

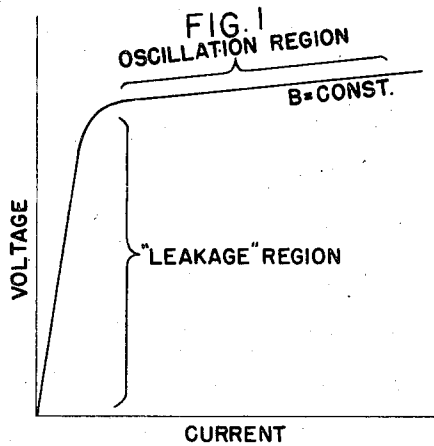
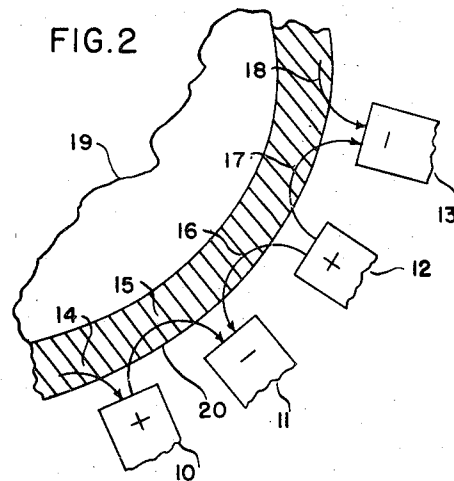
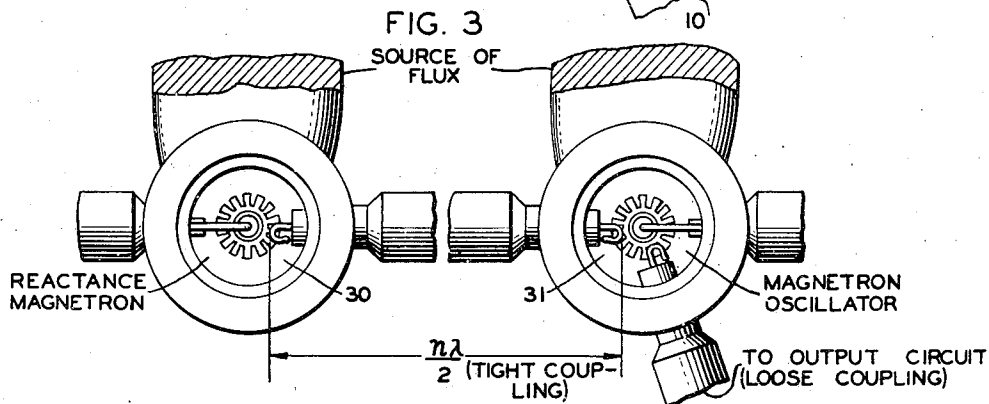
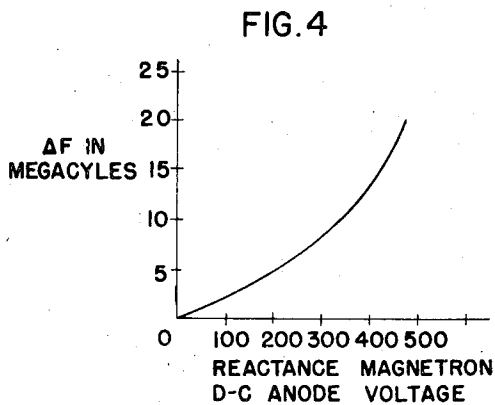
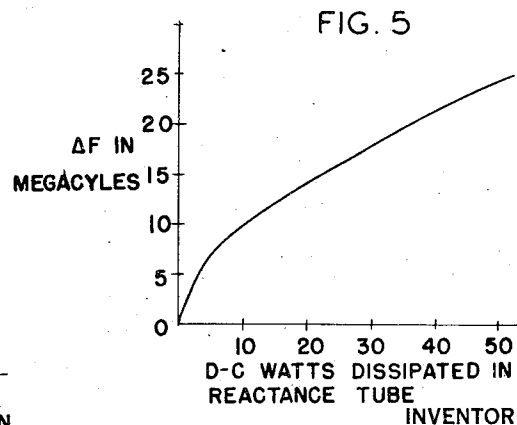
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2,472,200

VARIABLE FREQUENCY MAGNETRON CIRCUIT

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VARIABLE FREQUENCY MAGNETRON
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9 Claims. (Cl. 332-5)

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This invention relates in general to magnetrons and more particularly to the use of magnetrons as reactance tubes.

