Oct. 8, 1946. C. W. HANSELL 2,409,038

MAGNETRON AND CIRCUIT THEREFOR

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Fig. 1.

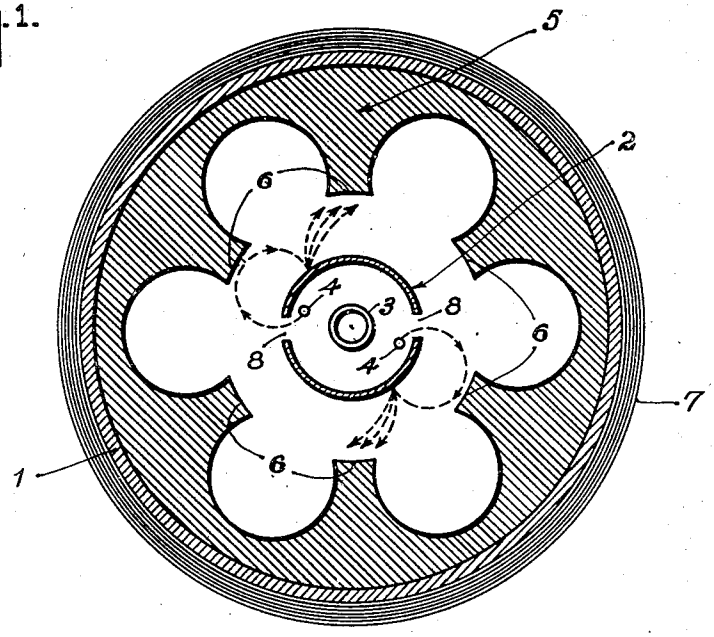
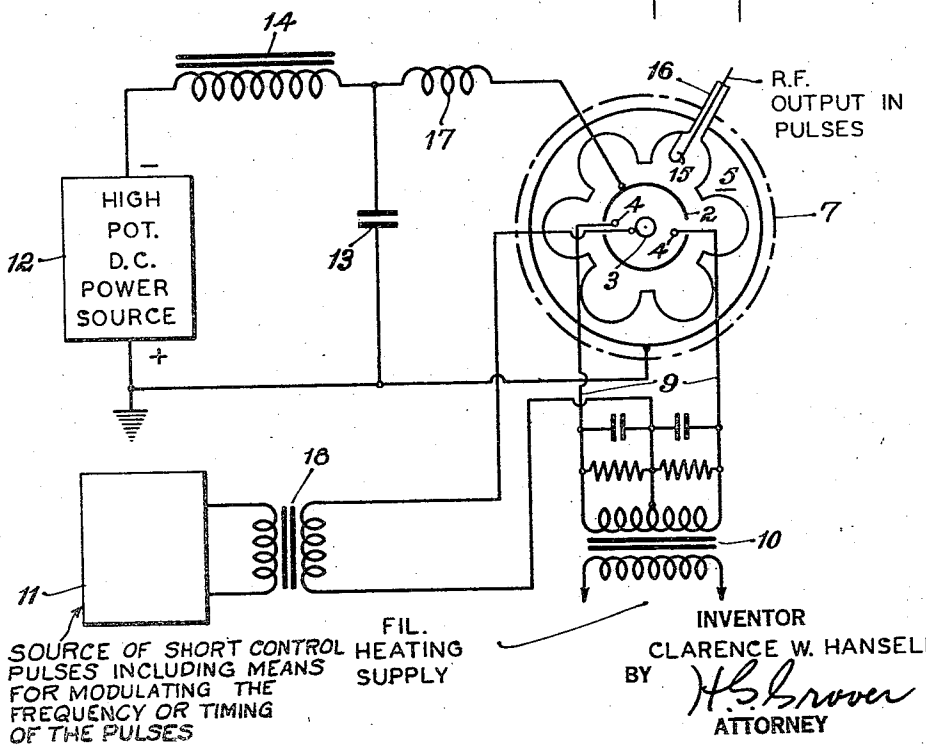


Fig. 2.



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Fig. 3.

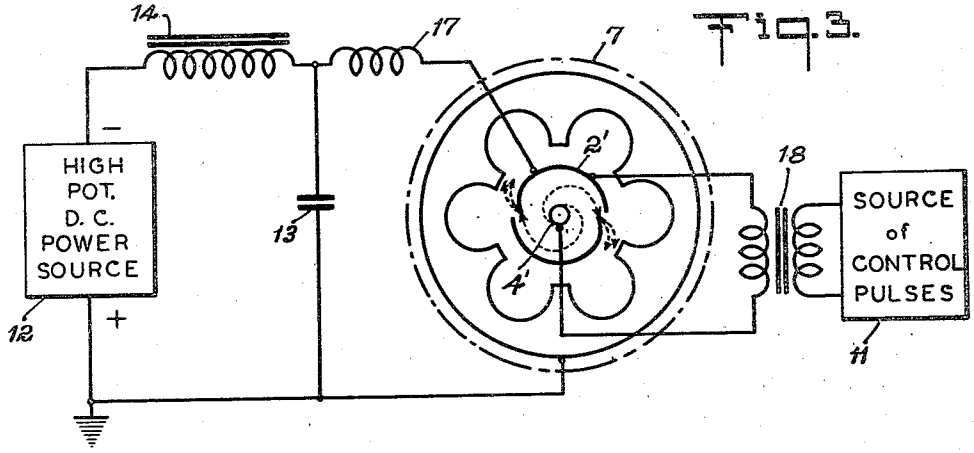


Fig. 4.

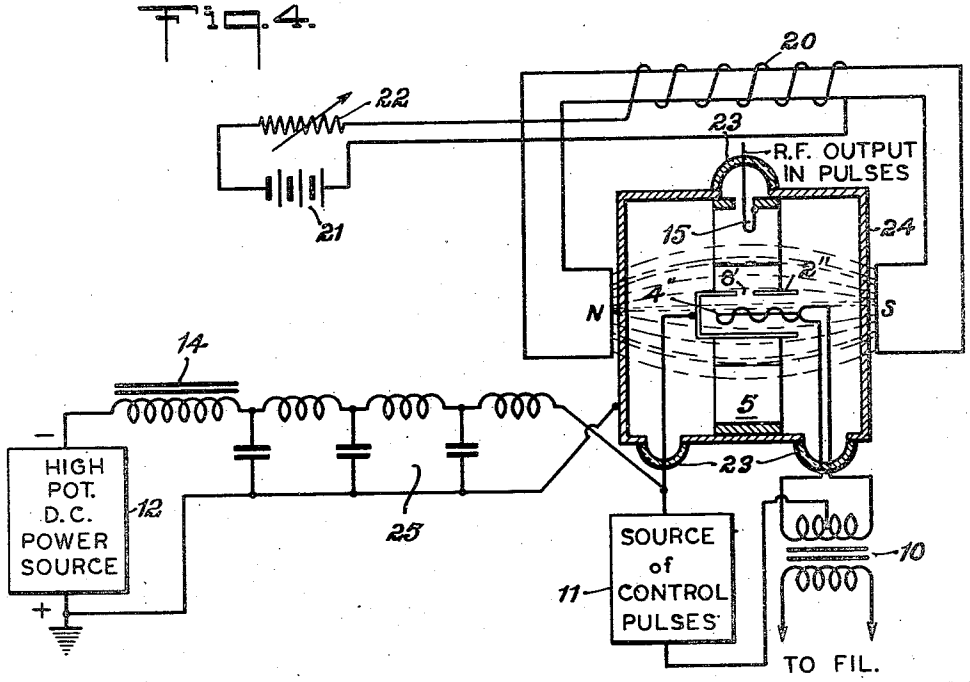
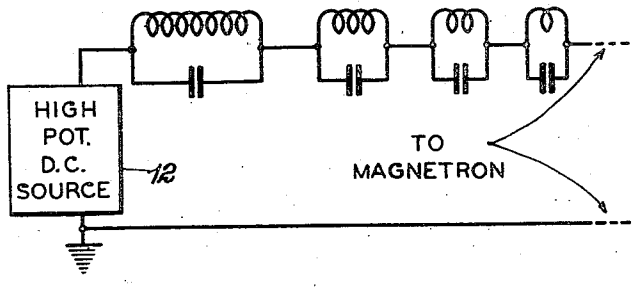


Fig. 4a.



