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[54] **POWER SUPPLY CIRCUIT FOR CONTINUOUS-WAVE MAGNETRON**

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[51] **Int. Cl.**..**H01j 29/72**

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[56] **References Cited**

UNITED STATES PATENTS

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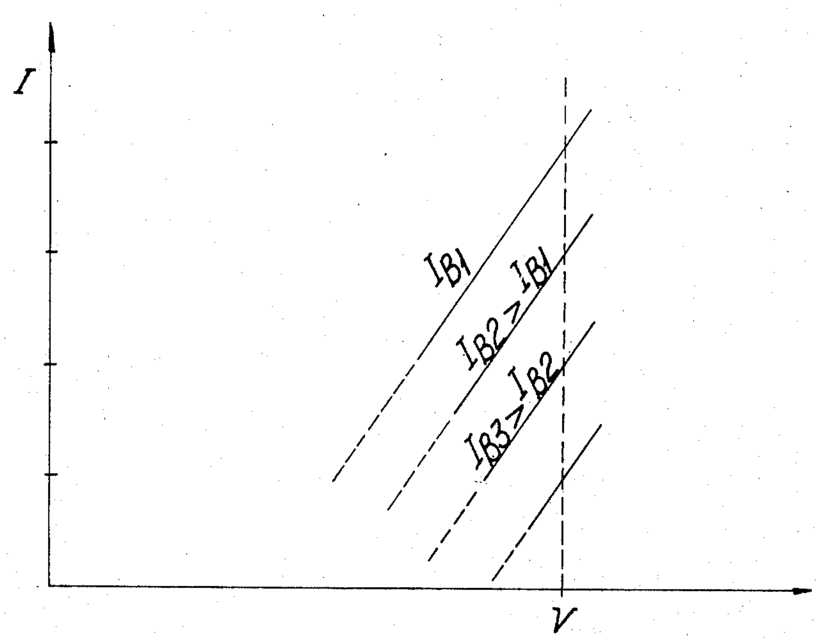
[57] **ABSTRACT**

A power supply circuit for a continuous wave magnetron provides selectively adjustable microwave power levels that are stable at each level. The unregulated direct voltage supplied to the magnetron cathode is combined with an additional voltage derived from a common alternating current source to provide a total direct current which passes through the electromagnet coil of the magnetron. Variations in the power source are compensated by the variations of the added current in the coil to provide stable magnetron power at each level. The circuit providing the added current to the coil includes a simple rectifier, filter, zener diode and series resistor arrangement with a switch for selecting different diode, resistor and voltage combinations.

