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MAGNETRONS

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FIG. 1

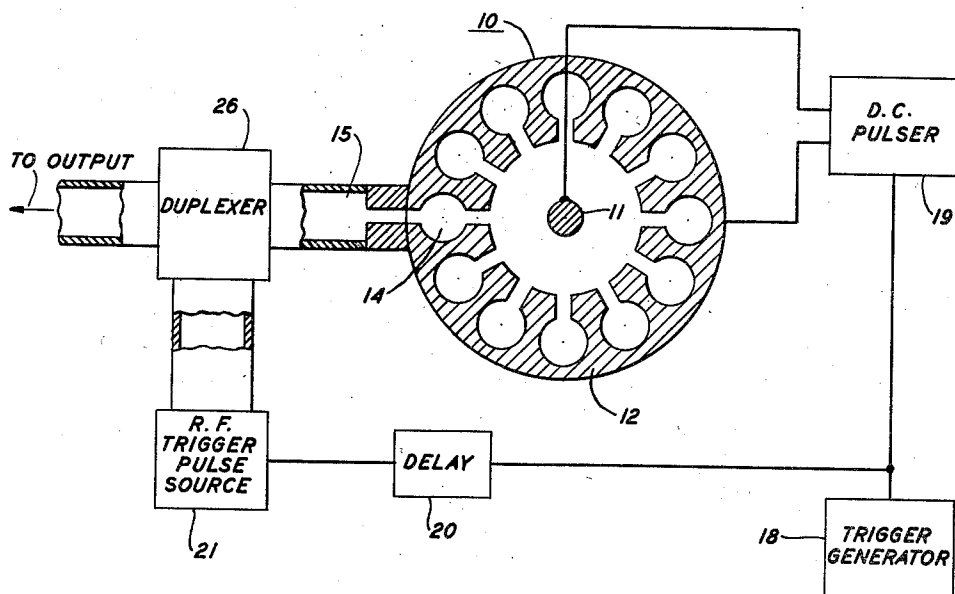
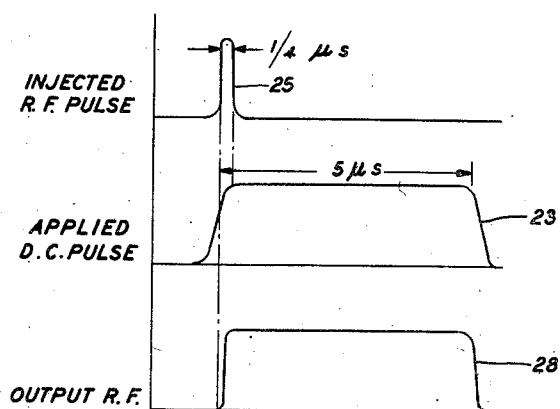


FIG. 2



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## MAGNETRONS

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This invention relates to magnetrons and more particularly to the triggering of pulsed magnetrons.

It has been customary for magnetrons to include a resonant anode structure encompassing a thermionic cathode. Triggering is attained by applying a direct current voltage pulse between the anode structure and the cathode. The thermionic emission of the cathode assures a sufficient supply of electrons to attain the desired triggering of the magnetron.

It has been observed however that once the magnetron has been triggered and for the remainder of the applied pulse, secondary electron emission at the cathode plays the dominant role in the steady-state magnetron operation rather than thermionic emission. Accordingly it appeared that the heating of the cathode was only essential during the initiation of the magnetron operation. As there is considerable power consumption in maintaining the cathode thermionic it would be very desirable if the dominant secondary electron emission could be relied on solely for operation of the magnetron.

Further, as is well known, magnetrons are subject to a form of misproper operation known as moding in which oscillations commence in other than the desired  $\pi$ -mode of oscillation, operation being in one of the so-called degenerate modes of oscillations. This may occur for a variety of reasons, well known in the art. In general one may consider competition to exist on initial firing or triggering of the magnetron between the various modes; priorly a large number of suggestions have been advanced to hinder the undesired modes in this competition and to give additional advantage to the desired mode of oscillation.

