Sept. 23, 1947. C. W. HANSELL 2,427,781

MAGNETRON AND CIRCUIT

Filed Feb. 25, 1943 2 Sheets-Sheet 1

Fig. 1.

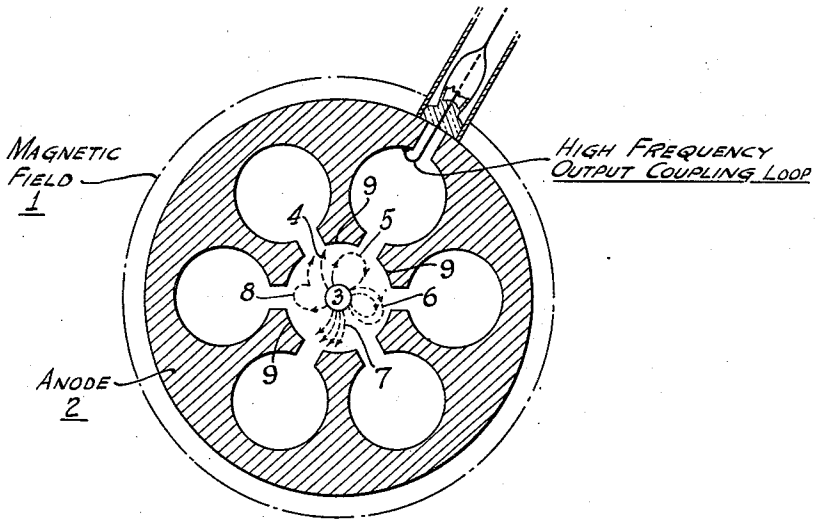
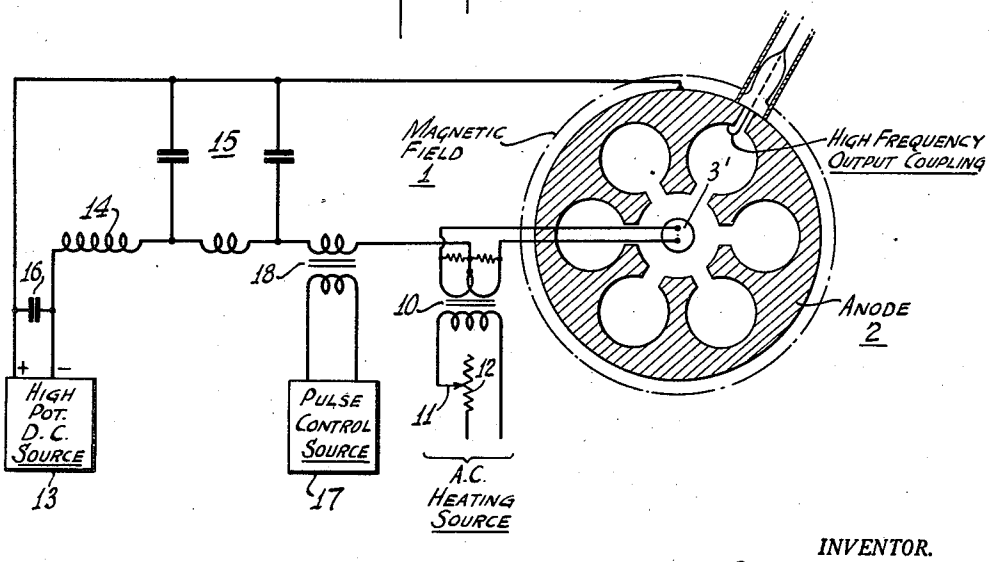


Fig. 2.



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Filed Feb. 25, 1943 2 Sheets-Sheet 2

Fig. 3.