7 Claims, 5 Drawing Figures



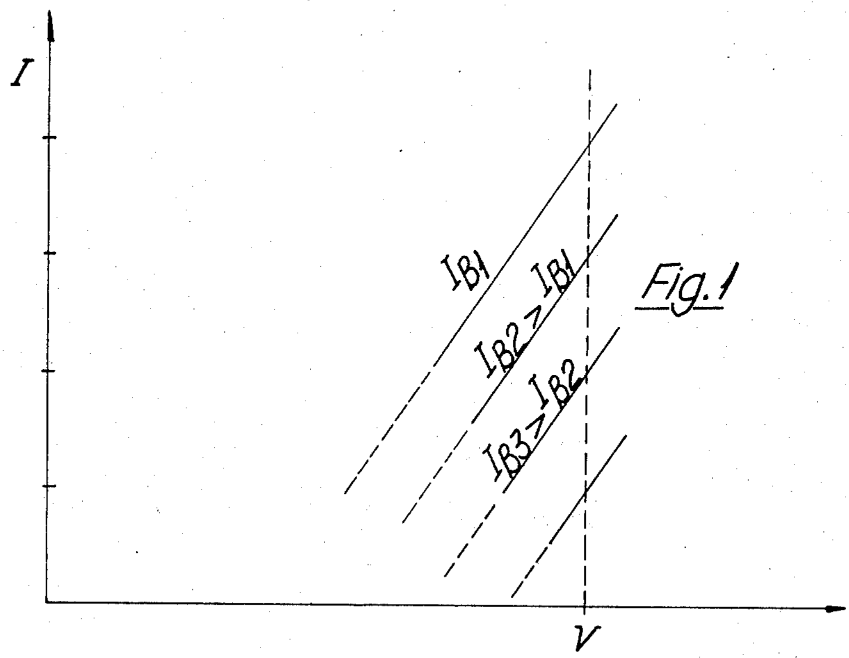


Fig. 1

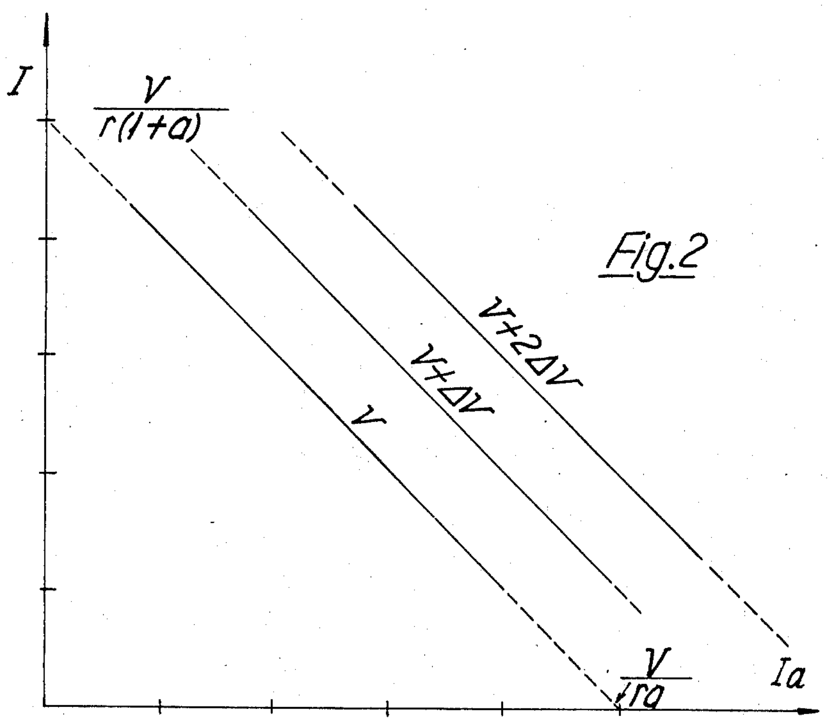


Fig. 2

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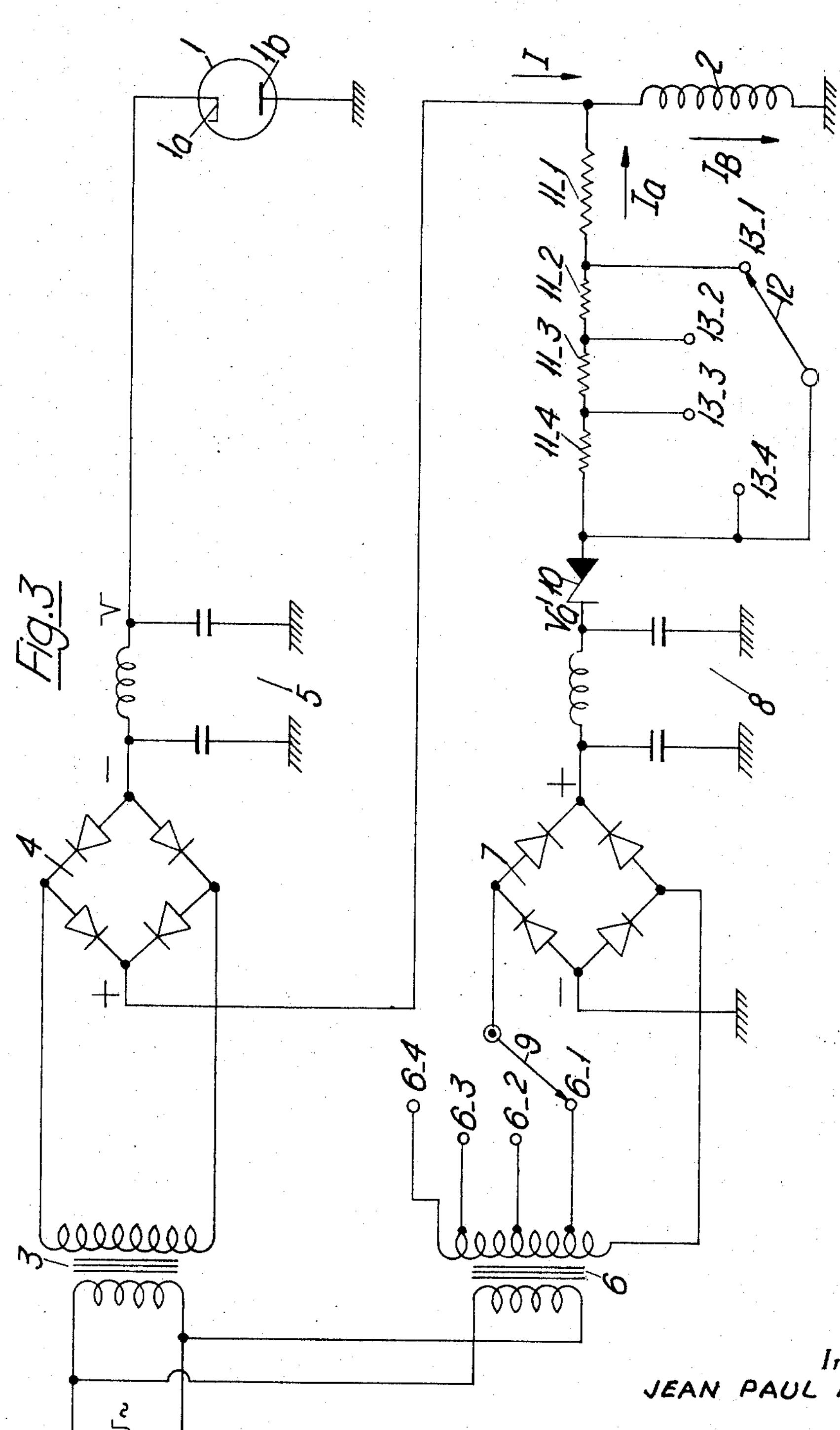

