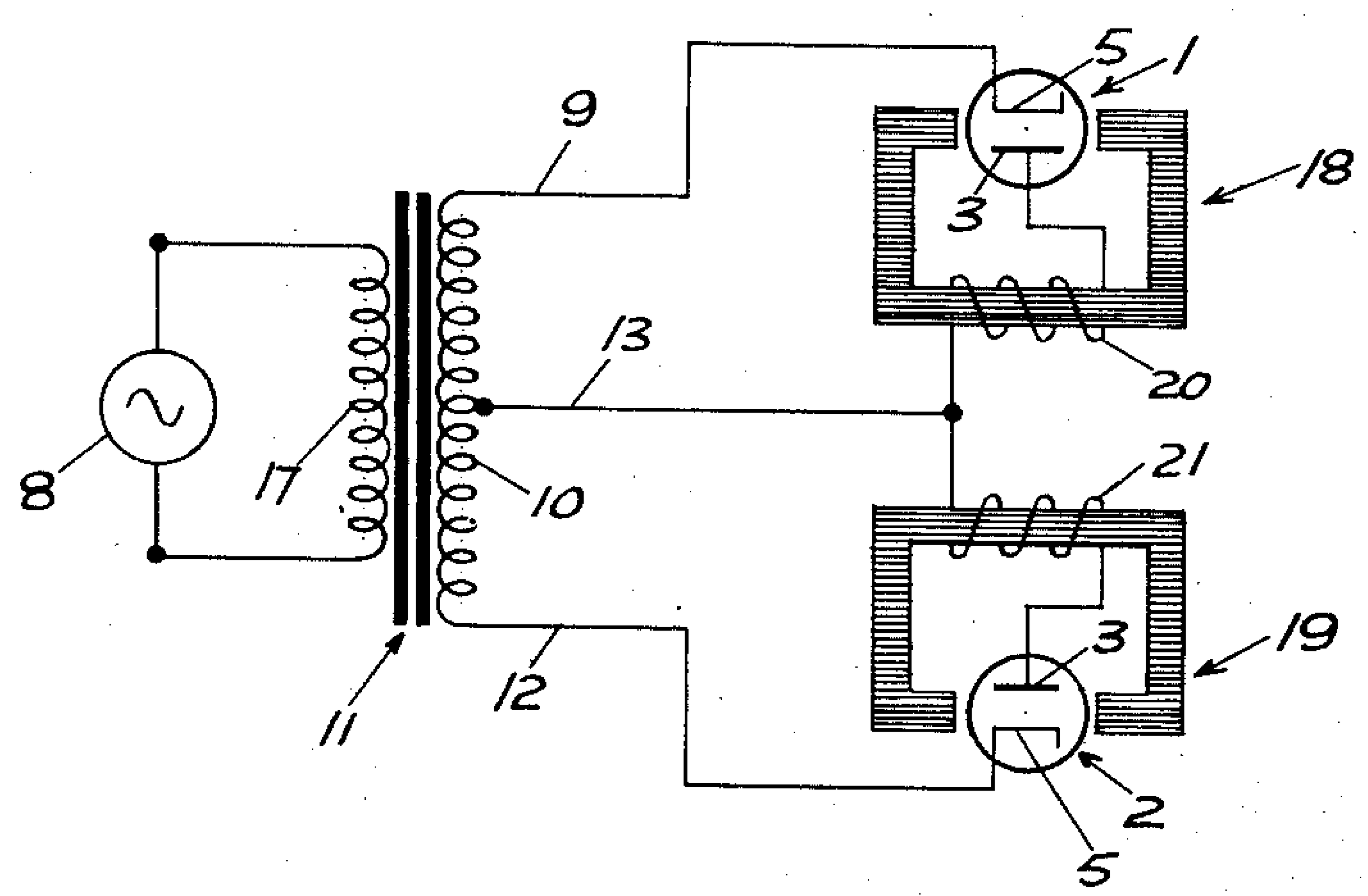


FIG. 4

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# UNITED STATES PATENT OFFICE

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## MAGNETRON POWER SUPPLY CIRCUITS

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11 Claims. (Cl. 250—27)

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This invention relates to electrical circuits, and more particularly to electrical circuits utilizing electron-discharge devices of the so-called magnetron type.

An object of this invention is to devise circuits for operating a plurality of magnetrons, whereby an increase in overall efficiency of operation may be obtained.