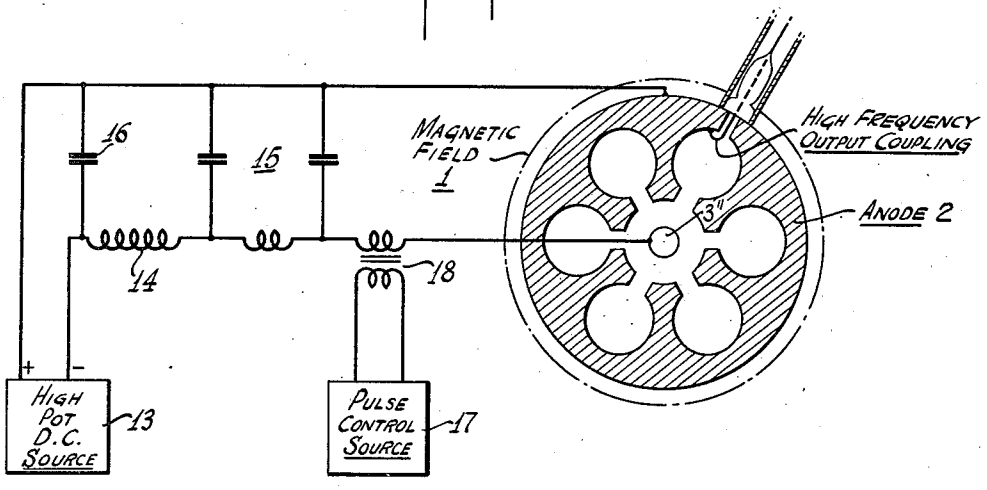
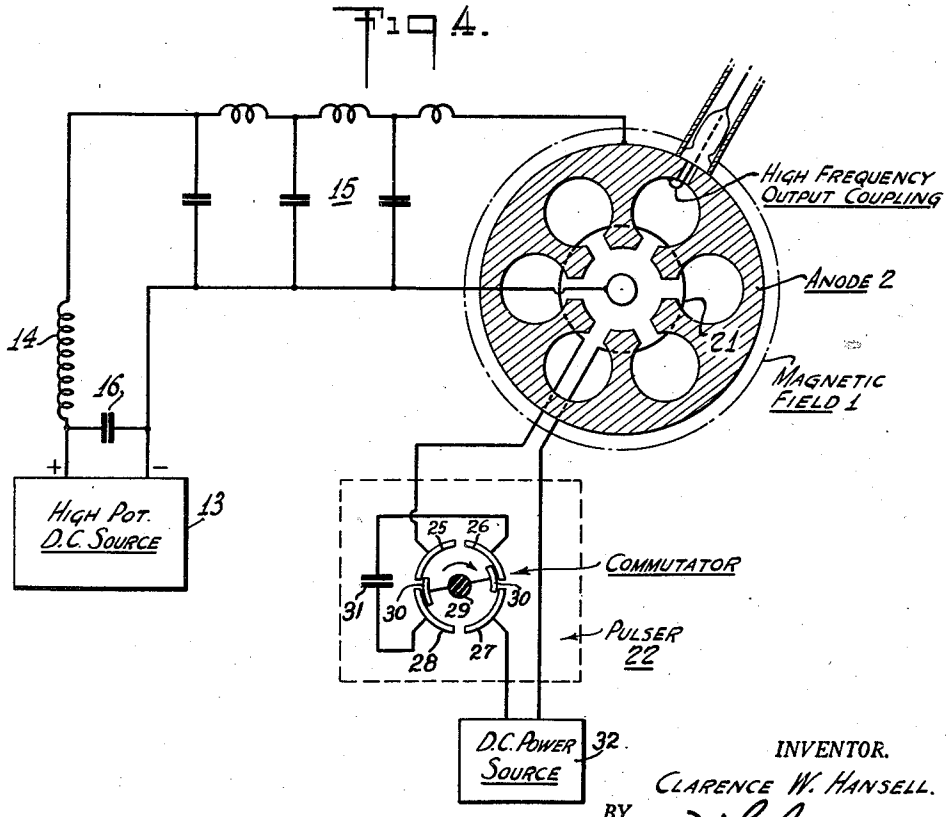


Fig. 4.



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UNITED STATES PATENT OFFICE

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MAGNETRON AND CIRCUIT

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Application February 25, 1943, Serial No. 477,062

20 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 continuous wave oscillation.

This invention is an alternative arrangement for the magnetron system disclosed in my copending application Serial No. 470,768, filed December 31, 1942, Patent No. 2,409,038, dated October 8, 1946.

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 produces pulses of oscillation in response to relatively low power control pulses; to provide a novel form of magnetron construction which includes a cold cathode capable of producing secondary electrons upon bombardment by primary electrons; to produce a magnetron which oscillates by virtue of a falling electric field between the anode and cathode; and to produce a magnetron which oscillates by virtue of a rising magnetic field.

A more detailed description of the invention follows in conjunction with drawings, wherein:

Fig. 1 illustrates in cross-section a magnetron construction with electron paths indicated diagrammatically for the purpose of explaining the principles of the present invention;

Figs. 2 and 3 schematically illustrate two different embodiments of the invention employing a falling electric field to produce oscillations; and

Fig. 4 schematically illustrates a third embodiment of the invention which employs a rising magnetic field to produce oscillations.