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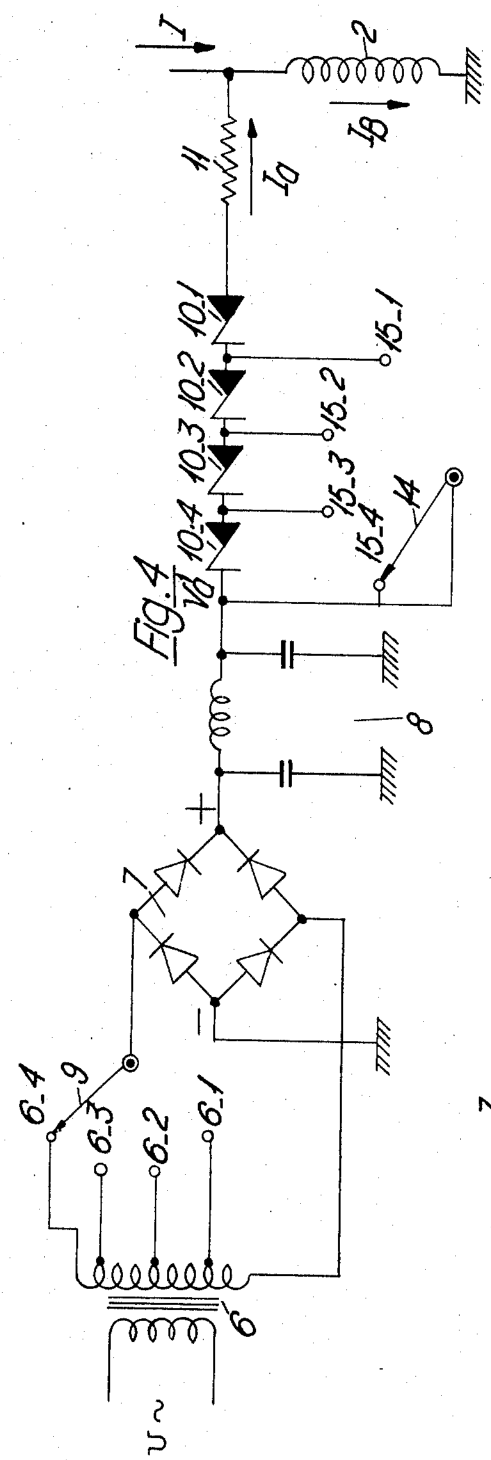

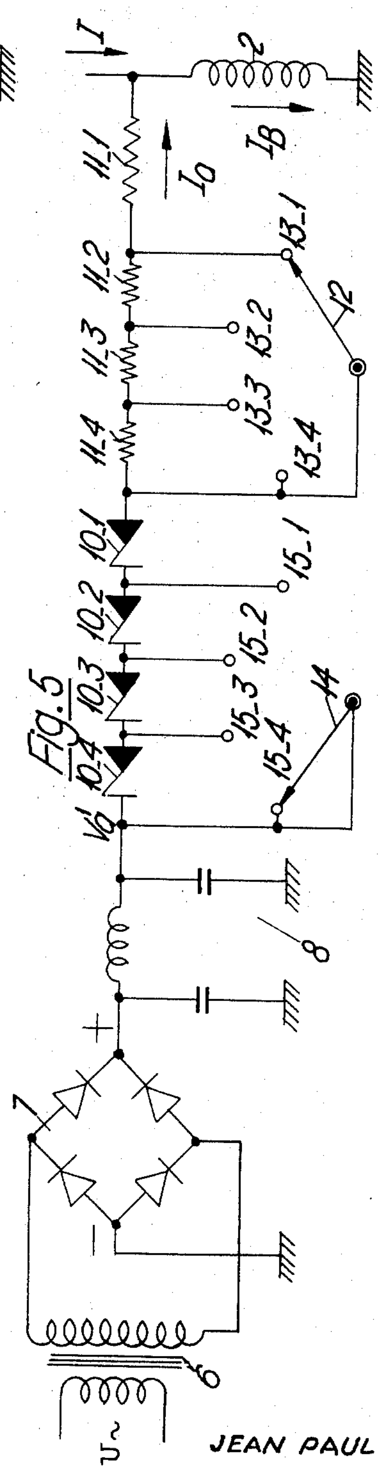

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POWER SUPPLY CIRCUIT FOR CONTINUOUS-WAVE MAGNETRON

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a power supply device for continuous-wave magnetrons which provides microwave power that is adjustable at various levels and is stable for every level.