Another object is to provide circuits by the use of which magnetrons may be operated directly from an alternating current source, without the necessity of using therewith a separate rectifier power supply.

A further object is to devise circuits for operating magnetron or a pair of magnetrons from an alternating current source in a self-rectifying manner.

A still further object is to devise magnetron circuits which provide a self-regulating action, whereby no external voltage regulators are required.

An additional object is to devise magnetron circuits wherein the magnetron anode current is utilized as a source of excitation for the electromagnet which provides the magnetic field for the magnetron.

Still another object is to devise magnetron circuits wherein the means used for producing the magnetic field for the magnetron has additional functions.

The foregoing and other objects of the invention will be best understood from the following description of some exemplifications thereof, reference being had to the accompanying drawings, wherein:

Fig. 1 is a set of curves useful in explaining the operation of the invention; and

Figs. 2, 3, and 4 are diagrammatic representations of different circuit arrangements according to the invention.

Now referring to Fig. 1, a family of representative anode voltage-anode current ($E_p$ vs. $I_p$) curves A, B, C, and D are shown for an electron-discharge device of the magnetron type. Each of the curves A, B, C, and D is drawn for a single constant value of magnetic intensity in the magnetron, these values of magnetic intensity increasing from the lowermost curve A to the uppermost curve D. As will be noted, curves A, B, C, and D are substantially parallel to each other, and each curve is substantially linear and has a very small slope throughout the greater portion of its length.

It is very often desirable to operate magnetrons directly from a source of alternating current,

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rather than operating them from a separate auxiliary power supply (as is conventionally done), in order to eliminate the rectifier power supply together with the losses naturally present therein. It is desirable, of course, to reduce total system losses in order to raise the overall efficiency of the system.

If, now, the sinusoidal alternating anode supply voltage represented by curve F is applied to a magnetron which has a constant magnetic intensity therein of the value represented by characteristic curve D, no plate current will flow in the magnetron until voltage F reaches a value *a*, at which curve D intersects the axis of zero $I_p$, since a voltage of this value is required to overcome the current-cutoff effect of the magnetic field. As voltage F reaches and passes value *a*, the magnetron plate current G will start from zero and will increase rapidly, because of the very small slope of characteristic curve D. The magnetron plate current G increases as plate voltage F increases, until voltage F reaches its maximum or peak value *b*. At this peak voltage value, a value *c* of plate current flows in the magnetron, this value being quite large as shown, due to the small slope of characteristic D. As the magnetron plate voltage F decreases from its peak value *b*, the magnetron plate current G also decreases rapidly from its maximum value *c*, until voltage value *a* is reached in the downward swing of voltage F, at which time the magnetron plate current G is again zero, as determined by characteristic D.

The time interval $t_1$, between the instant at which voltage F reaches value *a* in its upward swing and the instant at which said voltage again reaches value *a* in its downward swing, is quite small as compared to the time $t_3$ of a full half-cycle of voltage F, as is apparent from the drawing, since value *a* is well up on the upward swing of voltage F. Therefore, during the half-cycle of voltage F in which the magnetron anode is positive with respect to its cathode, only a very short steep high-amplitude pulse G of plate current will flow. Of course, since a magnetron is an asymmetrical device or rectifier, no plate current will flow during the next half-cycle of voltage F, in which the magnetron anode is negative with respect to its cathode.

Since the total length $t_1$ of the pulse of anode current is small compared to the time $t_3$ of a half-cycle of anode voltage, the power factor of the tube load is rather low and, also, since the input transformer is loaded only over a relatively small portion of the cycle, the transformer is being operated in a rather inefficient manner.

It is ordinarily preferable, with alternating current operation of magnetrons as above described, to utilize a pair of magnetrons connected in push-pull relation, or as a full-wave rectifier, across the alternating current source, in which case a pulse G of plate current would be produced during each half-cycle of the alternating current input.

The above analysis of alternating current magnetron operation, since it involves a characteristic curve such as D, will be understood to refer to a magnetron in which the magnetic intensity remains constant during operation thereof, this constant magnetic intensity being supplied by a permanent magnet, for example.

Pursuant to this invention it has been found that, if the magnetron current is used as a source of excitation for an electromagnet which provides the magnetic field for the magnetron, the above-described disadvantages may be eliminated and the magnetron may be operated very efficiently from a source of alternating current.