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MAGNETRON AND CIRCUIT THEREFOR

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Fig. 5.

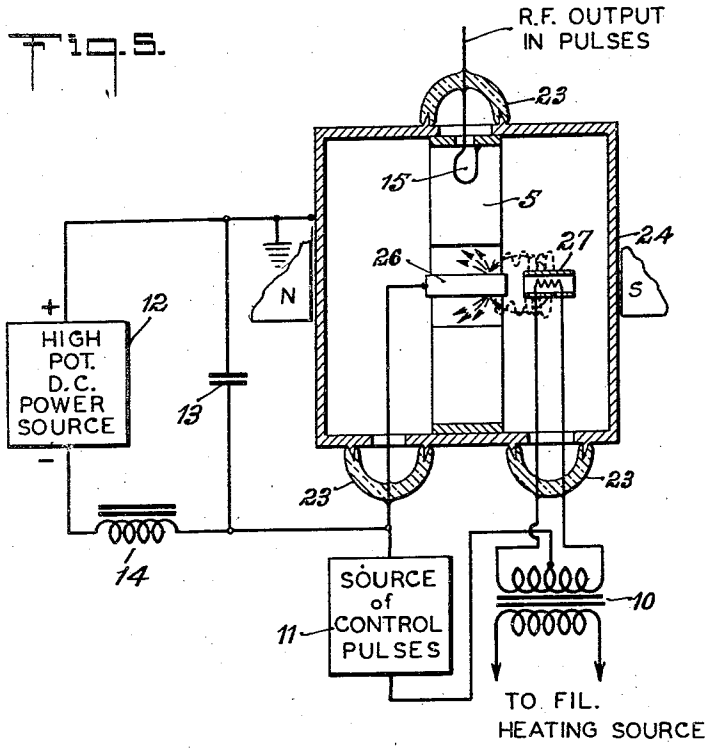
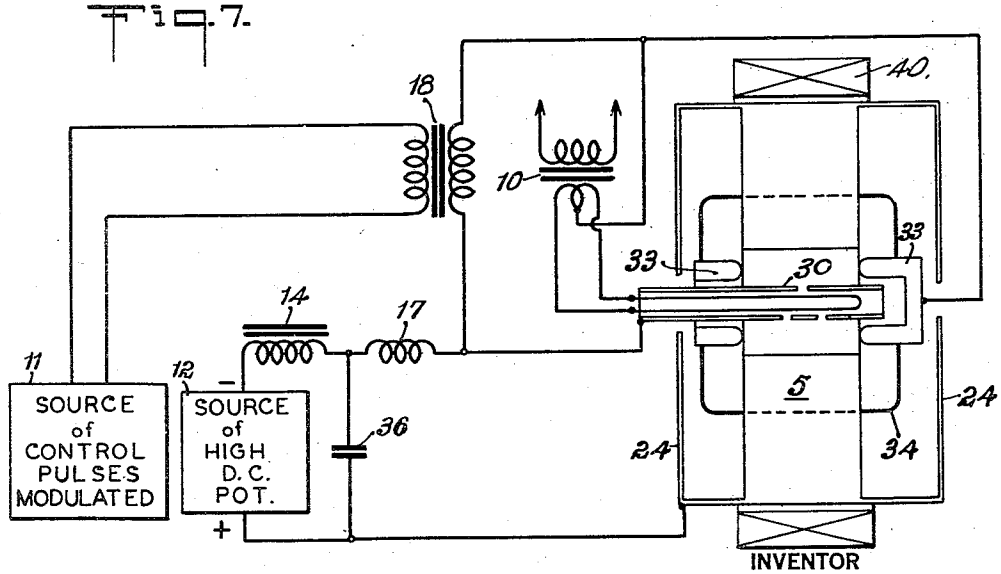


Fig. 7.



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Fig. 6.

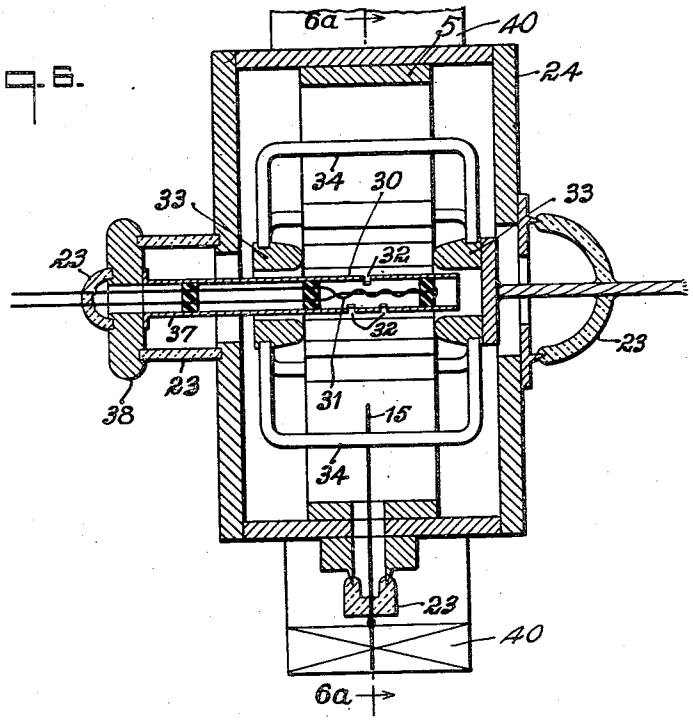
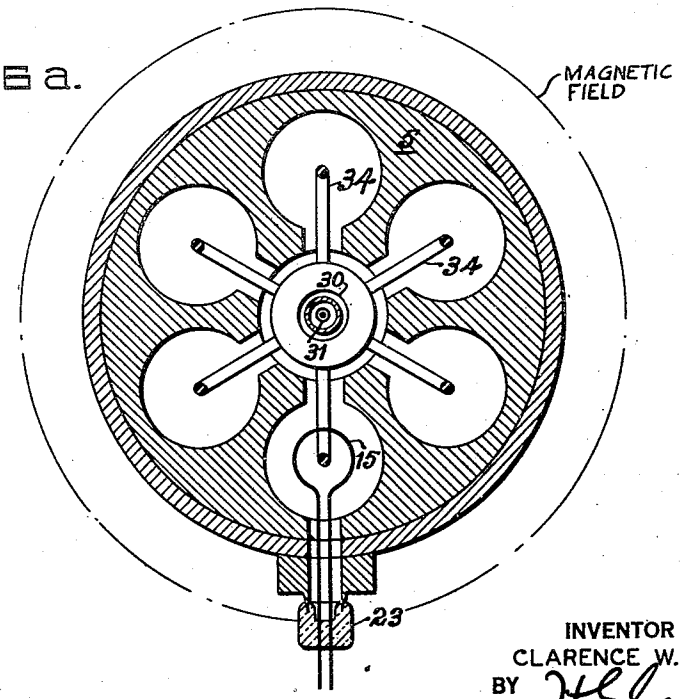


Fig. 6a.