2. Description of the Prior Art

Continuous-wave magnetrons are particularly designed for use in industrial applications where high microwave power must be permanently available. In most cases, such applications relate to insulator materials which are more or less wet and which are dried by heating, such heating resulting from dielectric losses within insulator materials.

Continuous-wave magnetron operation is in no way different than other pulsed magnetron operations such as, for example, those used in radar. However, needs for obtaining high continuous power under economical conditions require a specific technology and, particularly, a specific mode for generating high voltage and induction fields which control the magnetron current and consequently the microwave power.

It is often very important for users of heating magnetrons to obtain microwave power which is adjustable and stable for each adjustment.

Some presently known power supply devices permit varying the available microwave power in discrete stepped levels, but none provides satisfactory results as far as simplicity, device reliability or power stability at each level are concerned.

In order to better understand continuous-wave magnetron operation and the difficulties usually found in known power supply devices, it is noted that electrical magnetron characteristics within the useful range may be represented by a linear law of the kind:

$$I = 1r\,(V - bB) \qquad (1)$$

In this formula:

I is the magnetron current intensity,

V is the high voltage,

B is the magnetic induction field,

r is the internal dynamic resistance which is of some tens of ohms, and b is very large, which means that a small variation of B causes a large variation on I, V being constant. By way of comparison, B may be said to be acting like the grid voltage in a high slope triode.

For predetermined values of the high voltage V the applied electric power is:

$$P = VI \qquad (2)$$

The microwave power supplied to the load is equal to:

$$P_m = k\,VI$$

where k is the magnetron efficiency. Experience shows that, if the load is sufficiently well matched, k is substantially a constant over the whole useful range of tube characteristics, k being usually about 70 to 80 percent.

It is conceivable that a continuous or stepped variation of V and/or B will permit adjustment of P, and consequently P_m, in a predetermined manner.

In a first type of application, the induction B may be provided by a permanent magnet. In that case, B is steady and P_m can vary only if the high voltage V is varied.

The supplied power, for a predetermined adjustment of V, is very sensitive to instabilities of V.

A simple calculation using the formulas (1) and (2) leads to the following relation expressing the relative variation of power $\Delta Pm/Pm$:

$$\Delta Pm/Pm = (1 + V/rI)\,\Delta V/V$$

For a usual magnetron having the following values:

$V = 5$ kV

$I = 1$ A

$r = 100$ ohms

it is found that:

$$\Delta Pm/Pm = 50\,\Delta V/V$$

Therefore, in this case, the power regulation requires very good stabilization of the high voltage V.

In practice, V is generated by an a.c. source whose current is rectified by well known means. The need for simultaneously being able to adjust Pm by discrete levels and for good regulation of each level generally requires complex and costly power supply devices which often use a saturated-current transformer. This precludes varying V and Pm, in a continuous manner.

In a second type of application, for generating B, an electromagnet is used which has a coil traversed by a current I_B. In a first approximation, B may be assumed to be proportional to the magnetic field created by the coil, or proportional to the current I_B.

The formula (1) may be then written:

$$I = 1/r\,(V - r_B\,I_B) = V/r - a\,I_B \qquad (3)$$

Taking into account the rapid variations of I with I_B, $r_B/r - a$ is a coefficient substantially higher than 1.

Pm can be adjusted very simply by continuous or stepped variations of the current I_B (V being steady). I_B is generated by a source of relatively low voltage V_B obtained after having rectified the source of alternating current. If, for a predetermined adjustment, V and V_B are subject to the same relative variations, equal to those of an a.c. source of voltage U, a simple calculation shows that:

$$\Delta Pm/Pm = 2\,\Delta U/U$$

The regulation of Pm is therefore easier to obtain than in the case of use of a permanent magnet and requires substantially less accurate stabilization of the sources. The main drawback of this type of power supply is in the very high sensitivity $\Delta Pm/\Delta I_B$ wherein a low variation of I_B that is not compensated by an associated variation of V may cause a large variation of Pm.

In certain embodiments of this second type, a part P of the magnetron current I is used as current I_B. The properly sized coil is electrically connected between the tube anode and the ground. An adjustable resistor is mounted in parallel across the coil and permits variation of p and consequently of the power Pm within a particular range.

The formula (3) shows that the power Pm is equal to:

$$Pm = k\;1/1 + ap\;V^2/r$$

If V is constant, the power Pm is regulated by variation of p. The maximum power corresponds to the minimum value of p and the minimum power to the value $p = 1$. In this last case, a shunt resistor is suppressed.

The device is simple, but it does not provide sufficient variations of Pm. Moreover, as previously: $\Delta Pm/Pm = 2\,\Delta V/V = 2\,\Delta U/U$

In other more improved devices, the coil is traversed by the entire magnetron I and the coil current is set to the proper value I_B by means of an additional variable current source which provides a current I_a.