One problem in pulsed magnetrons has been that for each mode of oscillation there is a particular voltage level existing between the anode and cathode of the magnetron. When these voltage levels are below that of the desired  $\pi$ -mode of oscillation, as is generally the case, there may be an additional advantage for the undesired modes as the applied voltage pulse between the anode and the cathode builds up to its final value. This is particularly true of most present pulsed magnetron circuits where the direct current voltage pulsers are the so-called line type modulators which employ hydrogen thyatrons and have very poor voltage regulation so that the voltage of the input pulse is in large measure dependent on the impedance presented to it by the magnetron and thus on the current present in the magnetron. If a magnetron therefore starts to be triggered in an undesired mode at a lower pulse voltage level between the anode and the cathode, the pulse may not build up to the value necessary to trigger the magnetron in its desired mode of oscillation. While this situation is particularly serious with gas tube pulsers, it still exists to a lesser extent with hard or vacuum tube pulser circuits.

It is a general object of this invention to provide an improved magnetron.

It is another object of this invention to provide an im-

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proved magnetron employing a cold cathode. Thus it is an object of this invention to reduce the power consumption of magnetrons.

It is a further object of this invention to prevent moding in magnetrons.

In specific illustrative embodiments of this invention, a magnetron employs a resonant structure and a metallic center member which is encompassed by the resonant structure. Either the center member or the resonant structure itself may serve as a cold cathode and the other as the anode of the magnetron, depending on the polarity of the applied direct current voltage pulse. Triggering is obtained in embodiments of this invention by means of a radio frequency signal injected into the output of the magnetron while the direct current pulse is applied.

The function of the injected radio frequency signal in initiating oscillation build-up is believed to be in increasing the energy of the backbombarding electrons. Hence, if one postulates the presence of a few electrons, presumably due to field emission, cosmic rays, or other causes, in the presence of radio frequency field of sufficient magnitude some of these electrons would gain energy so that the secondary emission yield would exceed unity. Some of the electrons produced by this process would then also be thrown back against the cathode to produce more secondaries, while others would pass to the anode, giving up their increasing potential energy in building up the magnetron radio frequency voltage.

The frequency of the injected radio frequency signal need not be the operating frequency of the magnetron, but should advantageously be in the vicinity of a resonance of the system which gives rise to the radio frequency fields near the cathode. We have found that there is a relationship between the injected radio frequency power necessary to trigger the magnetron and cause sufficient secondary emission from the cold cathode and the frequency of the power thus injected into the output of the magnetron. Specifically we have found that for each specific magnetron structure, depending on the material of the cold cathode, the size and shape of the resonators, etc., there is a minimum value of radio frequency power necessary to start the cold cathode magnetron. As the incident radio frequency power is reduced towards this value, the starting becomes much more critical with respect to the frequency of the incident radio frequency. At the threshold the critical bandwidth is only a few megacycles at a frequency of resonance of the system. This effect is apparently a function of the loaded Q of the system.

In accordance with an aspect of our invention the triggering radio frequency pulse is injected or introduced into the output of the magnetron at a critical time during the build-up of the D.-C. pulse applied between the anode and the cathode in order to prevent moding. Specifically the R.-F. pulse is introduced into the magnetron just before the D.-C. pulse has built up to that voltage at which the desired  $\pi$ -mode of operation will occur so that, when that voltage level is reached by the D.-C. pulse between the anode and cathode, there will be sufficient current flow to prevent the source of the D.-C. voltage raising the voltage further. Additionally before that voltage level, as the direct current voltage pulse rises through lower voltages at which spurious or degenerate modes can be maintained, there is insufficient electron excitation to trigger the magnetron. Thus in accordance with our invention the probability of moding is greatly reduced and will not occur during build-up of the direct current voltage pulse applied between the anode and cathode of the magnetron.

We have found that an injected radio frequency signal

of a much lower power level could be employed to trigger the magnetron if it is introduced at the cathode structure rather than at the anode structure of the system. In accordance with another aspect of our invention this is attained by applying the direct current pulse between the center post and the encompassing resonant structure of such a polarity that the center post, which is normally the magnetron cathode, is pulsed positive and the resonant structure, which normally defines the anode, is pulsed negative. Secondary electron emission then occurs from the ends of the vanes or islands between adjacent cavity resonators. In this case the R.-F. signal entering through the output slot is effectively introduced at the emitting electrode. As neither emissive coatings nor thermionic or other heaters are requisite, the structure of the magnetron is not complicated in this embodiment. In fact when the center post is a solid copper cylinder and the resonant structure defined in a copper block, the same physical magnetron structure may be operated with either element as cathode and the other as anode.