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Patented Oct. 8, 1946

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UNITED STATES PATENT OFFICE

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MAGNETRON AND CIRCUIT THEREFOR

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Application December 31, 1942, Serial No. 470,768

28 Claims. (Cl. 250—36)

1

The present invention relates to improvements in magnetron oscillation generators and their associated circuits. More particularly, the invention is concerned with an ultra high frequency magnetron to be used for the production of pulses of oscillation, as distinguished from the production of oscillations resulting in continuous waves.

In my experiments, I have observed that magnetrons with small thermionic emission, as low as say fifty milliamperes, will oscillate and can be made to pass currents during oscillation ranging up to, say, fifty amperes, provided the magnetic field and the anode-to-cathode potential are sufficiently high. It is my theory that oscillation produces a rapid growth in cathode emission due to secondary emission from bombardment of the cathode by out-of-phase electrons. By out-of-phase electrons I mean those electrons which absorb energy from the high frequency electric fields set up in the magnetron during oscillations as distinguished from those which give up energy to maintain the oscillation. These out-of-phase electrons after one transit out toward the anode and back, strike the cathode with enough energy to produce secondary emission, while in-phase electrons may make 1.5 or more excursions before striking the anode and deliver more power to produce oscillations than the power absorbed by out-of-phase electrons. Absorption of the out-of-phase electrons on the cathode after one excursion is an important factor in electron grouping to enhance the strength of oscillations.

I have also observed that there is a time lag between the application of the high anode-to-cathode potential and the beginning of oscillation, and that I can control this time lag by controlling the amount of thermionic emission. According to my theory, there is an accumulation of space charge and circulating electron current in the space between the anode and cathode, following the application of the anode-to-cathode potential, and the initial rate of this accumulation is proportional to the electron emission from the cathode. When the space charge and circulating electron current reach a critical value, there occurs a condition of high frequency negative resistance greater than positive resistance in the oscillatory electric circuit of the anode. Oscillations then start just as they do in any negative resistance oscillator. If the anode-to-cathode potential is too low, or if the cathode is a very poor secondary emitter, the oscillations continue only long enough to dispel most of the circulating space charge by causing some electrons to be

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accelerated and forced back to the cathode while others are slowed down and caused to strike the anode. On the other hand, if the anode potential is high enough, and the cathode is a good secondary emitter, the circulating space charge will be replenished by secondary emission as fast as or faster than it is dissipated and oscillation will continue at great strength so long as the anode potential remains high.

According to a feature of the invention, the magnetron, when used with suitable circuits, is made to stop its own oscillations as the potential across the magnetron is lowered by dissipation of energy stored in the input circuit connections. To achieve this result, the magnetron is shunted by a condenser or an artificial line which, in turn, is charged through a suitable impedance, as a result of which oscillations of the magnetron, once started, continue until the condenser or line circuit is discharged down to a potential too low to maintain sufficient secondary cathode emission. The condenser or line circuit will then be charged through the series impedance and space charge will accumulate in the space between anode and cathode, and oscillations will start again. This process will repeat itself indefinitely. Thus, so long as the cathode emission is low enough to lengthen the time for re-establishment of circulating space charge to more than the time constant of the charging circuit, the magnetron will pulse itself automatically. Putting it in other words, in order to achieve self-pulsing, the anode potential should be restored to its maximum value before the space charge has been re-established sufficiently to initiate oscillations. The resulting pulses will be of nearly equal energy, and their frequency or repetition rate may be controlled by controlling the amount of thermionic emission.

Inasmuch as it is not very practical to control and modulate the thermionic emission, it is proposed in accordance with the invention to utilize a controllable electron source for establishing the initial circulating space charge needed to start each pulse.

This feature is quite important when using the magnetron of the invention in pulse communication or in pulse echo systems of the radio locating type, sometimes referred to as obstacle detection systems. Heretofore, in radio locating pulse systems, it has been customary to pulse the magnetron by delivering the whole input power to the magnetron in pulses, which required pulses of potential to be applied between the anode and cathode. Such known systems require a switch-

ing arrangement in series with the magnetron which can handle large amounts of power. In the prior art, one type of switching arrangement has required modulator vacuum tubes in series with the magnetrons and a high potential power source. In operation, the control electrodes of the modulator vacuum tubes are pulsed to permit pulses of current to flow through the magnetrons. In this type of modulator, difficulties have arisen because of secondary emission from the control electrodes of the modulator tubes which makes it difficult to interrupt the current at the ends of the pulses. Another type of modulator requires storing energy at high potential and then discharging the stored energy through a spark gap into the magnetron. Reference is made to the copending applications of Nils E. Lindenblad, Serial No. 441,311, filed May 1, 1942, and Serial No. 454,661, filed August 13, 1942, for detailed descriptions of other known systems. By means of my invention, however, I can use a relatively small amount of control energy to make the magnetron act as its own modulator, or control switch, and I do this by using a pilot source of control pulses of small pulse energy.

According to another feature of the invention involving the construction of the magnetron, the controllable electron source is, in effect, a priming current which I can turn on and off. A cold cathode (as distinguished from a thermionic or heated cathode) capable of emitting copious electrons upon bombardment by the priming current is placed physically near the controllable electron source. By modulating the priming current, and turning it on and off, I can control the frequency of the magnetron pulses and start and stop them at will. The length and energy of the pulses is controllable by varying the amount of the dielectric capacity between the anode and cathode of the magnetron, by varying impedances in series with the magnetrons, and to some extent by controlling the potential.

According to a preferred detail feature of the invention, the magnetic field may be tapered somewhat in strength along the axis of the magnetron, with a minimum at the center, so that the circulating space charge tends more nearly to accumulate where it is most needed and not to diffuse out to the end walls. A suitable electric field distribution for aiding in this grouping of the space charge is also desirable.

Among the objects of the invention are: To simplify the design and construction, and reduce the weight, bulk and cost of radio systems employing magnetrons for producing pulses of high frequency energy; to provide a magnetron which requires a relatively small amount of control energy to start oscillations; to provide a novel form of magnetron construction which includes a cold cathode capable of producing copious secondary electrons upon bombardment of primary electrons, and a source of priming current; and to provide a magnetron capable of producing pulses whose frequency or repetition rate can be varied by controlling an electron source which establishes the initial circulating space charge needed to start each pulse.

The following is a detailed description of the invention in conjunction with the drawings, wherein:

Fig. 1 shows, in cross-section, a view of a magnetron oscillator in accordance with one embodiment of the present invention;

Fig. 2 shows the magnetron of Fig. 1 and a

circuit associated therewith for causing the production of radio frequency energy in pulses;

Figs. 3, 4 and 5 show other constructional features of magnetrons in accordance with the present invention, together with different kinds of circuits for producing pulses of radio frequency energy;

Fig. 4*a* shows an alternative type of artificial line which can be used for that shown in the system of Fig. 4;

Fig. 6 shows in cross-section the essential novel features of construction of a magnetron in accordance with another embodiment of the invention;

Fig. 6*a* is a sectional view of the magnetron of Fig. 6 along the lines 6*a*—6*a*; and

Fig. 7 schematically illustrates the magnetron of Fig. 6, together with a circuit arrangement for operating the same.