Where the magnetic field of the magnetron is supplied by the magnetron plate current, it has been found that the operating line or $E_p$—$I_p$ characteristic of the magnetron is substantially as represented by curve H′—H, which, as will be seen, passes through the origin, is curved only very slightly over its length and which has a substantial slope over its entire length.

If the magnetic field of the magnetron is supplied by the plate current, when there is no plate current there will be no magnetic field, and there is nothing to prevent the increase of plate current from zero as soon as the plate voltage becomes greater than zero because there is then no magnetic field to produce a current-cutoff effect. Of course, as the plate current increases, the magnetic field intensity also increases, which might tend to cause the plate current to decrease, but this does not happen because the plate voltage has also increased to cause an increased plate current. Therefore, characteristic H′—H extends approximately as shown. This characteristic goes substantially through the origin as shown because the hysteresis loop of the material of which the electromagnet core is made is very narrow.

If, now, the sinusoidal alternating anode supply voltage F is applied to the magnetron under these conditions (with the plate current flowing in series through the electromagnet), the operating line in this case will be H′—H, as stated above, so that magnetron plate current (represented by curve J) will begin flowing as soon as the voltage F rises above zero. The plate current J will rise as the voltage F rises, as determined by characteristic H′—H. Since characteristic H′—H is substantially linear, the rise of plate current J will be substantially sinusoidal. Characteristic H′—H is substantially linear and goes through the origin, so that in effect the magnetron under these conditions acts substantially as a pure resistance load across the alternating current source. The magnetron plate current J continues to increase as the plate voltage F increases, until voltage F reaches its maximum or peak value *b*. At this peak voltage value, a value *d* of plate current flows, this current value being determined from characteristic H. It will be noted that value *d* is substantially less than value *c*.

As voltage F begins its downward swing toward the zero axis from its peak value *b*, the magnetron plate current J swings downwardly toward the zero axis as determined by characteristic H—H′, this downward swing of the current again being substantially sinusoidal because of the fact that characteristic H—H′ is substantially linear as above described. Plate current J continues to decrease as the plate voltage F decreases, until at the time when the supply voltage F is zero, the plate current J is also zero.

It will be apparent, from the above analysis, that under these conditions the magnetron acts as a pure resistance load across the alternating current source, and plate current J flows in a substantially sinusoidal manner throughout the entire time $t_3$ of a half-cycle of source voltage F.

As stated above, the peak value *d* of the magnetron plate current J (in the series electromagnet arrangement of the second case) is substantially less than the peak value *c* of the magnetron plate current G (in the permanent magnet arrangement of the first case). Since the plate current J in the second case flows over the entire half-cycle time $t_3$, which time is substantially in excess of the time $t_1$ over which the plate current G flows in the first case, for the same average power in the two cases the peak current *d* in the second case can be substantially less than the peak current *c* in the first case. This decrease of the peak magnetron plate current is advantageous because it tends to lengthen the effective life of magnetron devices.

Since the plate current J in the second case flows over the entire half-cycle time $t_3$, the input transformer secondary is loaded over this entire half-cycle, thus effectively raising the efficiency of operation of said transformer. Also, from a comparison of curves G and J, it can be seen that curve J is substantially sinusoidal, whereas curve G is not, and also that curve J extends throughout the entire half-cycle, whereas curve G extends over only a relatively small portion of said half-cycle of supply voltage F. Therefore, the power factor in the second case (curve J) is substantially better than in the first case (curve G). Of course, it is desirable to keep the power factor of any alternating current load as high as possible.

For reasons which will be explained hereinafter, it is desirable or even preferable to provide a constant direct magnetic flux or bias through the electromagnet core, this flux being in series aiding relationship with that produced by the pulsating direct anode current of the magnetron flowing in series through the electromagnet exciting coil. Therefore, when the anode current goes to zero, there will still be magnetic flux through the magnetron as a result of this bias, so that the lower end of solid line curve H does not go through the origin, but slopes off as shown. Characteristic H is curved only very slightly over the major portion of its length and has a substantial slope over the major portion of its length. As will be seen, the solid line characteristic H differs somewhat from the characteristic H′—H in the lower portion thereof.