Because the R.-F. signal in this embodiment is injected at the emitting electrode we have found that the minimum power necessary to trigger the magnetron is considerably reduced and may be of the order of 100 times less than requisite in the normal operation of the magnetron, described above. To distinguish the two types of magnetron operation which we are discussing we prefer to refer to the operation in which the center post is pulsed negatively and serves as a cold, secondary emitting cathode as the normal operation of the magnetron and the operation in which the resonant structure is pulsed negatively and serves as the cold, secondary emitting cathode as backward magnetron operation. In both types of operation in the presence of the normal magnetic field and an injected R.-F. signal into the resonant structure at a frequency near a resonance of the resonant structure, the magnetron will oscillate in its  $\pi$ -mode. Further for both modes of operation it is advantageous, in accordance with this invention, that the R.-F. pulse be injected into the magnetron output just before the D.-C. pulse reaches the voltage level requisite for  $\pi$ -mode oscillation.

With backward operation, as with normal operation, the frequency range over which the injected signal is effective in triggering the tube decreases with decreasing injected power. However, we have found that in one specific embodiment of this invention wherein the magnetron was first oscillated in normal and then in backward operation, the minimum injected R.-F. power to trigger the tube was of the order of 350 watts for normal operation but was only of the order of 4 watts for backward operation. In both instances as the injected power level was reduced toward the threshold, the voltage and magnetic field were both increased slightly in order to keep the tube in oscillation.

It is a feature of this invention that a magnetron be triggered by applying an R.-F. signal into the output of the magnetron and thus to the resonant structure of the magnetron while the D.-C. voltage is being applied between the anode and cathode of the magnetron.

It is another feature of this invention that the magnetron have a cold cathode, secondary electron emission providing essentially the entire magnetron current. Thus it is a feature of this invention that the magnetron structure comprise a center post and an encompassing resonant structure, the R.-F. signal being introduced into the resonant structure.

It is still another feature of this invention that the R.-F. signal pulse be applied at a point during the build-up of the direct current pulse or voltage between the center post and resonant structure at which the voltage level of the D.-C. pulse is just below the voltage necessary to sustain the desired  $\pi$ -mode oscillations in the mag-

netron, whereby moding of the magnetron during build-up of the anode-to-cathode voltage is prevented.

It is a still further feature of this invention that the D.-C. voltage pulse may be applied between the center post and resonant structure with either polarity, whereby for normal operation of the magnetron the center post serves as the secondary emitting cathode on injection of the R.-F. signal and for backward operation of the magnetron the resonant structure itself serves as the secondary emitting cathode.

A complete understanding of this invention and of these and various other features thereof may be gained from consideration of the following detailed description and the accompanying drawing, in which:

Fig. 1 is a schematic representation of one specific illustrative embodiment of this invention, capable of either normal or backward operation depending on the polarity of the applied D.-C. pulse; and

Fig. 2 is a time plot showing the relationships between the injected R.-F. pulse, the D.-C. pulse, and the output signal of the magnetron for one specific embodiment of this invention in accordance with Fig. 1.

The illustrative embodiment of this invention depicted in Fig. 1 comprises a magnetron 10 having a center post 11 and a resonant structure 12 which may comprise a solid block through which extend the resonant cavities. One of the cavities 14 serves as the output of the magnetron and is connected, through appropriate transformers, as is known in the art, to the output waveguide 15. When the center post 11 serves as the secondary electron cathode, it is advantageously solid to provide better transfer of heat away from the cathode to the supporting structure. The post 11 may advantageously be of copper, molybdenum, or, when serving as the cathode, of such materials as beryllium-copper which are known to have relatively high secondary emission ratios. However, we have found that center posts of the copper or molybdenum also may be utilized when the center post is the cathode for normal operation.

The block of the resonant structure 12 may advantageously also be of copper, whether the structure is employed in normal or backward magnetron operation.