Throughout the figures of the drawings, the same reference numerals designate the same or like parts.

The oscillation generator shown in Fig. 1 comprises an envelope 1, made of any suitable material such as copper, containing within it a hollow cylindrical non-thermionic or cold cathode 2, a cylindrical control electrode 3 located along the axis of the magnetron, a pair of thermionic cathods 4, 4 located between the control electrode 3 and the cold cathode 2, and a cylindrical anode structure 5 having an even number of protruding anode portions 6 which are substantially or effectively spaced from one another by one-half wavelength and which bend inwardly toward the cathode, more or less in the manner shown in Fig. 1. This type of anode, which is a preferred type, though not essential in the practice of the invention, is of the type generally shown and described in my United States Patent 2,217,745, granted October 15, 1940. A field coil 7, which may or may not employ iron to aid its effect surrounds the envelope and functions to produce an intense but constant magnetic field which has flux lines running through the envelope in a direction more or less parallel to the axis of the cold cathode so as to influence the movement of the electrons emanating therefrom.

The envelope 1 is evacuated in the manner of any vacuum tube. The cold cathode 2 is apertured at diametrically opposite points 8, 8 to permit electrons emanating from the hot cathodes 4, 4 to enter the space between the cold cathode 2 and the anode 6 under conditions described hereafter. The cold cathode 2 is made from a metallic material and is of the type whose exterior surface is capable of emitting copious electrons when bombarded by primary electrons emanating from the hot cathodes. The cold cathode is preferably made of some light metal, such as aluminum or an alloy of light metals which emit secondary electrons easily. Alternatively, the cold cathode may be of metal, coated with oxides of earth metals such as barium and strontium oxides formed by the reduction of the carbonates in vacuum, which oxide coatings I have found to be sufficiently good secondary emitters for the purpose of the invention. The apertures 8, 8 in the cold cathode 2 may be in the form of slots extending nearly the entire length of the cathode, in which case the control electrode 3 will extend the entire length of the cathode. It is only necessary for the control electrode 3 to have substantially the same or somewhat greater length than the length of the apertures 8.

The hot cathodes or filaments 4, 4 and the con-

trol electrode 3 are so positioned that when the control electrode has a positive potential with respect to the filaments 4, 4, electrons will leave the hot filaments and circulate out into the magnetic field, passing through the slots 8, 8 in the cold cathode. The positive potential on the control electrode 3 will draw electrons from the filaments toward it, but the magnetic field will bend the electron paths and cause them to pass out through the slots and into the space between the cold cathode and the anode; in the manner shown by the dotted lines, having arrows thereon to indicate the direction of electron motion. When the control electrode 3 is at zero or negative potential relative to the filaments, substantially no electrons will pass through the slots in the cold cathode. In the operation of the magnetron of Fig. 1, if (while the control electrode 3 is zero or negative relative to the filaments 4, 4) a large potential from a suitable source is applied between the anode 6 and the cold cathode 2, substantially no current will flow due to the absence of emission from the cold cathode 2. No current will flow through the slots to bombard the cold cathode due to the fact that there is nearly complete shielding of the filaments 4, 4 from the electric field produced by the anode-to-cold cathode potential, under the above condition. In this situation, there will be substantially no accumulation of circulating electron space charge between the cold cathode and the anode. However, if the control electrode 3 is made to be positive relative to the filaments 4, 4, electrons will pass through the cold cathode slots 8, 8, and a circulating electron space charge will begin to accumulate in the space between the anode and the cold cathode. As this circulating space charge grows, and if the anode-to-cathode potential is high enough, though of a direct current character, a point will be reached where oscillations start. The cold cathode 2 will then be bombarded by out-of-phase electrons, and emission will grow rapidly due to secondary emission; as a result of which a large anode-to-cathode current will flow. This flow of current may discharge a condenser or line circuit connected between the anode and cathode in the manner described more in detail later, and reduce the anode-to-cathode potential, thus stopping the oscillations again.

If the control electrode 3 is kept positive relative to the filaments 4, 4 and a dielectric capacity between anodes 6 and cold cathode 2 is charged through an impedance, the magnetron will act in a manner quite similar to a "Thyratron" gaseous discharge tube, operating in pulses and at a rate which may be determined by the time constant of the power supply circuit or by the rate of growth of circulating space charge, depending upon which is quicker. Alternatively, the control electrode may be rendered negative when the oscillation and anode current start, and not made positive until a pulse of anode current and oscillation is desired. Thus, by means of a relatively small potential change and very little energy applied to the control electrode, I can control the timing and rate of pulses of radio frequency energy obtainable from the magnetron and stop and start them as desired, using the magnetron itself as a modulator as well as an oscillator. This is also described later in connection with the circuits of Figs. 2 to 4, inclusive.

Fig. 2 schematically shows a complete circuit arrangement utilizing the magnetron of Fig. 1 for producing pulses of radio frequency energy. The hot cathodes or filaments 4, 4 are supplied with filament heating current over leads 9, which connect to opposite terminals of the secondary winding of an ordinary sixty cycle power transformer 10. In shunt to or across the cold cathode 2 and the anode 5, there is provided a charging circuit including a storage condenser 13, a charging reactor or choke coil 14, and a high potential direct current power source 12. A relatively small cushioning choke 17 is provided between the charging reactor 14 and the cold cathode. Source 12 supplies a substantially constant current through the choke coil 14 to the storage condenser 13, and this condenser 13 is discharged through the magnetron solely during pulses of oscillation, at which time the cold cathode 2 has high secondary emission. Choke coil 17 aids in starting oscillation and in obtaining flat top pulses in the output of the magnetron by virtue of the potential drop in the choke coil, due to rate of change of current therethrough. In order to obtain output pulses of high frequency energy from the oscillator, there is provided a loop 15, one end of which is directly connected to the anode (as shown) and the other end of which extends outwardly through a concentric line 16 for utilization by suitable apparatus, such as an antenna.

In order to control the initiation of circulating space charge and oscillation (that is to start the pulses) there is provided a source 11 of control pulses which is coupled (through transformer 18) between the control electrode 3 and the hot cathodes 4, 4, as shown. Source 11 is, in effect, a keyer of very short pulses of moderate power and potential which are applied to the control electrode 3 and are sufficient to cause electron current from the hot cathodes 4, 4 to flow through the slots in the cold cathode to initiate a growth of circulating space charge and oscillations. Source 11 (which is a pilot of relatively small pulse energy) starts the pulse while the magnetron with its circuit 12, 13, 14 makes and breaks the circuit to start and stop the main power pulse. In other words, I employ a small amount of control energy from 11 to make the magnetron act as its own switch.