With characteristic H, the sinusoidal supply voltage F must rise to the value *e* before any plate current (represented by curve K) flows, since a voltage of this value is required to overcome the current cutoff effect of the biasing magnetic field. As voltage F rises beyond value *e*, magnetron plate current K increases from zero, rising approximately sinusoidally to the same value *d* as before, this value being determined by peak voltage value *b* and characteristic curve

H. As voltage F swings downwardly, current K does also, the magnetron anode current falling to zero at the instant when voltage F reaches value *e* in its downward swing. Since value *e* is reached by voltage F rather early in the upward swing thereof and rather late in the downward swing thereof, the time $t_2$ during which plate current K flows is only very slightly less than the half-cycle time $t_3$. Therefore, the time interval $t_2$ is substantially greater than the time interval $t_1$ of the pulse G which flows when no electromagnet is used, so that the power factor in this third case is still very much better than in the first case. Again, the peak current *d* can be substantially less than the peak current *c* for the same average power, because the plate current K flows over a much longer period of time than does plate current G. Also, with curve K the input transformer is loaded over a much greater portion of the half-cycle than is the case with curve G.

Since the greater portion of characteristic curve H is substantially linear, the greater portion of anode current curve K is substantially sinusoidal, so that the magnetron again acts as as a resistive load across the alternating current source, thus enabling a rather high power factor to be achieved.

In this third case, in which a direct constant magnetic bias is used along with a plate-current-excited electromagnetic field, it is true that the portion of the supply voltage curve F between zero and value *e* is in effect lost as far as the magnetron load is concerned. However, the voltage is relatively low in this region, so that only an unimportant proportion of the total available volt-amperes is lost. Also, magnetrons will not ordinarily function to produce a radio-frequency output in this region of very low anode voltage anyway, so that there is no loss of radio-frequency power in so far as the radio-frequency load is concerned. In addition, the envelope of a magnetron is ordinarily made of a highly conductive material, such as copper, and the magnetic flux for the magnetron passes through and links with this envelope; it is desirable to limit the change of magnetic flux linking with this envelope so as to prevent an unduly high voltage being induced therein by transformer action with the envelope acting as a short-circuited secondary winding; therefore the magnetic flux should be kept from going completely to zero at any time. For the above reasons, it is desirable to use a direct magnetic bias along with a series plate-current-excited electromagnetic field as the magnetic field for the magnetron.

Although the above description of magnetron operation with a plate-current-excited electromagnetic field has been made with reference to a single magnetron connected across an alternating current source, it has been found that it is ordinarily preferable to utilize a pair of magnetrons connected in push-pull or as a full-wave rectifier across a source of alternating current, the magnetrons themselves providing the only load across said source, and said magnetrons acting as their own power supplies. In this case, the above analylsis still holds, so that an anode current wave such as K will be produced in the appropriate one of the pair of magnetrons during each successive half-cycle of the source voltage F. The advantages described in detail above are obtainable with a pair of magnetrons, as with a single magnetron, provided that the magnetrons utilize plate-current-excited electro-magnets for their magnetic fields. The advantages of this invention are obtained, as discussed above, by using the magnetron anode current as a source of excitation for the electromagnet which furnishes the magnetic field for the magnetron.

By the utilization of magnetron anode current to excite the magnetron electromagnet, the magnetron anode current is held substantially constant, regardless of line voltage variations, so that no special provisions for voltage regulation are necessary with this invention.

Referring again to Fig. 1, assume that a magnetron is being operated with a permanent magnet field having a value corresponding to that represented by characteristic curve C, and that the applied sinusoidal alternating anode voltage is as represented by curve L. From characteristic curve C, we see that under these conditions the anode current has a peak value *f*. Now, if the line voltage varies, downwardly for example, the applied sinusoidal alternating voltage will be as represented by curve M. Under these conditions, the anode current will have a peak value *g* which, as can be seen, is very much lower than value *f*. Similar reasoning applies to increases in line voltage. Therefore, there are ordinarily extremely wide variations of anode current with small differences in applied anode potential in a magnetron. As a result, in order to maintain the desired substantially constant power input to the magnetron, regardless of variations in line voltage, very sensitive voltage-regulating devices are ordinarily required.

Now, utilizing this invention, the operating characteristic of the magnetron is again, as before, represented by curve H. With the applied anode voltage L, from curve H it may be seen that the anode current utilizing the invention has a peak value *h*. Now, if the applied anode voltage changes to curve M, the anode current will have a peak value *j*. As can be seen, due to the large slope of characteristic H, there is very little difference between values *h* and *j*. Similar reasoning applies to increases in line voltage. Therefore, by means of our invention, without the use of any external or additional voltage-regulating devices, the magnetron plate current is stabilized or maintained substantially constant regardless of variations in line voltage, so that the desired substantially constant power input to the magnetron is maintained regardless of such variations.