A reactance tube is a thermionic vacuum tube whose output reactance is adjustable by varying, for instance, a certain voltage applied to the tube. Due to the ease and speed at which the output reactance of such a tube may be varied, it is often used as a means for frequency modulating a resonant circuit or as the controlling element in an automatic frequency control circuit.

Reactance tubes for use at hyper frequencies must employ thermionic tubes which operate relatively efficiently at those frequencies. As herein used, the term "hyper frequencies" will refer to those frequencies at which conventional coils, condensers and resistors may no longer be used to practical advantage. Some such device as a cavity resonator must be used for the resonant circuit at such frequencies. The magnetron is such a tube which can be made to operate relatively efficiently at these hyper frequencies. The multi-cavity magnetron is particularly applicable for use as a reactance tube because of a change in dielectric constant with change in cathode-to-anode voltage when the tube is run below cut-off, at too low voltage to cause conduction with the existing magnetic field. This is due to space charge which surrounds the cathode but does not extend out as far as the anode because of the large magnetic field or the low cathode-to-anode voltage. An increase in magnetron voltage causes an expansion of space charge and results in a change in dielectric constant. The capacitive reactance and thus the resonant frequency of the magnetron cavity oscillators changes with variation in D. C. voltage, and the magnetron operated below cut-off acts as a rapidly tunable cavity. When tightly coupled into a transmitter oscillator, the reactance tube achieves such rapid electronic tuning as is desired for frequency modulation purposes.

The frequency modulation system, and especially its reactance magnetron tuner, is lossless with respect to R.F. energy; that is, the R.F. output of the transmitter does not vary measurably with tuning. There is an amount of D. C. power absorbed in the reactance tube due to what is known as end-space leakage, which will be described later, but such loss is not too great and it is not the loss of the useful R.F. energy.

The multi-cavity magnetron is one in which the anode comprises a number of cavity resonators placed symmetrically about the cathode each

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cavity being coupled to the cathode-anode space by means of slots.

Accordingly it is an object of this invention to provide a magnetron oscillator coupled to the other magnetron of similar physical dimensions as the dimensions of the oscillator magnetron, the second magnetron acting as a variable reactance tube for controlling the frequency of the magnetron oscillator.

Still another object of this invention is to provide a magnetron oscillator whose frequency is modulated by a reactance magnetron coupled to the magnetron oscillator, the reactance of the reactance magnetron being varied by varying its cathode-anode voltage.

Still another object of this invention is to provide a magnetron oscillator whose frequency may be either modulated or adjusted by a reactance magnetron coupled to it, the reactance magnetron having a cathode-to-anode diameter ratio in the order of .60-.85 and a flux density in the order of $2B_0$.

Accordingly, among the objects of the present invention are:

1. To provide a magnetron oscillator for use at hyper frequencies; and
2. To provide a method of using such a magnetron as a reactance tube.

In accordance with the present invention there is provided a multi-cavity magnetron oscillator with a normal high anode voltage and large magnetic field, loosely coupled to its load. Tightly coupled to this magnetron oscillator is a reactance magnetron, having a normal large magnetic field, but a very small anode voltage, below the "cut-off" region of voltage as hereinafter referred to. As the anode voltage of the reactance magnetron is varied, its output reactance is varied and the frequency of oscillation of the magnetron oscillator is changed.

This invention will best be understood by reference to the drawings, in which:

Fig. 1 is the voltage-current characteristic for a multi-cavity magnetron;

Fig. 2 is a simplified drawing of a multi-cavity magnetron showing the structure of the fields existing in the cathode-anode space;

Fig. 3 is a functional diagram of a magnetron oscillator controlled by a reactance magnetron;

Fig. 4 is a graph of variation in magnetron oscillator frequency (Δf) as a function of the D.-C. anode voltage of the reactance magnetron; and

Fig. 5 is a graph of the variation in D.-C. power dissipated in the reactance magnetron as a func-

tion of frequency change in the magnetron oscillator.

Referring now to a description of the operation of the apparatus and to Fig. 1, it is seen that as the anode voltage of a multi-cavity magnetron is increased from zero, the anode current increases slowly at first and then suddenly starts a rapid increase. The knee of this curve is the so-called "cut-off" region of the magnetron oscillator. At lower voltages the tube current is due to "leakage" current, not current that reaches the anode by conventional multi-cavity magnetron action. At voltages higher than those at the knee of the curve, the magnetron oscillates in a normal manner.