In the operation of the system of Fig. 2, the pulse voltage from source 11 will prime the magnetron to cause it to begin oscillations. This occurs because the electrons from the hot cathodes or filaments 4, 4 flowing through the slots of the cold cathode 2 will produce a growing circulating space charge inside the anode structure until oscillations start. These oscillations start by virtue of the negative resistance. Once the oscillations start, the electrons in the space charge are replenished as fast as they are used up, by virtue of the bombardment of the exterior surface of the cold cathode by out-of-phase electrons and the consequent production of secondary emission. These oscillations continue until condenser 13 is discharged below a critical potential, at which time the bombardment of the cold cathode by the out-of-phase electrons does not take place with sufficient energy to replenish the circulating space charge as fast as it is used up. The oscillations then stop suddenly. The time between the initiation of oscillations and the cessation of oscillations constitutes the duration of one pulse of radio frequency current as taken out from loop 15. After the cessation of oscillations, condenser 13 will be recharged from source 12 through choke coil 14. Source 12 has a magnitude of voltage necessary to cause the magnetron to oscillate efficiently by virtue of the cold cath-

ode emission phenomenon. Source 11 initiates each pulse and thus determines when the oscillations start, and controls the time of the initiation of the pulse and the rate of the pulses. In practice, the source 11 may generate pulses of 1000 volts (by way of example) of extremely small current, at a rate of a few cycles per second up to 20,000 or 30,000 cycles per second, depending upon the type of detection or communication system associated with the circuit of Fig. 2.

If the system of Fig. 2 is designed for use in a pulse echo system (sometimes known as an obstacle detection system of the type employed now for military purposes), source 11 can generate pulses anywhere in the range from 120 to 4000 or 5000 cycles per second, whereas if the system of Fig. 2 is to be used for telephone communication, the pulse rate of this source might be 20,000 or 30,000 cycles per second, in which case this pulse rate or the pulse timing might be frequently modulated by voice currents. Where the system of Fig. 2 is used for telephone communication purposes, the pulse rate of source 11 must be higher than the audio frequency range utilized for communication. Source 11 can be a small synchronous motor driving a commutator doing the pulsing or it may be a vacuum tube pulser which is small and inexpensive. For telephony purposes, source 11 should be a vacuum tube pulser which can be modulated in frequency or timing. As for high potential direct current power source 12, considering present types of magnetrons, this source should have a voltage between 10,000 and 50,000 volts, depending upon the particular design of the magnetron. The magnetron itself may generate oscillations having a frequency anywhere in the range from 300 to 30,000 megacycles, more or less.

Fig. 3 shows a modification of the system of Fig. 2. In Fig. 3, the magnetron differs somewhat from that shown in Figs. 1 and 2 in the absence of a control electrode. Instead of the control electrode described in connection with Figs. 1 and 2, Fig. 3 employs a hot cathode 4'. The non-thermionic or cold cathode 2' has certain ones of its edges curved slightly inwardly to provide a target area for the electrons emanating from the hot cathode in order to produce secondary emission from these curved ends. Control potential from source 11 is now applied between the cold cathode 2' and the hot cathode 4', as shown. It should be noted that the electrons from the hot cathode 4' first strike the curved ends of the slots of the cold cathode to produce secondary electrons which then emerge from the slots to be added to the circulating space charge. The electrons emerging from the slots of the cold cathode 2' will, of course, strike the exterior surface of the cold cathode to produce additional secondary electrons. It has not been deemed necessary to show the heater circuit for the hot cathode in the interest of simplification of the drawings. The elements of the system of Fig. 3 which are same as the elements of the system of Fig. 2 have been given the same reference numerals, while the elements of Fig. 3 which are equivalent in purpose or structure to those in Fig. 2 have been given the same reference numerals with a prime designation. The operation of the system of Fig. 3, except for the difference mentioned above, is the same as that of Fig. 2 and will not be repeated.

Fig. 4 shows another embodiment of the invention wherein a magnetron and the associated circuit are slightly different from the magnetron and circuits of Figs. 2 and 3. In Fig. 4, the magnetron is shown along a section parallel to the axis, rather than perpendicular to the axis. The cold cathode in Fig. 4 is represented by the reference number 2'', while the hot cathode is represented by the reference 4''. The cold cathode of Fig. 4 is made up of a cylinder, one end of which is closed and connected to the source of control pulses 11, as shown, and the other end of which is open to permit the emergence of the leads from the hot cathode 4'' to the filament heating transformer 10. The slot 8' in the cold cathode is circumferential instead of parallel to the axis, as hereinbefore described. This slot 8' may approximate one-third of the circumference of the cold cathode 2''. It should be understood that there may also be other slots in the cold cathode. The anode 5 is substntially the same in construction as the same numbered elements in Figs. 2 and 3. The magnetic field in Fig. 4 is produced by a pair of pole pieces marked "N" and "S," representing north and south. These pole pieces are connected together by a yoke which is surrounded by a coil 20, in turn energized from a direct current source 21 through a variable resistor 22. The arrangement of the magnetic field is such that it is somewhat tapered in strength along the axis of the magnetron with a minimum at the center so that the circulating space charge tends to more nearly accumulate where it is wanted and not to diffuse out to the end walls. Putting it in other words, the tapering magnetic field is such that electrons tend to concentrate in a plane at right angles to the axis of the tube located at the center. Because the intensity of the magnetic field is a minimum at the center, the circulating electrons have a tendency to drift toward this minimum field location. Suitable glass seals 23, 23 serve to provide a vacuum tight enclosure for the magnetron. The leads from the filament heating transformer 10 to the hot cathode and the lead from the source 11 to the cold cathode, as well as the lead from the output circuit to the loop 15, enter the interior of the magnetron through these glass seals. A metallic can-like arrangement 24 provides an envelope for the magnetron. An artificial line 25 serves the same purpose as condenser 13 of Figs. 2 and 3 but gives a modified wave form of input potential and current for the magnetron. The system of Fig. 4 has the advantage of providing a more nearly rectangular wave form for the pulses obtainable from the output loop 15.

An alternative arrangement for the line 25 of Fig. 4 is shown in Fig. 4a. It consists of a series of circuits each containing inductance and capacity in parallel. These taper in size as one goes from the source 12 to the magnetron. This arrangement, I believe, is called a Guillemin line, after Prof. Guillemin, its inventor.

Fig. 5 is another embodiment of the invention and again shows the magnetron in cross-section in a plane passing through the axis of the tube. The magnetic field has been shown in Fig. 5 for the sake of simplicity of the drawings as taking the form shown in Fig. 4, although if desired it may take the form shown in Figs. 2 and 3. The non-thermionic or cold cathode of Fig. 5 is shown as a rod or hollow metallic cylinder 26, while the hot cathode is at one end and designated as 27. This hot cathode may be of the indirectly heated type as shown and serve to supply the priming electrons for bombarding the cold cathode 26. Although the hot or thermionic cathode of Fig. 5

can emit continuously, movement of electrons from the hot cathode to the control electrode can be prevented or reduced sufficiently by making the thermionic cathode sufficiently positive with respect to the cold cathode. It takes only moderate potentials, as compared with the anode-to-cold cathode potential, to control electron motions in directions parallel to the magnetic field. The operation of the system of Fig. 5, except for the difference just pointed out, is substantially the same as that described above in connection with Figs. 1 and 2.

My construction of the magnetron which employs the use of a cold cathode and a thermionic cathode, to the latter of which a controllable potential can be applied, has the practical advantage that during the building of the tube there can be applied temporarily much more than normal potential between the thermionic and cold cathodes, thus heating the cold cathode high enough temporarily to activate it. This cold cathode may be oxide coated, similar to the hot cathodes in the known types of magnetrons. The magnetron of the invention has the further advantage that the equipment needed with it is much less expensive, much less bulky and much lighter than many prior art alternatives used in pulsing transmitters. I might thus more readily use the magnetron of the present invention in portable and mobile military equipment.