Referring to Fig. 1 in more detail, there is shown a magnetron construction including a cylindrical cathode 3 within an evacuated envelope, which envelope comprises a surrounding anode 2 having an even number of anode segments, and any suitable means such as a permanent magnet or a magnetic field winding 1 surrounding the envelope for producing flux lines extending parallel to the axis of the cathode. The anode is composed of an even number of inwardly protruding anode portions 9, 9 which are substantially or effectively spaced from one another by one-half wavelength at the operating frequency of oscillations. This kind of anode, which is a preferred type, though not essential in the practice of the invention, is of the type

2

generally shown and described in my United States Patent 2,217,745, granted October 15, 1942. The cathode 3 is, in accordance with the invention, one which is a good secondary emitter but which has low emission due to other causes than secondary emission. Thus, cathode 3 may be a cold cathode of cylindrical form, as described latter in connection with Fig. 3, or be one which has associated therewith a thermionic element whose temperature is relatively low, to reduce thermionic emission, as described later in connection with Fig. 2.

In order to understand the operation of the magnetron of Fig. 1 to produce pulses of high frequency energy, in accordance with the invention and as described in more detail later in reference to the circuit embodiments of Figs. 2, 3 and 4, there are shown different electron paths labeled 4, 5, 6, 7 and 8 which are given for the purpose of exposition.

If, according to usual practice and theory, the anode to cathode potential is adjusted to be less than the cut-off potential, and we assume that loss of electrons due to motions parallel to the axis of the magnetron are prevented due to the use of suitable electric and magnetic field configurations, then any electrons leaving the cathode are caused to miss the anode and return to the cathode. A portion of them, upon returning to the cathode, run into negative space charges sufficient to prevent their re-absorption on the cathode. These tend to be more or less permanently detached from contact with either anode or cathode, and as they increase in number a rapidly rotating electron space charge will accumulate in the space between anode and cathode. When this space charge becomes dense enough, oscillations take place. Under the described conditions, these oscillations may take place in an uncontrolled manner and may be either pulsing or continuous, depending upon the magnetron design and the conditions of operation.

On the other hand, if the anode-to-cathode potential of the magnetron is somewhat greater than the cut-off potential corresponding to the particular intensity of magnetic field chosen, then nearly all electrons which leave the cathode 3 will strike the anode 6 on the first outward trip, following paths qualitatively indicated by 4 in Fig. 1. Putting it in other words, the direct current potential on the anode is adjusted to be high enough to prevent accumulation of space charge. For this condition, there is no accumulation of rotating space charge around the cathode, in-

side the anode, and oscillations cannot take place. Now, if the anode potential is reduced rapidly, as by pulsing, to a value below cut-off (i. e. ,below the value at which all electrons strike the anode on their first outward trip), then electrons will begin to miss the anode and return to the cathode, following paths qualitatively indicated by 5 in Fig. 1. If the reduction or fall in anode potential is sufficiently rapid, electrons drawn from the cathode or from the space close to it, while the potential is falling, will circulate out from the cathode and return to the cathode with an excess of energy, striking it and causing the emission of additional electrons due to secondary emission. Each electron returning over path 5 may, for example, cause emission of two secondary electrons which will be drawn out over paths 6, return to the cathode and cause emission of four electrons which traverse path 7, etc. Thus, while the anode-to-cathode potential is decreasing, there is obtained a rapid growth in total cathode emission due to secondary emission. When, due to the growth of total emission from secondary emission, the total space charge has become great enough, high frequency oscillations in the anode structure will start, due to the condition of negative resistance. Once oscillations have reached sufficient amplitude, bombardment of the cathode by incorrectly timed, or out-of-phase electrons can maintain the total cathode emission at a high value without any need for continued rapid reduction of anode potential. Oscillations will then continue indefinitely, or until the anode-to-cathode potential drops to a value too low to maintain oscillation. The beginning of oscillation may, in some cases, be made more certain if the downward pulse of anode-to-cathode potential is immediately followed by an upward pulse, or oscillation, so that the whirling electron space charge, after it has grown to great density, is expanded by the rising potential until it reaches out to the anode projections.

Various features of the present invention relate to the input circuit in the form of an energy storage circuit to produce the required high anode potential in excess of the cut-off value; the cathode which is a good secondary emitter but has low emission due to other causes than secondary emission; and to the complete circuit which includes the source of short duration control pulses of low power to pulse the anode potential downwards.