This characteristic may be explained by noting the fields existing in the cathode-anode space, shown highly simplified in Fig. 2, in which a cut-away view of the magnetron is given. A portion of anode vanes 10, 11, 12, and 13, which are the walls separating the various cavity resonators, are shown with alternate instantaneous positive and negative electric charges upon them, which is the situation for one desirable mode of operation. The anode electric field vectors 14, 15, 16, 17 and 18 may then take the curved paths substantially as shown. The cathode 19 of the magnetron is shown situated symmetrically with respect to the anode vanes. At low anode voltages, the space charge 20 which surrounds the cathode, shown functionally in Fig. 2, extends only part way across the cathode-anode space. The magnetic field must be large in order for this condition to occur.

An increase in anode voltage causes an extension of the space charge toward the anode, with the result that the effective dielectric constant of the cathode-anode space of the magnetron is changed. The capacitive reactance and thus the resonant frequency of the magnetron changes with variation in D.-C. anode voltage, and thus the "cut-off" magnetron acts like a rapidly tunable cavity. It is desirable that the reactance magnetron 30, Fig. 3, and the magnetron oscillator 31 be reasonably tightly coupled together for the reactance magnetron to have the optimum effect. One possible arrangement involves the use of a line, connecting the two magnetrons, having an effective length of a multiple of a half wavelength $n\lambda/2$, at the operating frequency, $nL/2$, where n is any integer and λ is the operating wavelength of the system. With this arrangement, rapid electronic tuning may be accomplished for frequency modulation or automatic frequency control purposes.

A typical graph of the amount of D.-C. anode volts required on the reactance magnetron to effect a given change in frequency of the magnetron oscillator is shown in Fig. 4. This curve is for continuous-wave oscillations from one magnetron oscillator of approximately 15 watts power level. The change in radio-frequency power over the electronic tuning range was found to be not more than 10 per cent in this case.

There is an amount of D.-C. power absorbed in the reactance magnetron due in part to end-space leakage, which involves the flow of electrons around the end plates and out to the magnetron case. The amount of D.-C. power required in a typical case, the constants being the same as those used to obtain the graph of Fig. 4, is shown in Fig. 5.

It was found that there is a relationship between the range of electronic tuning obtainable and the cathode-to-anode diameter ratio. Of

three typical magnetrons tried, the first with 88 per cent cathode-to-anode diameter ratio gave a tuning range of 3 megacycles; the second with 75 per cent cathode-to-anode diameter ratio gave 9 megacycles range; and the third having an 85 per cent ratio gave a range of 20 megacycles, the three magnetrons being tested under comparable conditions. This large cathode is believed to bring the space charge closer to the anode fringing fields and so to increase the tuning effect.

The operation of the reactance magnetron was also found to be dependent upon the magnetic field strength. Tuning is found to be maximum and R. F. loss minimum when magnetic field B_0 , in gauss, is between $1\frac{1}{2}$ and $3B_0$, where B_0 is equal to $10,700/\lambda$, where λ is the operating wavelength in centimeters. With B approximately equal to B_0 a considerable amount of R. F. loss is encountered. The tuning is substantially a maximum and the R.-F. loss is substantially a minimum when the magnetic field B is in the region of $2B_0$. At $B=B_0$ there was a maximum of loss, and at $B=3B_0$ the reactance magnetron cathode became too hot and no tuning advantage was found.

While there has been described what is at present considered to be the preferred embodiment of the invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A reactance controlled oscillator comprising a first multicavity magnetron supplied with a cathode-anode voltage and a magnetic field of conventional values for causing said first magnetron to operate as an oscillator in one of its resonant modes, a second multicavity magnetron having a system of resonant modes, one of the modes of said second magnetron having substantially the same resonant wave length as the wave length of one of the modes of said first magnetron said second magnetron being supplied with a magnetic field and an adjustable cathode-anode voltage to cause said second magnetron to act as a reactance whose value is determined by the cathode-anode voltage, and a coupling circuit interconnecting said magnetrons, whereby said second magnetron acts as an adjustable reactance capable of modifying the reactance of the resonance cavities of said first magnetron for adjusting the frequency of said first magnetron.