The systems of Figs. 1 to 5, inclusive, are well suited for telephone and like types of pulse communication in which the pulse length is held constant and the pulse frequency or pulse timing is varied in response to modulation. From a practical standpoint, the magnetron of Figs. 1 to 5 is not so well suited for modulation which requires varying the length of the pulses.

Figs. 6 and 6*a* illustrate a magnetron in accordance with another embodiment of the invention, and Fig. 7 shows this new type of magnetron in connection with a circuit arrangement, as a result of which the pulse oscillations can be both controllably started and stopped, even though a substantially constant direct current potential is maintained between the anode and the cold cathode. This magnetron is therefore suitable for pulse length modulation in addition to the other types of modulation.

Referring to Fig. 6 in more detail, I have shown a magnetron having a hollow cold cathode **30** of the type generally illustrated in Fig. 4, except that this cold cathode is provided with a plurality of circumferential slots **32, 32**. The cold cathode **30** accommodates in its interior a hot cathode **31** having leads which extends externally of the magnetron through a glass seal **23**. The cold cathode is provided with a metallic tube **37** which terminates in a disc-like terminal **38**. Tube **37** shields the heater leads for the hot cathode **31**. There is provided a strong axial magnetic field for producing lines of flux extending parallel to the axis of the cold cathode, and this is accomplished by means of a field coil **40**. Electron absorber electrodes **33** are provided at opposite ends of the cold cathode, in order to stop the oscillations in a manner to be described later in connection with Fig. 7. These absorber electrodes are supported by metal rods **34, 34**. The metal support rods are positioned in places of balanced high frequency field and so are very little coupled to the effective oscillating circuit. A suitable evacuated metallic can-like arrangement **24** constitutes the envelope of the device, and glass seals **23, 23** serve to provide a vacuum tight enclosure for the elements within the can **24**. The usual output loop **15** is shown for deriving high frequency oscillations from the magnetron.

Fig. 6*a* is a cross-section of the magnetron of Fig. 6 along the lines **6***a*—**6***a*. The magnetron of Figs. 6 and 6*a* is shown in connection with a complete circuit arrangement in Fig. 7. In Fig. 7 there is provided a source **11** of control pulses of a relatively low power which may be modulated in length, frequency or timing by the use of conventional vacuum tubes and circuits. Source **11** is coupled to the two electron absorber electrodes **33, 33** through a coupling transformer **18**. It should be noted that both absorber electrodes **33, 33** are connected together by means of supports **34**. A source **12** of high direct current potential is shown coupled across the cold cathode **30** and the can **24**. A condenser **36** in series with the high impedance smoothing reactor **14** is shown shunted across the source **12**. Condenser **36** is a large smoothing condenser which prevents substantial potential drop across itself in response to pulse currents into the magnetron. It is much larger than the storage condensers of the other figures.

In the operation of Fig. 7, the hot cathode **31** is held at a positive or a relatively low negative potential with respect to the cold cathode so that, as a result of this potential and the presence of a strong axial magnetic field produced by field coil **40**, substantially no electrons emitted by the hot cathode **31** pass out through the slots **32** of the cold cathode **30**. However, by pulsing the hot cathode **31** sufficiently negative with respect to the cold cathode **30**, electrons from the hot cathode will pass out from the slots of the cold cathode and will cause secondary emission from the cold cathode and accumulation of rotating space charge between the anode **5** and the cold cathode **31**. If the anode **5** is sufficiently positive with respect to the cold cathode **30**, but not more positive than the magnetron cut-off potential for the magnetic field strength used, oscillations will start as soon as sufficiently large circulating space charge is accumulated and these oscillations will continue as long as the anode potential remains high enough.

The starting of oscillations in the system of Fig. 7 will cause a rapid increase in anode-to-cold cathode direct current, which in turn may cause a decrease in anode-to-cold cathode potential due to reactance **17**. This decrease in potential is an aid to growth of total cold cathode emission due to secondary emission, by causing out-of-phase or wrongly timed electrons to strike the cold cathode with greater energy. It is important to control the amount of the potential drop, by adjusting the value of reactance **17**, to prevent the potential from falling too low; otherwise emission may fail again and cause oscillations to stop too soon, after which the oscillations may start again.

To prevent the starting and stopping of oscillations from causing undesirable amplitude and frequency modulation of the radio frequency output current, which will throw the energy out over a very wide frequency band at the expense of decreased energy in the desired frequency band, it is important that the total effective series impedance in the direct current input circuit to the magnetron be kept low but not nearly zero. If pulses effectively one microsecond long with peak currents of about 30 amperes at about 18,000 volts are desired, then I have found, under one set of conditions, that the direct current input circuit

may contain not more than about 1,000 microhenrys of inductive reactance, and better results seem to be obtained with about 200 microhenrys of reactance, provided the direct current supply potential and magnetic field strength are properly coordinated. That is, for those conditions, reactance 17 should have a value less than 1,000 microhenrys. These figures are given for a particular magnetron desired to operate at about 13,000 gausses magnetic field with an initial peak potential up to about 25,000 volts and during the main body of the pulse of about 18,000 volts. In this magnetron, the cathode diameter was about one-quarter of an inch, while the anode had an inside diameter of about one inch.

Once oscillations are started, in the system of Fig. 7, if the anode potential remains high enough, the oscillations will continue indefinitely. I have provided a means to stop oscillations comprising a pair of electron absorber electrodes 33, 33. During oscillation, these absorber electrodes are maintained at the same or a more negative potential than the cold cathode 30, so that almost no electrons are absorbed by them from the circulating space charge. However, if oscillations are once started, and it is desired to stop them again, I propose pulsing the absorber electrodes 33 to a positive potential with respect to the cold cathode 30 by means of source 11. By pulsing the absorber electrodes, they will exert a component of force upon the electrons in a direction parallel to the magnetic field and this force will greatly reduce the space charge by absorption of circulating electrons and by reduction of bombardment of the cold cathode. At the same time, secondary emission from the absorber electrodes 33, 33, by wrong timing and unsuitable dimensions for aiding oscillations, will throw electron loading on the oscillation circuit, thereby tending to stop oscillation. Since, after oscillations have been started, the margin of excess secondary emission from the cold cathode 30 beyond that required to maintain oscillations may be made quite small; the disturbance to the space charge produced by positive potential applied by source 11 to the absorber electrodes 33, 33 need not be very great to stop oscillations. The stopping of oscillations, like the starting, tends to be regenerative or self-helping. Absorption of space charge by the absorber electrodes, by reducing the anode-to-cold cathode current, tends to cause the anode potential to rise. A rising anode potential reduces the energy of electrons striking the cold cathode and this also tends to reduce secondary emission. Explained in another way, the input impedance of the magnetron tends toward zero or even a negative alternating current impedance, so that it tends toward starting and stopping itself in pulses, as a result of which the amount of control energy from source 11 to cause either starting or stopping of oscillations may be made very small.

In summing up the description of the operation of the system of Fig. 7, it may be said that the start of a direct current or rectangular wave control current pulse from source 11 momentarily forces the inner hot cathode to be negative with respect to the cold cathode, as a result of which electrons pass out through the slots in the cold cathode and cause circulating space charge to accumulate. The magnetron oscillations thus start and the magnetron passes heavy input and output power. The end of a control current pulse forces the absorber electrodes to be positive with respect to the cold cathode, as a result of which the space charge is thrown out of the active volume of electrons and the circuits are loaded and oscillations stopped. Thus, oscillations last as long as the length of the control pulses from source 11. These control pulses are of relatively low power and may be modulated in length, frequency or timing by the use of conventional vacuum tube circuits already developed for the control of magnetron pulses, in which modulator tubes are used in series with the magnetron.