Fig. 2 shows a complete circuit arrangement in accordance with one embodiment of the invention for producing pulses of high frequency oscillation. In Fig. 2, the magnetron construction is substantially the same as that of Fig. 1, except that the cathode, labeled 3' in Fig. 2, is heated by a low frequency heating source (60 cycles or so) over transformer 10 by adjustment of tap 11 on resistor 12 to a temperature much below the usual operating temperatures of magnetron cathodes and just enough to produce a small priming current of electrons. The anode potential is supplied from a high potential direct current source 13 which is connected between anode and cathode through a charging choke coil 14 and an artificial line 15. A large condenser 16 for by-passing the pulse frequency is connected across the direct current source 13. The artificial line 15, which may have a greater number of sections than has been shown, acts as a storage reservoir input circuit for supplying a potential between anode and cathode which is in excess of cut-off potential. This line storage circuit should have a characteristic impedance which is considerably lower than the input resistance of the magnetron, so that when pulse current through the magnetron starts, the potential does not drop too far but (after a time interval corresponding to the pulse length desired) the potential will change again, due to a wave reflected over the line, in a manner to stop oscillation again.

In the condition of anode-to-cathode potential greater than the cut-off potential, all of the electrons emitted by the low heated cathode are drawn to the anode at their first trip out from the cathode. In order to prevent a large loss due to all the thermionic emission electrons striking the anode, it is proposed to reduce the cathode temperature to such an extent that the thermal emission is very small, less than say one milliampere.

A relatively low power source of control pulses 17, coupled to a transformer 18 in the circuit between the source 13 and the cathode, serves to pulse the anode-to-cathode potential downward; that is, reduce the anode potential at a rapid rate to a value below cut-off potential, in order to start the accumulation of rotating space charge around the cathode and the initiation of oscillations. The downward pulsing of the anode-to-cathode potential causes bombardment of the cathode by the priming electrons thermally emitted, which, in turn, produces secondary emission, an increase in total emission and a growth of circulating space charge, as a result of which oscillations will start. Once oscillations start, there is a discharge of the energy stored in the artificial line 15 across the magnetron, as a consequence of which (after a definite time interval determined by the effective length of the line) the anode potential is lowered to a value too low to maintain sufficient strength of oscillations to maintain secondary emission, at which time oscillations stop. The storage circuit (artificial line 15) is then recharged from the direct current source 13 through the relatively large reactance 14, and when the anode potential exceeds cut-off, the foregoing cycle of operations will be repeated.

Preferably, the value of the charging choke coil 14 is made very large, in which case constant current can be made to flow through choke 14 in order to charge the storage circuit 15 and the potential across the magnetron just before a pulse is nearly equal to the potential from source 13.

It should be noted at this time that while the storage circuit (artificial line) is being charged and the anode-to-cathode potential is increasing, secondary emission from the cathode is inhibited because electrons emitted due to thermionic emission do not return to the cathode, but when returning stop short of the cathode, as illustrated qualitatively by path 8 of Fig. 1. In order to assure, absolutely, that no sufficient amount of space charge accumulates to allow oscillations to start while the anode potential is increasing, it is preferred that the thermionic emission be reduced by reducing the cathode heating current by an initial adjustment, until oscillations start only due to the control pulses from source 17. In view of the fact that cathode heating occurs during oscillation, due to cathode bombardment by electrons, the heating current required to start operation may be a certain value, whereas a much lower value (or zero) heating

current may be required after operation has started.

In cases where quick starting of operation is not essential, the feature of externally heating the cathode may be omitted, in which case a cold cathode can be employed, as shown in the embodiment of Fig. 3. The cold cathode 3'' of Fig. 3 can be a solid rod or in the form of a hollow cylinder made of material which has a good secondary emission ratio. In the system of Fig. 3, reliance is had upon the presence of a few accidental electrons at places near the cathode while the anode potential is falling in order to start oscillations. Such electrons may be produced by cosmic rays, thermal factors, radio-active materials, light shining on the cathode, and other considerations, to produce the necessary few electrons to cause the first pulse, after which there are residual charges on insulated portions of the cathode surface and ionization which will maintain emission to start oscillation at every control pulse. In operation, the input power is then kept below the point at which the cathode temperature rises high enough to produce substantial thermionic emission. Otherwise, the system of Figs. 2 and 3 are alike and operate in similar manner.

The use of a cold cathode (as shown in Fig. 3) eliminates the need of a cathode heating transformer and source of heating energy, and thus decreases the complexity, volume, weight and cost of such a magnetron system.