If reference is made to the formula (3), by replacing I_B with $I+I_a$, I is given by the relation:

$$I=V/r\ (1+a)-a/1+a\ I_a$$

As a is substantially higher than 1, it is possible to represent I by the formula:

$$I=V/ra-I_a=V/r_B-I_a \quad (4)$$

The current I_a will usually be produced by a source of rectified voltage V_a supplying a resistor R connected in series with the coil of resistance R_B.

The calculation then shows that I is given by the formula:

$$I=V/r_B\ (1+R_B/R)-Va/R \quad (5)$$

and the generated microwave power by

$$(6) \qquad Pm=kVI=k\left[\frac{V^2}{r_B}\left(1+\frac{R_B}{R}\right)-\frac{V_aV}{R}\right]$$

Proper selection of the values of V and R, by varying V_a, with R and V being constant, or R with V and V_a being constant, or V_a and R simultaneously with V being constant, results in a continuous variation or in discrete levels, of Pm from a maximum value to a very low value.

V and V_a are supplied by an a.c. source after rectification. If, for a predetermined adjustment, they are subject to the same relative variations, still equal to those of an a.c. source of volt-age U, a calculation using the formula (6), shows that:

$$\Delta Pm/Pm=2\ \Delta U/U$$

This last type of power supply is more advantageous than the preceding ones because the sensitivity ΔPm/ΔVa may be low.

However, good regulation of Pm requires sufficient stabilization of the alternating current source from which V and V_a are derived.

SUMMARY OF THE INVENTION

A purpose of the present invention is to provide an additional source of current that is added to the magnetron current in the induction coil, such that for each setting of the voltage of the additional source there is a corresponding value of delivered microwave power which is substantially independent of the instabilities of the common a.c. power source or of the magnetron power supply high voltage and of those of the additional source voltage.

According to the invention, the circuits associated with the additional source are designed so that, for each adjustment of the voltage thereof, or of the associated circuits and of the microwave power Pm, the effects of the instabilities of the high power supply voltage V are compensated by those of the instabilities of the additional source to maintain Pm stable.

According to a feature of the invention, the additional source of voltage V_a is replaced by a source of voltage V_a' having an output connected to a non-linear circuit comprising in series an element of very stable counter electromotive force (c.e.m.f.) E_o and very low internal resistance, a resistor R and the induction coil. V_a' is given by the relation:

$$V_a'=V_a+E_o.$$

According to another feature of the invention, the magnetron operating at fixed high voltage V, the c.e.m.f. E_o, the resistor R and the magnetron current intensity I corresponding to a predetermined adjustment of the delivered microwave power are related by the formula:

$$E_o=2RI.$$

According to another feature of the invention, the additional source voltage V_a' is equal to:

$$V_a'=E_B+E_o/2\ (1+I_B/I),$$

E_B being the voltage across the induction coil terminals and I_B being the intensity of the current passing through the said coil.

According to an embodiment of the invention, to obtain q regularly spaced discrete levels of microwave power, the non-linear circuit includes q identical Zener diodes and a series resistor R. Decreasing microwave power levels are obtained by successively short-circuiting one, two, three, . . . , (q-1) Zener diodes and by simultaneously lowering the voltage V_a' of the additional source by $e_o/2$, e_o being the equivalent Zener diode counter electromotive force.

According to another embodiment of the invention, to obtain q discrete microwave power levels, the non-linear circuit includes a single Zener diode and q resistors in series. Increasing microwave power levels are obtained by successively short-circuiting one, two, three, . . . , (q-1) resistors while each corresponding voltage V_a' is made to vary linearly with the value of the resistance of the circuit. In addition, in order to obtain q discrete microwave power levels, the additional source voltage V_a' is constant and for each microwave power level a coupling circuit comprising a Zener diode and a resistor R is used.

According to a further embodiment of the invention, wherein the microwave power is continuously varied, the q resistors are replaced by a rheostat and the a.c. source which generates the voltage V_a' comprises a variable autotransformer with a sliding contact, the movement of the sliding contacts of the rheostat and of the autotransformer being properly coupled. The main advantage of the power supplies of the present invention is the excellent regulation of the microwave power delivered by using a non-stabilized high voltage and an additional voltage source, and consequently a reduced cost from that of power supplies used in the prior art. Only two efficient low pass filters are required.

The various purposes and features of the present invention will appear more clearly from the following description of embodiments, taken in conjunction with the following drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows the family of characteristics $I=f(V, I_B)$ of a continuous-wave magnetron,

FIG. 2 shows the family of characteristics $I=f(I_a, V)$, I_a being the intensity of the current supplied by an additional source, and

FIGS. 3, 4 and 5 show three different embodiments of power supply circuits according to the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 shows the characteristic curves of the magnetron current I with the high voltage V for various values of the current I_B passing through the magnetron electromagnetic coil. With V constant, as shown by the dashed line, the current I decreases rapidly as I_B increases slowly. In other words, the applied power $P = VI$ varies from a maximum value down to a quasi-null value with a relative increase of I_B which practically is of about 1 to 2.