Although the magnetron of the present invention has been illustrated particularly with respect to a scalloped type of anode, of the kind generally described in my Patent 2,217,745, it should be clearly understood that the invention is not limited to this construction of anode since any suitable anode structure can be used, provided the growth of total emission from the cold cathode due to secondary emission can take place as a result of oscillation. By way of example, reference is made to my application Serial No. 470,438, filed December 29, 1942, for an alternative anode structure arrangement which is an improvement upon the anode structure here shown in that it has only one resonant frequency and is therefore proof against oscillation on undesired or spurious frequencies.

What is claimed is:

1. An electron discharge device comprising a metallic hollow cylindrical cold cathode having spaced apertures therein on opposite sides thereof, a pair of heated filaments within said cold cathode, means for producing a constant magnetic field having flux lines extending parallel to the length of said cold cathode, said heated filaments being so positioned near said apertures that the magnetic field curves the electrons emanating from said filaments in such manner as to permit their passage through said apertures.

2. A magnetron oscillator comprising a metallic hollow cylindrical cold cathode having a pair of spaced apertures on opposite sides thereof and extending parallel to the axis, a control electrode in the interior of and at the center of said cold cathode, and a thermionic cathode positioned near each of said spaced apertures and in the interior of said cold cathode and located between said control electrode and the cold cathode.

3. A magnetron oscillator comprising a hollow, substantially cylindrically-shaped cold cathode capable of emitting secondary electrons upon bombardment by electrons, and a thermionic cathode at the center of said cold cathode for supplying primary electrons, said cold cathode having electron impermeable side walls except for oppositely disposed slots arranged parallel to the axis for enabling the passage of electrons therethrough, at least one edge of each slot bending inwardly to the center in order to present a target for the electrons emanating from said thermionic cathode and to emit secondary electrons when impinged upon by said electrons from said thermionic cathode.

4. A magnetron oscillation generator comprising an envelope having therein a hollow anode, a cold cathode coaxially located with respect to and within said hollow anode and capable of emitting secondary electrons upon bombardment by electrons, a thermionic cathode near said cold cathode, a storage unit connected between said cold cathode and anode, a source of relatively high direct current potential connected across said storage unit for charging the same, and a source of control pulses coupled to said thermionic cathode for causing electron current to flow

from said thermionic cathode to said anode and cold cathode.

5. A magnetic oscillation generator comprising an envelope having therein a hollow anode, a cold cathode coaxially located with respect to and within said hollow anode and capable of emitting secondary electrons upon bombardment by electrons, a thermionic cathode near said cold cathode, a storage condenser connected between said cold cathode and anode, a source of relatively high direct current potential connected through a high impedance coil to said condenser for charging the same, and a source of control pulses coupled to said thermionic cathode for causing electron current to flow from said thermionic cathode to said anode and cold cathode.

6. A magnetron oscillation generator comprising an envelope having therein a hollow anode, a cold cathode coaxially located with respect to and within said hollow anode and capable of emitting secondary electrons upon bombardment by electrons, a thermionic cathode near said cold cathode, a storage unit in the form of an artificial line connected between said cold cathode and anode, a source of high direct current potential connected through a high impedance coil to said artificial line for charging the same, and a source of control pulses coupled to said thermionic cathode for causing electron current to flow from said thermionic cathode to said anode and cold cathode.

7. A magnetron oscillation generator comprising an envelope having therein a hollow anode, a cold cathode coaxially located with respect to and within said hollow anode and capable of emitting secondary electrons upon bombardment by electrons, a thermionic cathode near said cold cathode, means for applying a constant magnetic field having flux lines extending nearly parallel to said cold cathode and whose intensity is a minimum at the center of said envelope, a storage unit connected between said cold cathode and anode, a source of high direct current potential connected across said storage unit for charging the same, and a source of control pulses coupled to said thermionic cathode for causing electron current to flow between said thermionic cathode and said anode and cold cathode.

8. An oscillation generator comprising an anode, a metallic hollow cylindrical cold cathode having spaced apertures therein for enabling the passage of electrons therethrough, a heated filament within said cold cathode, means for producing a constant magnetic field having flux lines extending parallel to the length of said cold cathode, said heated filament being so positioned near said apertures that the magnetic field curves the electrons emanating from said filaments in such manner as to permit their passage through said apertures, a storage unit connected between said cold cathode and anode, a source of high direct current potential connected across said storage unit for charging the same, and a source of control pulses coupled to said thermionic cathode for causing electron current to flow from said thermionic cathode to said cold cathode.

9. A magnetron oscillator comprising an anode, a metallic hollow cylindrical cold cathode having a pair of spaced apertures on opposite sides thereof, a control electrode in the interior of and substantially at the center of said cold cathode, and a thermionic cathode positioned near each of said spaced apertures and in the interior of said cold cathode and located between said control electrode and said cold cathode, a storage unit connected between said cold cathode and anode, a source of high direct current potential connected across said storage unit for charging the same, and a source of control pulses coupled between said control electrode and said thermionic cathodes in common for causing electron current to flow from said thermionic cathodes to said anode and cold cathode.

10. An oscillation generator in accordance with claim 4, characterized in this that said source of control pulses is a pulser circuit having means coupled thereto for modulating the frequency or timing of said control pulses in accordance with the intelligence to be conveyed.

11. A magnetron oscillation generator comprising a hollow anode, a cold cathode within said anode and capable of emitting secondary electrons upon bombardment by electrons, a thermionic cathode near said cold cathode for supplying primary electrons, an energy storage unit connected between said anode and cold cathode, a source of charging potential connected to said storage unit, and a source of control pulses coupled to said cold cathode for periodically causing said cold cathode to become periodically and momentarily positive relative to said thermionic cathode, to thereby cause the primary electrons to be attracted toward said cold cathode during the time said cold cathode is positive.

12. A magnetron oscillation generator comprising a hollow anode, a cold cathode within said anode and capable of emitting secondary electrons upon bombardment by electrons, a thermionic cathode near said cold cathode for supplying primary electrons, an energy storage unit connected between said anode and cold cathode, a source of charging potential connected to said storage unit, and a source of control pulses coupled to at least one of said cathodes for periodically initiating a circulating space charge at a rate substantially not exceeding a supersonic frequency.

13. A magnetron oscillator comprising a hollow substantially cylindrically shaped cold cathode capable of emitting secondary electrons upon bombardment by electrons, and a thermionic cathode at the center of said cold cathode for supplying primary electrons, said cold cathode having electron impermeable side walls except for oppositely disposed slots arranged parallel to the axis for enabling the passage of electrons therethrough, at least one edge of each slot bending inwardly to the center in order to present a target for the electrons emanating from said thermionic cathode and to emit secondary electrons when impinged upon by said electrons from said thermionic cathode, and a source of control pulses coupled between said cold cathode and said thermionic cathode.

14. The method of operating, in pulses, an electron discharge device oscillation generator having a cold cathode capable of emitting copious electrons upon bombardment by electrons, and a thermionic cathode for supplying primary electrons, which includes the steps of storing between pulses a potential charge across said device of a value sufficient to sustain oscillations, then pulsing the potential of said thermionic cathode to cause the initiation of circulating space charge and a flow of electron current to said cold cathode, discharging the stored potential charge through said device during the occurrence of said circulating space charge to a value below that

necessary to sustain said oscillations, and periodically repeating the foregoing steps.