The magnetron itself may be of any type known in the art. We have found it advantageous, in embodiments of this invention, to replace the oxide coated thermionic cathodes and heaters of known magnetrons, such as that known as the 4J52 and disclosed in Patent 2,466,922, issued April 12, 1949, of N. Wax, with solid cathodes or center posts, as of copper or molybdenum. The magnetrons were then found to operate with approximately normal characteristics when triggered in accordance with this invention. In fact such known magnetrons may be utilized in combinations in accordance with this invention with the existing thermionic cathode cold, no voltage being applied across the heater. However when the center post 11 has a thermionic coating thereon, as is known in present magnetron cathodes, the electron back-bombardment may result in sufficient heating of the cathode so that, after a few minutes of normal pulsed operation, the incident R.-F. becomes ineffectual and could actually be removed and the magnetron started as in standard operation due to the cathode's primary emission. This will depend on the duty ratio on which the magnetron is pulsed. Thus for lower duty ratios there is insufficient heating to produce the necessary primary emission and starting of the magnetron is then accomplished solely by the application of the external R.-F. pulses.

A trigger generator or pulse 18 applies pulses at a rate determined by the desired duty ratio or cycle of the pulsed magnetron to both the direct current voltage pulser 19 and, through a delay line 20, to the radio frequency trigger pulse source 21. The D.-C. pulser 19 may be of any type of D.-C. pulser or modulator known in the art or presently employed in the operation of

pulsed magnetrons. In one specific embodiment of this invention the D.-C. pulser applied a five microsecond D.-C. pulse 23, shown in Fig. 2, between the center post 11 and the resonant structure 12. In accordance with an aspect of this invention the polarity of the applied pulse 23 may be such that either the center post 11 is pulsed negative with respect to the resonant structure 12, for normal operation of the magnetron, or the resonant structure 12 is pulsed negative with respect to the center post 11, for backward operation of the magnetron as discussed above.

The initiating pulse from the trigger generator 18 is also applied to the R.-F. pulser 21 through the delay line 20. R.-F. trigger pulse source 21 may include any of many known R.-F. generator devices, such as another magnetron, klystron, or other discharge device, and a modulator circuit to determine the length of the R.-F. pulse. In one specific illustrative embodiment of this invention wherein the applied D.-C. pulse was of five microsecond duration, the R.-F. pulse 25, seen in Fig. 2, was of one quarter of a microsecond duration, though the length of the triggering pulse is not critical and shorter pulses, as of the order of a tenth of a microsecond might also be employed. It is to be understood that the pulse 25 depicted in Fig. 2 is actually the envelope of the R.-F. signal generated by the R.-F. pulser 21.

In accordance with an aspect of this invention the R.-F. signal 25 is injected, through a duplexer 26 or other switch known in the art, into the output waveguide 15 and thus into the output cavity 14 of the resonant structure 12. Duplexer 26 prevents the output pulse 28 of the magnetron, seen in Fig. 2, from being applied to the R.-F. pulser 21. The injection of the radio frequency pulse 25 serves to increase the energy of the residual free electrons in the magnetron so that, on bombarding the cathode when the D.-C. pulse 23 is applied, sufficient secondary electrons are emitted to trigger the magnetron, as discussed further above.

Delay line 20 serves, in accordance with another aspect of this invention, to provide the desired time relationship between the applied R.-F. and D.-C. pulses. When the D.-C. pulse 23 is applied between the center post 11 and the resonant structure 12, there is a delay while the voltage builds up to its maximum value. During this build-up, if sufficient electrons are present in the magnetron, moding may occur in one of the spurious or degenerate modes for which the requisite anode-cathode voltage is lower than for the desired  $\pi$ -mode of oscillation. In order to prevent this moding, a delay is interposed in accordance with this invention between the application of the D.-C. pulse 23 and the application of the R.-F. pulse 25, which latter causes sufficient current to flow to enable the magnetron to oscillate. In one specific illustrative embodiment wherein the rate of rise of the applied D.-C. pulse 23 was 100 kilovolts per microsecond and the magnetron operated with an anode-cathode voltage of 15 kilovolts, so that .15 microsecond was required for the D.-C. pulse 23 to rise from zero to the requisite voltage, the delay introduced by the delay line 20 and the R.-F. pulser 21 itself was such that the R.-F. pulse 25 was approximately .1 microsecond after the application of the D.-C. pulse and therefore shortly before the D.-C. voltage between the anode and cathode reached the desired value.