It will be seen, from all of the above, that pursuant to this invention, there have been devised magnetron arrangements, using the magnetron anode current as a source of excitation for the magnetron electromagnet, in which no rectifiers are necessary for operation of the magnetron or magnetrons, and in which no permanent magnets are necessary. In this invention, the means for providing the magnetic field, which field is required in every magnetron, functions also, as above described, to reduce the anode peak current while maintaining the same average power, to increase substantially the length of the anode current pulse, to raise the power factor of the magnetron load, to increase the input transformer efficiency, and to maintain the magnetron current substantially constant regardless of line voltage variations.

Figs. 2–4 represent, diagrammatically, three different circuit arrangements whereby the invention may be carried out. Referring now to Fig. 2, the numerals 1 and 2 generally designate electron-discharge devices of the magnetron type, each including, for example, an evacuated envelope 3 made of highly conductive material, such as copper, and provided with a plurality of inwardly-directed, radially-disposed anode vanes 4. The arrangement is such that each pair of adjacent anode vanes 4 forms, together with that portion of the envelope 3 lying therebetween, a cavity resonator whose natural resonant frequency is, as is well known to those skilled in the art, a function of the geometry of the physical elements making up the same.

Centrally located in each envelope 3 is a highly electron-emissive cathode member 5, for example of the well-known alkaline-earth metal-oxide type, said cathode member being provided with conventional means (not shown) for raising the temperature thereof to a level sufficient for thermionic emission.

An electromagnet, designated generally by 6, may consist of a three legged soft iron core structure having airgaps in the two outer legs thereof and having an exciting or variable-current coil 7 and a biasing or constant-current coil 22 wound around the central leg thereof. Device 1 is placed in one of the airgaps of the electromagnet and device 2 is placed in the other airgap, both in such a manner that the magnetic field provided by the electromagnet 6, when coils 7 and 22 are energized, extends in each device in a direction transversely of the electron path between each cathode 5 and the anode 3 associated therewith. Devices 1 and 2 are therefore placed side by side, and the electromagnet means 6 is common to the two devices.

Devices 1 and 2 are connected in a push-pull arrangement or as a full-wave rectifier across a source 8 of raw or unfiltered alternating current, for example the conventional 60-cycle power lines, with the exciting electromagnet coil 7 in series with the anode currents of each magnetron, and to this end cathode 5 of device 1 is connected by means of a conductor 9 directly to one terminal of the secondary winding 10 of an input transformer 11, while cathode 5 of device 2 is connected by means of a conductor 12 directly to the opposite terminal of said secondary winding. Secondary winding 10 is center-tapped, and a conductor 13 connects the center tap of said winding to one end of exciting electromagnet coil 7, the other end of said coil being connected to a point 14, from which point a pair of leads 15 and 16 branch; lead 15 is connected directly to anode 3 of device 1, while lead 16 is connected directly to anode 3 of device 2. Source 8 is connected across the primary winding 17 of transformer 11.

Biasing coil 22 is connected across a source 23 of direct current, for example a battery, a choke 24 being connected in series with coil 22. A condenser 25 is connected across battery 23, the condenser 25 and choke 24 functioning to isolate said battery from the alternating voltage which tends to be induced in coil 22 as a result of the pulsating voltage applied to exciting coil 7.

Biasing coil 22 is so wound and arranged with respect to exciting coil 7 that the biasing flux produced by the direct current flowing through coil 22 is in series aiding relation with the pulsating flux produced by the magnetron anode current flowing in series through said exciting coil. Therefore, by this means, the characteristic curve H of Fig. 1 results, as discussed above.

Thus, the electron-discharge devices 1 and 2 are connected as a single-phase full-wave rectifier across the source 8 of raw or unfiltered alternating current, with the exciting electromagnet coil 7 being connected effectively in series with the anode of each of the devices 1 and 2. It is apparent that the anodes of each of the magnetrons 1 and 2 are in series with the coil 7, so that the coil 7 will be supplied by the magnetron anode current of each of the devices 1 and 2, the magnetron anode current of each of the devices therefore acting as a source of variable excitation for the coil 7 of the electromagnet 6 which provides the magnetic fields for each of the magnetrons. Therefore, the advantages explained in detail hereinabove are obtainable with the circuit of Fig. 2, since the magnetron anode current is used to supply the exciting coil of the magnetron electromagnet, and since the magnetrons are operated directly from an alternating current source.