As previously mentioned, the current I is given by the formula (3):

$$I = V/r - a\, I_B$$

wherein r is the internal dynamic resistor of the magnetron (of about a few tens of ohms) and a is a coefficient of a high value, for example 50 to 100. If, according to the present system, I_B is the sum of the magnetron current I and of a current I_a supplied by an additional source, the current I depending on V and I_a is given by the relation:

$$I = V/r(1{+}a) - a/1{+}a\, I_a$$

FIG. 2 shows I varying with I_a, V being constant.

Considering the fact that $a >> 1$, it is further possible to write, as previously noted in the formula (4):

$$I = V/ra - I_a = {}_{Vl\,rb} - {}_{Ia}$$

According to the invention, I_a must always have the same direction. By assuming that I and I_a have the same sign, this implies that I is always kept lower than V/r_B.

Indeed V/rB is equal to the coil current I_B which, when V is constant, remains substantially constant. The selection of the winding readily fulfills this condition. There are empirical laws which, for a predetermined magnetic material, determine the variations of the induction B with the coil current and the number n of winding turns. These are of the form: $B = h\ n\ I_B$, wherein h is a constant.

Considering the magnetron tube geometry, a predetermined volume is available for the winding. If d is the diameter of the wire, n is roughly proportional tO A/d^2. Consequently, I_B , with other values being unchanged, is approximately proportional to d^2 and the resistance R_B varies inversely with d^4.

Considering again the formula (6) which, as in the prior art, gives the microwave power Pm depending on V and on the additional source voltage V_a, it is known that, if the relative variations of V and V_a are equal to those of the a.c. primary source voltage U, this results in:

$$\Delta Pm/Pm = 2\ \Delta U/U.$$

For each setting of Pm, and therefore of V, V_a and R, it is seen by combining the formulas (5) and (6), that ΔPm is kept at a minimum if the relative instabilities $\Delta V/V$ and $\Delta V_a/V_a$ verify the relation:

$$\Delta V_a/V_a = (2IR/Va + 1)\ X\ \Delta V/V$$

As $2IR/V_a$ is positive, $\Delta V_a/V_a$ must be higher than $\Delta V/V$.

Therefore, according to the invention, the additional source of voltage V_a is replaced by a source of higher voltage V_a' such that $V_a' - V_a = {}_{Eo}$.

E_o is a stable voltage corresponding, for example, to the Zener diode characteristic breakdown voltage or to a gas discharge lamp stabilization voltage. Zener diodes and gas discharge lamps, as it is known, operate with a particular value of current intensity passing through them to provide very stable c.e.m. force sources having very low and constant internal resistance.

Under such conditions, the absolute instability ΔV_a is equal to the absolute instability $\Delta V_a'$, but the relative instability $\Delta V_a/V_a$ is higher than the relative instability $\Delta V_a'/V_a'$ and thus than $\Delta V/V$. ($\Delta V_a'/V_a' = \Delta V/V$)

By replacing ΔV_a in the relation (7) by $\Delta V_a'$, V_a by $V_a' - E_o$ and $\Delta V/V$ by $\Delta V_a'/V_a'$, the result is that E_o, I and R verify the relation:

$$(8)\ E_o = 2IR$$

Within the predetermined range of values according to the assumptions made up to now, when V is constant, the microwave power Pm is proportional to I. Considering the formula (5) and taking (8) into account, it appears that the voltage V_a' is associated with the current I by the relation:

$$(9)\ V_a' = E_B + E_o/2\ (1 + I_B/I\ )$$

wherein: I_B represents the coil current which is substantially constant when I is varied, and E_B represents the voltage $R_B\ I_B$ across the terminals of the coil having a resistance R_B. Therefore E_B is also substantially constant.

If E_o is assumed to be the same for any adjustment of Pm and thus of I, the relations (8) and (9) show the values to be simultaneously assigned to R and V_a' for each value of I.

Practically, the value of E_o is selected within the range of values of the voltage E_B. Many Zener diodes are available which permit a c.e.m. force $E_o$to be obtained within a range of a few volts to tens of volts, and which are substantially stable as soon as the current passing through the diodes is over a predetermined value. It is also possible to connect several similar diodes in series by selecting a common Zener diode having a breakdown voltage of about 6 to 10 volts. Such Zener diodes are known to be particularly insensitive to temperature variations.

By way of example, the following table T1 shows the various values of R and V_a' for a continuous wave magnetron able to deliver, up a maximum microwave power $(Pm)_o$, from 75, 50 or 25 of $(Pm)_o$, all of which are regulated according to the invention.

The magnetron high voltage is 5 kV and the current intensity producing the maximum microwave power (Pm_o) is 1 A. With an efficiency of 70 for k, and with $P_{max} = 5$ kW, (Pm_o) is equal to 3.5 kW.