An alternative form of magnetron is one in which a relatively small heated auxiliary cathode is associated with the cold cathode to provide a relatively small but controlled electron emission for initiating growth of secondary emission due to a falling electric field or a rising magnetic field. Suitable combinations of hot and cold cathodes have been illustrated in my copending application Serial No. 470,768, filed December 31, 1942. In using these previously described compound cathode assemblies for the present invention, means is provided to maintain constantly or momentarily potentials which result in electrons from the hot cathode entering the space between the anode and cold cathode while the potential between the anode and cold cathode is falling or while the magnetic field is increasing.

The pulse rate of source 17 of Figs. 1, 2 and 3 may be anywhere in the range from 60 cycles per second up to 50,000 cycles per second, and higher. The higher pulse rates require greater means to remove heat from the cathode, such as large leads connected with radiators, or even liquid cooling of the cathode. For present applications in connection with military radio locators, there would be employed a pulse rate in the range from 120 cycles per second to 3000 cycles per second. However, for pulse communication systems employing speech, telegraph or facsimile modulations, the pulse rate would be above the highest modulation frequency. Source 17 may be any one of the known types of pulsers, including a vacuum tube pulser circuit. Such a vacuum tube pulser circuit would, of course, be employed when the system of the invention is used for communication purposes. By way of example, the direct current source 13 might supply a potential anywhere in the range from 7500 volts to 30,000 volts, depending upon the design of the magnetron. The magnetic field in the systems of Figs. 1 and 2 is preferably of a constant value and employs a magnetic yoke. A coil may be used to magnetize the yoke, or, if desired, the yoke may be permanently magnetized.

Fig. 4 shows another embodiment of the invention, wherein there is employed a constant anode-to-cathode potential, and a rising magnetic field is relied upon to obtain pulses of high frequency oscillation.

In the arrangement of Fig. 4, a high potential direct current power source 13 is connected between anode and cathode of the magnetron, through charging choke 14 and energy storage line 15 similarly to Figs. 2 and 3, but the pulsing source 17 and pulse coupling transformer 18 of Figs. 2 and 3 is omitted.

The magnetron has added to it an internal magnetizing coil 21, made up of two sections, one on each end of the magnetron, of which only one is shown in the cross-section of Fig. 4. An external magnetizing system in the form of an electromagnet or permanent magnet is provided as before, to produce an intense magnetic field at right angles to the electric field between anode and cathode. The externally applied magnetic field and the anode-to-cathode potential, are so adjusted that all or nearly all of the electrons emitted from the cathode travel out and strike the anode on the first outward passage.

If now a sufficiently powerful pulse of current is sent through the internal magnetizing coil, in a direction to increase the magnetic field between anode and cathode, the magnetic field strength will pass up through the cut off valve and any electron leaving the cathode will be returned to it. While in transit from the cathode out toward the anode and back to the cathode, each electron will be acted upon by a potential induced by the rising magnetic field and will return to the cathode with excess velocity and energy. If this energy is made great enough, and the cathode is a good secondary emitter, each returning electron will release more than one secondary electron and there will be a rapid increase or multiplication in total electron emission from the cathode while the magnetic field is rising. This may be made to produce sufficient accumulation of circulating space charge to start oscillation, after which oscillation will continue and produce its own secondary emission, so long as the anode-to-cathode potential is high enough.

For further exposition of the principles of electron acceleration by a rising magnetic field, reference is made to my copending application Serial No. 474,943, filed February 6, 1943, Patent No. 2,412,772, dated December 17, 1946.

To produce the pulses of magnetizing current for initiating oscillation, I have shown in Fig. 4 a commutator type pulser 22 similar to that described in a copending application of Nils E. Lindenblad, Serial No. 479,220, filed March 15, 1943. This pulser 22 comprises four spaced, equal length, arcuate-shaped metallic segments 25, 26, 27, 28 placed around a circle. An insulating rotor 29 in the center of the circle moves in the direction of the arrow and is driven by a motor, not shown. Attached to the insulating rotor at diametrically opposite sides thereof and in fixed relation thereto are two metallic brushes 30, 30 each of which is designed to bridge the adjacent ends of two adjacent arcuate segments as the brush rotates. A condenser 31 is connected between two diametrically positioned arcuate segments 26 and 28. A source 32 of direct current power is connected to arcuate segment 27 and to one terminal of magnetizing

coil 21. The other terminal of coil 21 is connected to arcuate segment 25. As the rotor 29 rotates, the condenser 31 charges and discharges in such manner that unidirectional pulses of short duration are passed always in the same direction through the magnetizing coil 21. Any other means for producing a suitable pulse current might be used. In particular, attention is directed toward arrangements used for magnetic deflection of cathode ray beams in television and similar cathode ray beam devices.