Now referring to Fig. 3, a pair of magnetrons 1 and 2 again are used, each magnetron including an anode 3 and a cathode 5. However, in this figure, each device has its own electromagnet to establish a magnetic field in the corresponding device in a direction transversely of the electron path between the cathode and the anode thereof; electromagnet 18 is magnetically coupled to device 1 while electromagnet 19 is magnetically coupled to device 2. Exciting coil 20 is wound around the iron core of electromagnet 18, while exciting coil 21 is wound around the iron core of electromagnet 19. If desired, each of the electromagnets of Fig. 3 may be provided with a separate biasing coil and source similar to that of Fig. 2.

Cathode 5 of device 1 is connected, in series with electromagnet coil 20, by means of lead 9, to one terminal of secondary winding 10 of input transformer 11; a cathode 5 of device 2 is connected, in series with electromagnet coil 21, by means of lead 12, to the opposite terminal of secondary winding 10. The anodes 3 of devices 1 and 2 are tied together and are connected by conductor 13 to the center tap of secondary winding 10.

Again, the electron-discharge devices 1 and 2 are connected as a single-phase full-wave rectifier across the alternating current source 8, with the electromagnet exciting coil of each device in series in the anode-cathode circuit thereof, so that each exciting coil is supplied by the anode current of the corresponding device, or, in other words, the anode current of each device acts as a source of excitation for the electromagnet which provides the magnetic field for the same magnetron. The advantages described in detail above are obtainable with this circuit also, because of the series connection of the electromagnet exciting coil and the magnetron anode-cathode circuit, with alternating current operation of the magnetrons.

Now referring to Fig. 4, a pair of magnetrons 1 and 2 having electromagnets 18 and 19, respectively, are again connected as a full-wave rectifier across the source 8, as in Fig. 3. However, in Fig. 4, the cathodes 5 of devices 1 and 2 are connected directly to opposite ends of secondary winding 10, while electromagnet exciting coil 20 is connected in series between anode 3 of device 1 and the common lead 13 from the center tap of transformer 10, and electromagnet exciting coil 21 is connected in series between anode 3 of device 2 and the common lead 13. In this case also, each of the electromagnets may be provided with a separate biasing coil and source similar to that of Fig. 1, if so desired.

As in Fig. 3, the electromagnet exciting coil of each device is connected in series in the anode-cathode circuit thereof, so that each such coil is supplied by the anode current of the corresponding device; the anode current of each device therefore acts as a source of excitation for the electromagnet which provides the magnetic field for the same magnetron. Therefore, the advantages described in detail above are obtainable with this circuit also.

Of course, it is to be understood that this invention is not limited to the particular details as described above, as many equivalents will suggest themselves to those skilled in the art. For example, it is possible to use a single electromagnet-type magnetron connected as a half-wave rectifier across an alternating current source, with the electromagnet exciting coil in series with the anode-cathode circuit, in accordance with the principles herein disclosed. If desired, a permanent magnet could be used to produce the electromagnet biasing flux, rather than a source and coil as illustrated. Various other variations will suggest themselves. It is accordingly desired that the appended claims be given a broad interpretation commensurate with the scope of this invention within the art.

What is claimed is:

1. An electrical circuit comprising: an evacuated electron-discharge device of the magnetron type having an anode element comprising a plurality of resonant cavities, a cathode element, and an electromagnet for establishing a magnetic field in a direction transversely of the electron path between said cathode and said anode; means connecting said device across a source of alternating current for energization solely therefrom; and means connecting the exciting coil of said electromagnet directly in series between said source and one of said elements.

2. An electrical circuit comprising: a pair of evacuated electron-discharge devices of the magnetron type each having associated together an anode element, a cathode element, and an electromagnet for establishing a magnetic field in a direction transversely of the electron path between each cathode and the anode associated therewith; means connecting said devices as a full-wave rectifier across a source of alternating current; and means connecting each electromagnet directly in series with one of the elements associated therewith.

3. An electrical circuit comprising: a pair of evacuated electron-discharge devices of the magnetron type each having associated together an anode element, a cathode element, and an electromagnet for establishing a magnetic field in a direction transversely of the electron path between each cathode and the anode associated therewith; means connecting said devices as a full-wave rectifier across a source of alternating current; and means connecting each electromagnet directly in series between said source and the cathode with which said electromagnet is associated.