The four power levels will be obtained for currents respectively equal to 1, 0.75, 0.5 and 0.25 Amperes.

A Zener diode or a series connected Zener diode assembly has been selected having a breakdown voltage E_o of about 30 V and needing a minimum current I_a of 0.4 A in order to consider the internal dynamic resistance as very low and constant. Under such conditions, I_B is substantially equal to 1.4 A and, with the resistor R_B being 28 ohms, E_B is equal to 40 V.

TABLE T1

Pm (W)	$0.25(Pm)_o$	$0.5(Pm)_o$	$0.75(Pm)_o$	$(Pm)_o$=3.5 kW
I (A)	0.25	0.5	0.75	1
I_B (A)	1.4	1.4	1.4	1.4
$E_B = R_B I_B$ (V)	40	40	40	40
R (ohm)	60	30	20	15
V_a' (V)	139	97	83	76

There is some freedom in selecting E_o. The significant condition to be fulfilled is that, within the range of possible variations of I_a, the internal dynamic resistance of the Zener diode remains very low and constant. Practically, it is possible to take into account the internal dynamic resistance of the Zener diode(s) for producing each value of R.

The configuration of the two sources of voltages V and V_a' is substantially simpler than those previously used in power supplies for continuous-wave magnetron. The invention is based on the fact that the two d.c. sources are both subject to the same relative variations as the a.c. source from which they are generated. Thus, it is possible, with a large variation in the common a.c. source, to stabilize the a.c. source to a certain extent by using limited-current transformer. However, according to the present invention, the rectified voltages V and V_a' are not to be stabilized and only good filtering is necessary to eliminate the residual a.c. voltages.

FIG. **3** shows the circuit of an embodiment of a power supply circuit for a continuous-wave magnetron, according to the present invention. The only parts of the magnetron **1** that are shown are the cathode **1***a* and the cavity-anode **1***b* which is directly connected to the ground. The negative high voltage applied to the cathode **1**a is obtained from an a.c. source U and a transformer **3** which is then rectified in a rectifier-bridge **4** and filtered in a filter made of an auto-inductance and capacitors **5**. The positive terminal of the rectifier-bridge **4** is connected to the ground via the coil **2** of the electromagnet.

The positive additional voltage V_a' is obtained from the same a.c. source U and a transformer **6** after having been rectified in a rectifier-bridge **7** and filtered in a filter formed by an autoinductant capacitors **8**. The secondary of **6** is provided with several outputs: **6-1**, **6-2**, **6-3** and **6-4**, which may separately be connected to the highest point of **7** via a rotating switch **9**. Movement of the switch **9** permits adjustment of the voltage V_a' to the proper value. The output of the filter **8** is connected, via a Zener diode **10**, to four resistors **11-4**, **11-3**, **11-2** and **11-1** connected in series. The opposite end of **11-1** is connected to the higher point of the coil **2**. The values of the resistors **11-4** to **11-1** are respectively 15, 5, 10 and 30 ohms.

A rotating switch **12** which can make contact with the taps **13-1**, **13-2**, **13-3** and **13-4** may put into operation, one, two, three or four of the resistors **11** from the right to the left. This provides the connections for the resistors R of the table T1. The movements of the two switches may be coupled in any suitable manner.

In a modified version of the power supply circuit shown in FIG. **3**, it is possible to obtain continuous variation of the microwave power (Pm) by replacing the set of resistors **11** and the switch **12** by a rotating rheostat and also by replacing the secondary of **6** and the rotating switch **9** with a variable autotransformer. The movements of the sliding contacts of the rheostat and of the autotransformer may be coupled to provide correspondence between V_a' and R for each value of I by using the formulas (8) and (9).

It is also possible, according to the present invention, to obtain discrete levels of microwave power by varying only R, with V_a' being constant, or V_a' with R being constant. However, in both cases, a Zener diode or a set of Zener diodes will be necessary for each power level.

The case where R is kept constant will be considered first.

For each power level, I is defined and from formula (**8**) results in a value for $E_o = 2RI$.

Likewise, with formula (9), V_a' is equal to:

$$V_a' = E_B + R\,(I + I_B)$$

With reference to the previous mentioned example for a magnetron delivering four microwave power levels and by selecting a resistor R of 30 ohms, the table T2 may be deduced as follows:

TABLE T2

Pm(W)	$0.25(Pm)_o$	$0.5(Pm)_o$	$0.75(Pm)_o$	$(Pm)_o$=3.5 kW
I (A)	0.25	0.5	0.75	1
I_B (A)	1.4	1.4	1.4	1.4
E_B (V)	40	40	40	40
E_o (V)	15	30	45	60
V_a' (V)	90	97	105	112

Due to the fact that the selected power levels are the successive multiples of a minimum level, the values of E_o are also the multiples of an initial minimum value. This is used in the circuit of FIG. **4** which slows only the circuitry of the additional source.