What is claimed is:

1. In a magnetron having a magnetic field, an anode, and a cathode characterized by low thermal emission and which emits electrons upon bombardment by primary electrons at a ratio greater than unity, means for establishing large cathode emission comprising a circuit for establishing a high anode-to-cathode potential of a value sufficiently high to attract all electrons emanating from the cathode directly to the anode on their first outward passage from the cathode, and means for decreasing this potential momentarily in pulses to a value below that at which all electrons strike the anode on their first passage outward toward the anode, to thereby cause said electrons to return to the cathode and bombard the cathode to produce secondary electrons, and an output circuit coupled to said anode for abstracting radio frequency energy in pulses repeated at a rate less than the frequency of said radio frequency energy.

2. In a magnetron having a magnetic field, an anode, and a cathode characterized by low thermal emission and which emits electrons upon bombardment by primary electrons at a ratio greater than unity, means for establishing large cathode emission comprising a circuit for producing an anode-to-cathode potential sufficiently high for the anode to absorb all electrons from the cathode on their first passage outward toward the anode, and means for rapidly pulsing this potential momentarily downward to a value which causes the electrons to take curved paths and bombard the cathode to produce secondary emission from the cathode and an output circuit coupled to said anode for abstracting radio frequency energy in pulses repeated at a rate less than the frequency of said radio frequency energy.

3. In a magnetron having a magnetic field, an anode, and a cathode characterized by low thermal emission and which emits electrons upon bombardment by primary electrons at a ratio greater than unity, means for establishing large cathode emission comprising a circuit for producing an anode-to-cathode potential sufficiently high for the anode to absorb all electrons from the cathode on their first passage outward toward the anode, and means for rapidly pulsing this potential first momentarily downward to a potential below that required to absorb all electrons leaving the cathode on their first passage outward, to thereby cause said electrons to take curved paths and bombard the cathode and produce additional electrons by virtue of secondary emission, and then momentarily upward to expand the whirling electrons to thereby assure the generation of oscillations, and an output circuit coupled to said anode for abstracting radio frequency energy in pulses repeated at a rate less than the frequency of said radio frequency energy.

4. In a magnetron having a secondary emissive cathode with small initial emission and an anode resonant to the operating frequency, means for establishing large cathode emission comprising a circuit for producing an anode-to-cathode potential sufficiently high for the anode to absorb all electrons from the cathode on their first passage outward toward the anode, and means for pulsing this potential momentarily downward to a potential below that required to absorb all electrons leaving the cathode on their first passage outward, to thereby cause said electrons to circulate around said cathode and bombard it to produce secondary emission, and an output circuit coupled to said anode for deriving pulses of radio frequency energy at a repetition rate less than the frequency of said radio frequency energy.

5. In a magnetron having a non-thermionic secondary emissive cathode and an anode resonant to the operating frequency, means for establishing large cathode emission comprising a circuit for producing an anode-to-cathode potential sufficiently high for the anode to absorb all electrons from the cathode on their first passage outward toward the anode, and means for pulsing this potential momentarily downward to a potential below that required to absorb all electrons leaving the cathode on their first passage outward, to thereby cause said electrons to circulate around said cathode and bombard it to produce secondary emission, and an output circuit coupled to said anode for deriving pulses of radio frequency energy at a repetition rate less than the frequency of said radio frequency energy.

6. A vacuum tube oscillator of high frquency oscillations having a cathode which emits electrons upon bombardment by primary electrons at a ratio greater than unity and which has low emission qualities due to other causes, an anode structure surrounding said cathode, said cathode extending substantially along the axis of said anode, means for producing a magnetic field having components parallel to said cathode, a source of potential coupled between said anode and cathode for supplying to said anode a potential whose value is so related to said magnetic field and sufficiently large to absorb all electrons on the first passage outward from the vicinity of the cathode, and means for periodically reducing said anode potential below said value necessary to absorb said electrons on their first outward passage, to thereby cause said electrons to circulate around said cathode and bombard it to produce secondary electrons.