4. An electrical circuit comprising: a pair of evacuated electron-discharge devices of the magnetron type each having associated together an anode element, a cathode element, and an electromagnet for establishing a magnetic field in a direction transversely of the electron path between each cathode and the anode associated therewith; means connecting said devices as a full-wave rectifier across a source of alternating current; and means connecting each electromagnet directly in series between said source and the anode with which said electromagnet is associated.

5. An electrical circuit comprising: a pair of evacuated electron-discharge devices of the magnetron type each having associated together an anode element, a cathode element, and an electromagnet for establishing a magnetic field in a direction transversely of the electron path between each cathode and the anode associated therewith; a transformer having a primary winding and a center-tapped secondary winding; means connecting a source of alternating current across said primary winding; means connecting the anode and cathode of one of said devices between said center tap and one end of said secondary winding; means connecting the anode and cathode of the other of said devices between said center tap and the other end of said secondary winding; and means connecting each electromagnet directly in series between said secondary winding and one of the elements with which said electromagnet is associated.

6. An electrical circuit comprising: a pair of evacuated electron-discharge devices of the magnetron type each having associated together an anode element, a cathode element, and an electromagnet for establishing a magnetic field in a direction transversely of the electron path between each cathode and the anode associated therewith; a transformer having a primary winding and a center-tapped secondary winding; means connecting a source of alternating current across said primary winding; means connecting the anode and cathode of one of said devices between said center tap and one end of said secondary winding; means connecting the anode and cathode of the other of said devices between said center tap and the other end of said secondary winding; and means connecting each electromagnet directly in series between said secondary winding and the cathode with which said electromagnet is associated.

7. An electrical circuit comprising: a pair of evacuated electron-discharge devices of the magnetron type each having associated together an anode element, a cathode element, and an electromagnet for establishing a magnetic field in a direction transversely of the electron path between each cathode and the anode associated therewith; a transformer having a primary winding and a center-tapped secondary winding; means connecting a source of alternating current across said primary winding; means connecting the anode and cathode of one of said devices between said center tap and one end of said secondary winding; means connecting the anode and cathode of the other of said devices between said center tap and the other end of said secondary winding; and means connecting each electromagnet directly in series between said secondary winding and the anode with which said electromagnet is associated.

8. An electrical circuit comprising: a pair of evacuated electron-discharge devices of the magnetron type each having associated together an anode element, a cathode element, and an electromagnet for establishing a magnetic field in a direction transversely of the electron path between each cathode and the anode associated therewith; a transformer having a primary winding and a center-tapped secondary winding; means connecting a source of alternating current across said primary winding; means connecting the anodes of both of said devices to said center tap; means connecting the cathode of one of said

devices to one end of said secondary winding and the cathode of the other of said devices to the other end of said secondary winding; and means connecting each electromagnet directly in series between said secondary winding and one of the elements with which said electromagnet is associated.

9. An electrical circuit comprising: a pair of evacuated electron-discharge devices of the magnetron type each having associated together an anode element and a cathode element; electromagnet means common to said pair of devices for establishing in each device a magnetic field in a direction transversely of the electron path between each cathode and the anode associated therewith; means connecting said devices as a full-wave rectifier across a source of alternating current; and means connecting said electromagnet means directly in series with one of the elements of each of said devices.

10. An electrical circuit comprising: a pair of evacuated electron-discharge devices of the magnetron type each having associated together an anode element and a cathode element; magnetic means common to said pair of devices for establishing in each device a magnetic field in a direction transversely of the electron path between each cathode and the anode associated therewith; an exciting coil for energizing said magnetic means; means connecting said devices as a full-wave rectifier across a source of alternating current; and means connecting said coil directly in series with one of the elements of each of said devices.

11. An electrical circuit comprising: a pair of evacuated electron-discharge devices of the magnetron type each having associated together an anode element and a cathode element; electromagnet means common to said pair of devices for establishing in each device a magnetic field in a direction transversely of the electron path between each cathode and the anode associated therewith; a transformer having a primary winding and a center-tapped secondary winding; means connecting a source of alternating current across said primary winding; means connecting the anodes of both of said devices to said center tap; means connecting the cathode of one of said devices to one end of said secondary winding and the cathode of the other of said devices to the other end of said secondary winding; and means connecting said electromagnet means directly in series between said secondary winding and one of the elements of each of said devices.

WILLIAM C. BROWN.
JOHN E. STACY.

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