The frequency of the injected R.-F. pulse 25 is not critical but should be in the vicinity of a resonant frequency of the resonant structure 12. There is however a direct relationship between the deviation of the frequency of the R.-F. pulse from a resonant frequency and the power of the R.-F. signal necessary to trigger the magnetron, as discussed above. However this power is considerably less, as of the order of 100 times less, for backward operation of magnetrons in accordance with this invention. The frequency of the R.-F. signal, being in the vicinity of a resonance of the system, gives rise to

R.-F. fields near the cathode. It is apparent that for backward operation of the magnetron wherein the R.-F. signal is applied directly to the cathode itself less power would be required. It should be pointed out that the frequency of the injected R.-F. pulse is not related to the moding problem in embodiments of this invention. Thus no attempt need be made to inject either the  $\pi$ -mode frequency itself or some harmonic thereof so that the injected power serves to lock the frequency of oscillation of the magnetron in the desired mode. In fact we have found that the injected pulse frequency may be that of the closest spurious or degenerate mode, in which the magnetron would be most likely to oscillate if moding occurs, and that in embodiments of this invention the magnetron will still oscillate in the desired  $\pi$ -mode. Thus the frequency of the R.-F. pulse itself, apart from its timing, is involved only with the attainment of sufficient current to sustain the oscillations and is not effective on the mode-selection process; and, in accordance with this invention, the mode-selection is attained by the time relationship between the injected R.-F. pulse and the applied D.-C. pulse.

It is to be understood that the above-described arrangements are illustrative of the application of the principles of the invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. An electrical circuit comprising a magnetron having a cold cathode and an anode, means for applying a first direct current pulse between said anode and cathode to pulse said magnetron, means for applying a second pulse of radio frequency energy to said magnetron to create a radio frequency field in the vicinity of said cathode, and means for determining the time relationship between said first and second pulses so the said pulse of radio frequency energy is applied to said magnetron during build-up of the voltage between said anode and cathode and just before said voltage has reached the level for the described mode of oscillation of said magnetron.

2. An electrical circuit comprising a magnetron having a cold cathode and an anode, output means connected to said magnetron, means for applying a direct current voltage between said anode and cathode, means for applying a short pulse of radio frequency energy to said output means, and means for delaying the application of said pulse of radio frequency energy until after commencement of the build-up of said voltage between said anode and cathode.

3. An electrical circuit in accordance with claim 2 wherein said cold cathode includes means defining a plurality of resonant cavities, said output means being connected to one of said resonant cavities.

4. An electrical circuit comprising a magnetron having a cold cathode and an anode, output means connected to said magnetron, means for applying a direct current voltage between said anode and cathode, means for applying a short pulse of radio frequency energy to said output means to trigger said magnetron, and means for preventing moding on application of said radio frequency energy, said last mentioned means comprising means for delaying the application of said triggering radio frequency pulse until the voltage between said anode and cathode has built up to a value just below the voltage for the desired mode of oscillation of said magnetron.

5. An electrical circuit comprising a magnetron having a center post member, means encompassing said center post member and defining a plurality of resonant cavities, a trigger pulse generator, a direct current voltage source responsive to receipt of a trigger pulse from said pulse generator to apply a direct current voltage between said center post member and said resonant cavity defining means, a radio frequency pulse source, and delay means connected between said radio frequency pulse source and said trigger pulse generator, said radio frequency pulse

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source responsive to receipt of said trigger pulse from said pulse generator through said delay means to apply a pulse of radio frequency energy to said magnetron to create a radio frequency field in said magnetron, said pulse of radio frequency energy being applied to said magnetron during build-up of the voltage between said center post member and said resonant cavity defining means and just before said voltage has reached the level for the desired mode of operation of said magnetron.

6. An electrical circuit in accordance with claim 5 10 wherein the polarity of said applied direct current pulse is such that said center post member is negative with respect to said resonant cavity defining means, said center post member defining a secondary electron emitting cathode.

7. An electrical circuit in accordance with claim 5 15

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wherein the polarity of said applied direct current pulse is such that said resonant cavity defining means is negative with respect to said center post member, said cavity defining means defining a secondary electron emitting cathode.

8. An electrical circuit in accordance with claim 5 wherein the frequency of said radio frequency pulse is in the vicinity of a resonance of said means defining said resonant cavities.

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