The differences with respect to FIG. **3** are the following: the set of four resistors is replaced by a single resistor **11**, instead of a single Zener diode, there are four similar Zener diodes mounted in series (**10-1** to **10-4**), each one having a breakdown voltage of 15 V, and it is possible to put into operation one, two, three or four diodes from right to left by means of a rotating switch **14**.

The contact position for both switches **9** and **14** of FIG. **4**, at points **6-4** and **15-4**, respectively corresponds to the maximum microwave power level.

Considering the case where V_a' is kept constant, for each microwave power level and for each value of I, E_o and R are defined by using the formulas (8) and (9), i.e.:

$$R = \frac{V'_a - E_B}{I + I_B} \text{ and } E_o = \frac{2I}{I + I_B}\,(V'_a - E_B).$$

With reference to the previous mentioned example for a magnetron delivering four microwave power levels and by having $V_a' = 100$ V, the following Table T3 may be deduced.

The circuit of FIG. **5**, which again shows only the part concerning the additional source, operates with a constant voltage V_a'. As in FIGS. **3** and **4**, the transformer **6** is shown, but with a secondary having only two connections to the rectifier-bridge **7** which is also connected to the filter **8**.

TABLE T3

Pm(W)	$0.25(Pm)_o$	$0.5(Pm)_o$	$0.75(Pm)_o$	$(Pm)_o$ = 3.5 kW
I(A)	0.25	0.5	0.75	1
I_B(A)	1.4	1.4	1.4	1.4
E_B(V)	40	40	40	40
R(ohm)	36	32	28	25
E_o(V)	18	32	42	50

The rotating switch **14** of FIG. **5** has four positions **15-1** to **15-4** which provide a series connection of one, two, three or four Zener diodes **10-1** to **10-4**, having bend voltages respectively of **18**, **14**, **10** and **8** volts. A rotating switch **12** with four positions **13-1** to **13-4** permits a series connection of one, two, three or four resistors **11-1** to **11-4** of which the values are respectively **25**, **3**, **4** and **4** ohms in order to obtain the resistances R of Table T3.

The position for both the switches indicated at **13-1** and **15-4** respectively, corresponds to the maximum microwave power level. The position **13-4** and **15-1** corresponds to the minimum power level.

The values of the resistors, i.e. 25, 3, 4 **and** 4 ohms, are actually theoretical values. In practice, they have to be corrected to take into account the internal resistances of the Zener diodes which may be not negligible le with respect to 3 or 4 ohms. Thus the value of the resistor **11-1** will be 25 ohms minus the sum of the internal resistances of the four Zener diodes **10-1** to **10-4**; the value of the resistor **11-2** will be 3 ohms plus the internal resistance of the Zener diode **10-1**; that of **11-3** will be 4 ohms plus the internal resistance of **10-2**; and that of **11-4** will be **4** ohms plus the internal resistance of **10-3**.

In all the described examples, it has been assumed that the c.e.m. force E_0 was provided by one or several Zener diodes. Obviously, it is possible to replace part or all of the Zener diodes by gas regulating tubes or fluorescent tubes.

While the principles of the present invention have been described in connection with several particular embodiments, it will be understood that this has been made only by way of example and does not limit the scope of the invention as set forth in the appended claims.

WHAT IS CLAIMED IS:

1. A continuous wave magnetron power supply circuit comprising:

an alternating current power source;

a magnetron tube having an enclosed cathode and anode electrodes and an external electromagnetic coil;

first direct current supply means including first rectifier and filter means connected between said alternating current power source and said magnetron electrodes and coil for supplying direct current thereto;

second direct current supply means connected between said alternating current power source and said magnetron coil for supplying additional direct current to said coil, said second direct current means including second rectifier and filter means and a plurality of series connected circuit elements including a resistor and an electron discharge device having a stable characteristic breakdown voltage; and

means for selectively adjusting said additional direct current supplied to said coil to establish a plurality of different stable power output levels.

2. The device of claim **1** wherein said plurality of series connected circuit elements includes a plurality of resistors and said selectively adjusting means includes means for connecting selected numbers of said resistors in series with said coil.

3. The device of claim **1** wherein said plurality of series connected circuit elements includes a plurality of zener diodes and said selectively adjusting means includes means for connecting selected numbers of said zener diodes in series with said coil.

4. The device of claim **1** wherein said selectively adjusting means includes means connected to said source of alternating current power for adjusting the voltage from said alternating current power source connected to said second direct current supply means.

5. The device of claim **2** wherein said selectively adjusting means includes means connected to said source of alternating current power for adjusting the voltage from said alternating current power source connected to said second direct current supply means.

6. The device of claim **2** wherein said plurality of series connected circuit elements includes a further plurality of zener diodes and said selectively adjusting means includes means for connecting selected numbers of said zener diodes in series with said resistors and coil.

7. The device of claim **3** wherein said selectively adjusting means includes means connected to said source of alternating current power for adjusting the voltage from said alternating current power source connected to said second direct current supply means.

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