15. A magnetron oscillator including resonant means and comprising an anode structure, a cold cathode extending through the center of said anode structure for supplying emission current by secondary emission produced during oscillation, means for producing a magnetic field acting transversely to the cathode to anode path, and auxiliary means including a source of periodically repeating pulses for providing electron current for starting oscillations, and for stopping oscillations, to thereby cause the magnetron to produce pulses of high frequency energy.

16. Means to start oscillations in a magnetron oscillator having an anode and a non-thermionic secondary emissive cathode located in the center of said anode, comprising an auxiliary heated cathode to one side of said center electrode for producing primary electrons, means for producing a magnetic field acting transversely to the cathode-to-anode path, means to cause said primary electrons to bombard said center electrode, and means to cause the electron current from said auxiliary heated cathode to start and stop at a repetition rate in the range of substantially 120 to 30,000 times per second.

17. Means to start oscillation in a magnetron oscillator having an anode and a non-thermionic secondary emissive cathode located in the center of said anode, comprising an auxiliary heated cathode to one side of said center electrode for producing primary electrons, and means in circuit with one of said cathodes to cause said primary electrons to bombard said secondary emissive cathode to supply a controllable electron current from said auxiliary heated cathode for periodically building up a circulating electron space charge between anode and secondary emissive cathode of the oscillator, and means for modulating the relative timing of the periods during which said space charge builds up.

18. Means to produce pulses of oscillation in a magnetron having an anode and a non-thermionic secondary emissive cathode coaxially arranged relative to said anode, comprising an energy storage circuit between said anode and cathode, means for storing electrical energy in said circuit, and means for causing secondary electron emission from the cathode to take place to thereby build up a circulating space charge sufficient to cause oscillations to start, said storage circuit having such constants as to dissipate the stored electrical energy when said oscillations start.

19. A magnetron oscillation generator comprising an envelope having therein a hollow anode, a cold cathode coaxially located with respect to and within said hollow anode and capable of emitting secondary electrons upon bombardment by electrons, a thermionic cathode near said cold cathode, a storage unit connected between said cold cathode and anode, a source of direct current potential connected across said storage unit for charging the same, and a source of control pulses coupled to at least one of said cathodes for causing electron current to flow to said anode and cold cathode in pulses.

20. A magnetron oscillator having an anode, a coaxially located hollow cold cathode capable of emitting secondary electrons upon bombardment by electrons, said cold cathode having a circumferential slot through a portion and between the ends thereof, a thermionic cathode located in the interior of said cold cathode and extending through the center of said anode for supplying primary electrons, means including a source of voltage for causing said primary electrons to emerge through said slot and bombard said cold cathode, means for producing a tapering magnetic field acting transversely to the cathode-to-anode path and whose intensity is a minimum at the center of said oscillator, and a source of pulses coupled to at least one of said cathodes for causing electron current to flow to said anode in pulses.

21. A magnetron oscillation generator including resonant means and comprising a hollow anode, a cold cathode within said anode and capable of emitting secondary electrons upon bombardment by electrons, a thermionic cathode near said cold cathode for supplying primary electrons, means for producing a magnetic field acting transversely to the cathode-to-anode path, a source of control pulses coupled to said thermionic cathode for causing the production of high frequency oscillations in pulses, said source producing pulses which are of short duration compared to the time intervals between them, and means for modulating the timing of said pulses in accordance with the signal to be transmitted.

22. In a pulse system, a magnetron oscillation generator comprising an envelope having therein a hollow anode, a cold cathode coaxially located with respect to and within said hollow anode and capable of emitting secondary electrons upon bombardment by electrons, a thermionic cathode near said cold cathode, a storage unit connected between said cold cathode and anode, a source of direct current potential connected across said storage unit for charging the same, and a source of control pulses coupled to at least one of said cathodes for causing electron current to flow to said anode and cold cathode in pulses, and means for modulating a characteristic of the control pulses in accordance with the intelligence to be transmitted.

23. An electron discharge device comprising a metallic anode structure having a plurality of similar inwardly projecting electron target portions surrounding a substantially cylindrically-shaped hollow cathode, said anode and cathode being coaxially arranged, the spacing between the outside diameter of said cathode and the internally projecting target portions being less than the diameter of said cathode.

24. A magnetron comprising a metallic anode structure having an even number of similarly arranged inwardly projecting electron target portions surrounding a substantially cylindrically-shaped hollow non-thermionic secondary emissive cathode, said anode and cathode being coaxially arranged, the spacing between the outside diameter of said cathode and the internally projecting target portions being less than the diameter of said cathode, and means for producing a magnetic field acting transversely to the cathode-to-anode path.

25. A magnetron oscillator having an anode, a coaxially located cylindrical hollow cold cathode within said anode and capable of emitting secondary electrons upon bombardment by electrons, means for producing a magnetic field acting transversely to the cathode to anode path, said cold cathode having a plurality of circumferential slots through a portion and between the ends thereof, a thermionic cathode located in the interior of said cold cathode for supplying primary electrons which emerge through said slots, said cold cathode being impermeable to the passage

or electrons except at the location of said slots, and a source of pulses of short duration compared to the time intervals between them coupled to at least one of said cathodes for producing a growing circulating space charge inside said anode, to thereby cause oscillations to start.

26. A magnetron oscillation generator comprising a hollow anode, a cold hollow cathode within said anode and capable of emitting secondary electrons upon bombardment by electrons, said cold cathode having an aperture therein between its ends, a thermionic cathode within said cold cathode for supplying primary electrons which emerge through said aperture to bombard said cold cathode, a source of control pulses coupled to said thermionic cathode for causing the production of high frequency oscillations in pulses, said source producing pulses which are of short duration compared to the time intervals between them.

27. A magnetron oscillator comprising an anode structure, a cold cathode capable of secondary emission extending through the center of said anode structure, a hot cathode, means for producing a magnetic field acting transversely to the cathode to anode path, and means including a source of periodically recurring electrical pulses

whose duration is short compared to the time intervals between pulses in circuit with said hot cathode for periodically initiating oscillation with emission from the hot cathode followed by maintenance of oscillation through secondary emission from the cold cathode, and for stopping the oscillations for time intervals which are long compared to the oscillation periods.

28. Means to start oscillation in a magnetron oscillator including resonant means and having an anode and a non-thermionic secondary emissive cathode in the center of said anode, which magnetron includes a magnetic field acting transversely to the cathode to anode path and which magnetron is capable of producing large emission from said cold cathode due to electron bombardment and secondary emission after oscillations are started, comprising an auxiliary heated cathode, and means in circuit with said heated cathode for introducing a controlled flow of electrons from said auxiliary heated cathode to build up a circulating electron space charge in the magnetron of sufficient value to cause oscillations to start followed by a cessation of oscillations, at a repetition rate not exceeding a supersonic frequency.

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Disclaimer

2,409,038.—*Clarence W. Hansell*, Port Jefferson, N. Y. MAGNETRON AND CIRCUIT THEREFOR. Patent dated Oct. 8, 1946. Disclaimer filed Dec. 1, 1948, by the assignee, *Radio Corporation of America*.

Hereby enters this disclaimer to claim 23 of said patent.

[*Official Gazette January 4, 1949.*]