7. A vacuum tube oscillator of high frequency oscillations having a cathode which emits electrons upon bombardment by primary electrons at a ratio greater than unity and which has low emission qualities due to other causes, an anode structure surrounding said cathode, said cathode extending substantially along the axis of said anode, means for producing a magnetic field having components parallel to said cathode, a source of potential coupled between said anode and cathode for supplying to said anode a potential whose value is so related to said magnetic field and sufficiently large to absorb all electrons on the first passage outward from the vicinity of the cathode, and a pulser circuit operating in the range from 60 cycles per second to 50,000 cycles per second for periodically reducing said anode potential below said value necessary to absorb said electrons on their first outward passage, to thereby cause said electrons to circulate

around said cathode and bombard it to produce secondary electrons.

8. A vacuum tube oscillator of high frequency oscillations having a cathode which emits electrons upon bombardment by primary electrons at a ratio greater than unity and which has low emission qualities due to other causes, an anode structure surrounding said cathode, said cathode extending substantially along the axis of said anode, means for producing a magnetic field whose flux lines extend substantially parallel to said cathode, a source of potential coupled between said anode and cathode for supplying to said anode a potential whose value is sufficiently large to absorb all electrons on the first passage outward from the vicinity of the cathode, and an electron discharge device pulser circuit for periodically reducing said anode potential below said value necessary to absorb said electrons on their first outward passage to thereby cause said electrons to take curved paths and bombard said cathode to produce secondary electrons.

9. In a pulse type communication system, a vacuum tube oscillator of high frequency oscillations having a cathode which emits electrons upon bombardment by primary electrons at a ratio greater than unity and which has low emission qualities due to other causes, an anode structure surrounding said cathode, said cathode extending substantially along the axis of said anode, means for producing a magnetic field having flux lines extending parallel to said cathode, a source of potential coupled between said anode and cathode for supplying to said anode a potential whose value is sufficiently large to absorb all electrons on the first passage outward from the vicinity of the cathode, and an electron discharge device pulser circuit operating at a rate above the highest modulation frequency for periodically reducing said anode potential below said value necessary to absorb said electrons on their first outward passage, to thereby cause said electrons to take curved paths and bombard said cathode to produce secondary electrons.

10. A vacuum tube oscillator of high frequency oscillations having a cathode which emits electrons upon bombardment by primary electrons at a ratio greater than unity and which has low emission qualities due to other causes, an anode structure surrounding said cathode, said cathode extending substantially along the axis of said anode, a substantially constant magnetic field having flux lines extending parallel to said cathode, a source of potential coupled between said anode and cathode for supplying to said anode a potential whose value is sufficiently large to absorb all electrons on the first passage outward from the vicinity of the cathode, and means for periodically reducing said anode potential below said value necessary to absorb said electrons on their first outward passage, to thereby cause said electrons to circulate around said cathode and bombard it to produce secondary electrons.

11. A vacuum tube oscillator of high frequency oscillations having a cathode which emits electrons upon bombardment by primary electrons at a ratio greater than unity and which has low emission qualities due to other causes, an anode structure surrounding said cathode, said cathode extending substantially along the axis of said anode, a source of potential coupled between said anode and cathode for supplying a voltage to said anode which is positive relative to said cathode, means for supplying a magnetic field having flux lines extending parallel to said cathode, and means for pulsing the magnetic field momentarily upward to a value which causes the electrons to curve and return to said cathode with sufficient strength to bombard the cathode and produce secondary electrons.

12. A magnetron having a secondary emissive cathode which emits electrons upon bombardment by primary electrons at a ratio greater than unity and which has small initial emission, means for establishing large cathode emission comprising a circuit for producing an anode-to-cathode potential sufficiently high for the anode to absorb all electrons from the cathode on their first passage outward toward the anode, a circuit for producing a substantially constant magnetic field, and means for rapidly and repeatedly pulsing this potential momentarily downward to a value below that required to absorb all electrons on their first passage outward from the cathode, to thereby cause the electrons to take curved paths and bombard the cathode with sufficient intensity to produce secondary electrons.

13. In a high frequency magnetron oscillator, means for supplying a substantially constant electric field between the anode and cathode, said cathode being capable of emitting electrons upon bombardment by primary electrons at a ratio greater than unity, means for supplying a magnetic field whose intensity is sufficiently low to permit all electrons in the vicinity of the cathode to be absorbed by said anode on the first passage outward, and means for periodically increasing the intensity of said magnetic field to a value which causes the electrons to curve and return to said cathode with sufficient intensity to bombard it and release secondary electrons to thereby permit a growth in number of circulating electrons around said cathode with a consequent initiation of oscillations.