2. In combination, a first magnetron having a system of resonant modes, said magnetron being provided with a magnetic field and a cathode-anode voltage producing oscillations corresponding to one of said modes, a second multicavity magnetron having a system of resonant modes, one of the modes of said second magnetron having substantially the same resonant wave length as the wave length of one of the modes of said first magnetron, with the intensity of the magnetic field of said second magnetron being on the order of $2(10,700/\lambda)$ where λ is the operating wave length of said first magnetron, and the cathode-anode voltage of said second magnetron being below the "cut-off" voltage of said second magnetron, and means for closely coupling said first and second magnetrons whereby said second magnetron acts as a reactance capable of influencing the frequency of oscillation of said first magnetron.

3. A reactance controlled oscillator compris-

ing, a first oscillating magnetron having a system of resonant modes, a second magnetron, means for intercoupling said first and second magnetrons, means for providing a magnetic field and a cathode-anode voltage for said first magnetron of the magnitude setting said first magnetron into oscillations corresponding to one of said modes, and means for providing a cathode-anode voltage for the second magnetron below its "cut-off" voltage, the cathode-to-anode diameter ratio of said second magnetron being on the order of .85, and a magnetic field to make said second magnetron to act as a reactance influencing the frequency of oscillation of said first magnetron.

4. A reactance controlled oscillator comprising, a first oscillating magnetron having a system of resonant modes, a second magnetron, means for intercoupling said first and second magnetrons, means for providing a magnetic field and a cathode-anode voltage for said first magnetron of the magnitude setting said first magnetron into oscillations corresponding to one of said modes, and means for providing a cathode-anode voltage, and a magnetic field to make said second magnetron to act as a reactance influencing the frequency of oscillation of said first magnetron the density of the magnetic flux of said second magnetron being on the order of

$$2\left(\frac{10,700}{\lambda}\right)$$

where λ is the operating wave length of said first magnetron.

5. A reactance controlled oscillator comprising, a first oscillating magnetron having a system of resonant modes, a second magnetron, means for intercoupling said first and second magnetrons comprising a concentric line having an effective length of

$$\frac{n\lambda}{2}$$

where n is any integer and λ is the operating wave length of the first magnetron, means for providing a magnetic field and a cathode-anode voltage for said first magnetron of the magnitude setting said first magnetron into oscillations corresponding to one of said modes, and means for providing a cathode-anode voltage for the second magnetron below its "cut-off" voltage, and a magnetic field to make said second magnetron to act as a reactance influencing the frequency of oscillation of said first magnetron.

6. A frequency modulated system comprising a first multicavity magnetron having a system of resonant modes, said first magnetron being supplied with a cathode-anode voltage and a magnetic field of conventional values for causing said first magnetron to operate as an oscillator, a second multicavity magnetron having a

system of resonant modes, one of the modes of said second magnetron having substantially the same resonant wave length as the wave length of one of the modes of said first magnetron, said second magnetron being supplied with a magnetic field and a varying cathode-anode voltage, the maximum value of said varying cathode-anode voltage being below the "cut-off" voltage of said second magnetron to cause said second magnetron to act as a reactance varying in response to the variation in the cathode-anode voltage of said second magnetron, and a coupling circuit interconnecting said magnetrons whereby said second magnetron frequency modulates the output of said first magnetron.

7. In combination, a first oscillating magnetron, a second magnetron tightly coupled to said first magnetron, each of said magnetrons having a cathode and an anode, said anodes having a number of cavity resonators, means to impress a variable voltage onto the cathode-anode circuit of said second magnetron, said voltage being below the "cut-off" region of said second magnetron to cause a variation in the resonant frequency of said first magnetron.

8. In combination, a first multicavity oscillating magnetron, a second multicavity magnetron tightly coupled to said first magnetron, a load loosely coupled to said first magnetron, and means to impress a variable voltage source onto the cathode-anode circuit of said second magnetron below the cut-off voltage of said second magnetron to cause a variation in the resonant frequency of said first magnetron.

9. A pair of magnetrons, each said magnetron having a cathode and a multiple element anode, resonator means, said resonator means and both said anodes being tightly coupled at high frequency, means to impress a separate voltage on the cathode-anode circuit of each said magnetron, one said voltage being above the "cut-off" region of the corresponding magnetron to produce oscillations, the other said voltage being variable below the "cut-off" region of the other magnetron to vary the resonant frequency of said pair of magnetrons.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,241,976	Blewett	May 13, 1941
2,404,212	Bondley	July 16, 1946
2,408,236	Spencer	Sept. 24, 1946
2,412,372	Usselman	Dec. 10, 1946