14. In a high frequency magnetron oscillator, means for supplying a substantially constant electric field between the anode and cathode, a cathode which emits electrons upon bombardment by primary electrons at a ratio greater than unity and which has low emission qualities due to other causes, means for supplying a magnetic field whose intensity is sufficiently low to permit all electrons in the vicinity of the cathode to be absorbed by said anode on the first passage outward, and means for periodically increasing the intensity of said magnetic field to a value which causes the electrons to curve and return to said cathode with sufficient intensity to bombard it and release secondary electrons to thereby permit the growth of circulating electrons around said cathode with a consequent initiation of oscillations.

15. The method of operating an electron discharge device oscillator having a secondary emissive cathode which emits electrons upon bombardment by primary electrons at a ratio greater than unity and which has low emission qualities due to other causes, an anode and a substantially constant magnetic field parallel to said cathode, which includes impressing on said anode a potential in excess of oscillation cut-off value, and periodically reducing said potential rapidly to a value below the cut-off value to cause the electrons to take curved paths and bombard the cathode with sufficient strength to release secondary electrons therefrom, and deriving radio frequency energy from said oscillator in pulses at a repetition rate less than the frequency of said radio frequency energy.

16. The method of operating an electron dis-

charge device oscillator having a secondary emissive cathode which emits electrons upon bombardment by primary electrons at a ratio greater than unity and which has low emission qualities due to other causes, an anode and a substantially constant magnetic field parallel to said cathode, which includes impressing on said anode a potential in excess of oscillation cut-off value, and periodically reducing said potential rapidly to a value below the cut-off value and at an audio frequency rate to cause electrons to curve and strike the cathode with sufficient strength to release secondary electrons therefrom, and deriving radio frequency energy from said oscillator in pulses at a repetition rate less than the frequency of said radio frequency energy.

17. The method of operating an electron discharge device oscillator having a secondary emissive cathode, said cathode being capable of emitting electrons upon bombardment by primary electrons at a ratio greater than unity, an anode and a magnetic field parallel to said cathode, which includes impressing a substantially constant anode-to-cathode potential on said oscillator, and periodically raising the intensity of said magnetic field to a value in excess of that needed to prevent all electrons in the vicinity of said cathode from striking said anode on their first passage outward, to thereby curve the paths of said electrons to produce bombardment of said cathode and emission of secondary electrons from said cathode.

18. A vacuum tube magnetron oscillator of high frequency oscillations having a cathode which emits electrons upon bombardment by primary electrons at a ratio greater than unity and which has low emission qualities due to other causes, an anode structure surrounding said cathode, said cathode extending substantially along the axis of said anode, means for producing a magnetic field having flux lines extending substantially parallel to said cathode, a source of potential including a storage circuit coupled between said anode and cathode for supplying to said anode a potential whose value is sufficiently large to absorb all electrons on the first passage outward from the vicinity of the cathode, and means for periodically reducing said anode potential below said value necessary to absorb said electrons on their first outward passage to thereby cause said electrons to take curved paths and bombard said cathode to produce secondary electrons.

19. A vacuum tube magnetron oscillator of high frequency oscillations having a cathode which emits electrons upon bombardment by

primary electrons at a ratio greater than unity and which has low emission qualities due to other causes, an anode structure surrounding said cathode, said cathode extending substantially along the axis of said anode, means for producing a magnetic field having flux lines extending substantially parallel to said cathode, a source of potential including a line storage circuit coupled between said anode and cathode for supplying to said anode a potential whose value is sufficiently large to absorb all electrons on the first passage outward from the vicinity of the cathode, said storage circuit having a characteristic impedance which is considerably lower than the input resistance of said magnetron, and means for periodically reducing said anode potential below said value necessary to absorb said electrons on their first outward passage to thereby cause said electrons to take curved paths and bombard said cathode to produce secondary electrons.

20. A magnetron oscillator of high frequency oscillations having a cathode which emits electrons upon bombardment by primary electrons at a ratio greater than unity and which has low emission qualities due to other causes, an anode structure surrounding said cathode, said cathode extending substantially along the axis of said anode, means for producing a magnetic field having flux lines extending parallel to said cathode, means for producing an electric field between said anode and cathode, said fields being so adjusted that electrons are absorbed by said anode on their first passage outward from said cathode, and means for periodically changing the value of one of said fields rapidly in such direction as to curve said electrons and cause them to return to and bombard said cathode to release secondary electrons, said last means including a line storage circuit coupled between said anode and cathode and a pulser.

CLARENCE W. HANSELL.

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