Oct. 31, 1950 W. V. SMITH 2,527,770

MAGNETRON PILOT CAVITY RESONATOR

Filed Oct. 10, 1945

FIG. 1

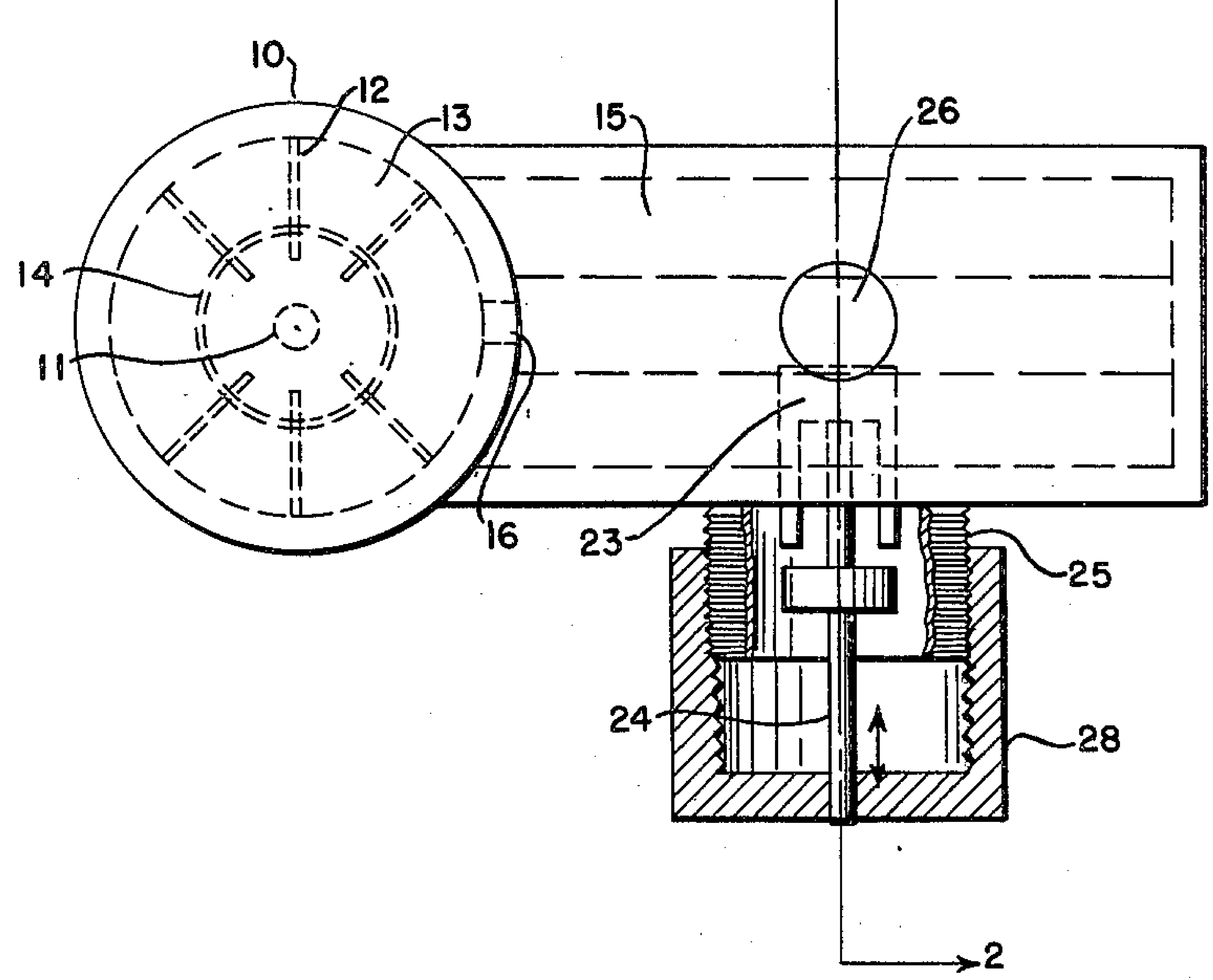
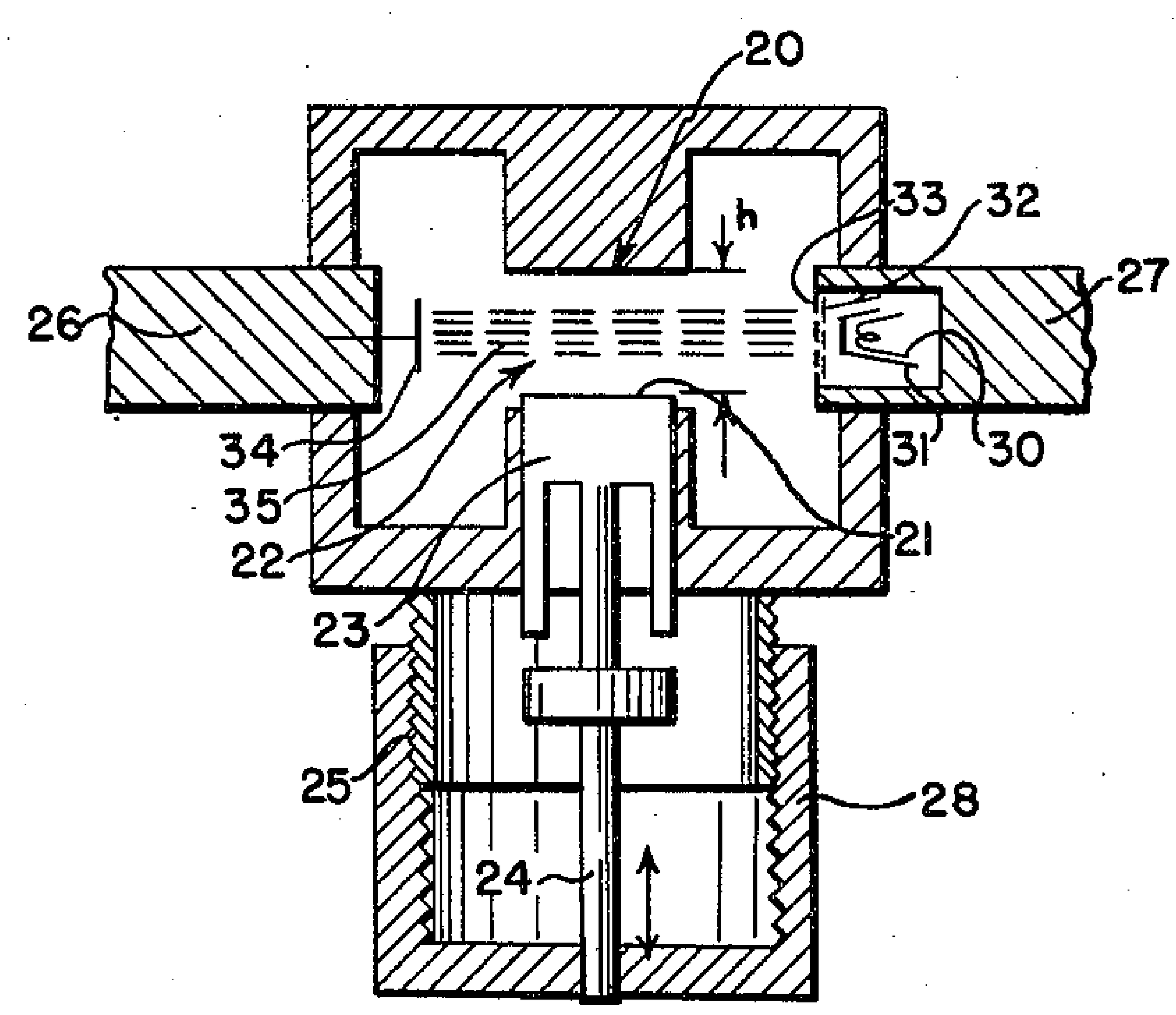


FIG. 2



INVENTOR.
WILLIAM V. SMITH
BY William D. Hall
ATTORNEY

Patented Oct. 31, 1950 2,527,770

UNITED STATES PATENT OFFICE

2,527,770

MAGNETRON PILOT CAVITY RESONATOR

William V. Smith, Medford, Mass., assignor, by mesne assignments, to the United States of America as represented by the Secretary of War

Application October 10, 1945, Serial No. 621,563

6 Claims. (Cl. 315—39)

1

The invention relates to improvements in electrical apparatus and more particularly to improvements in radio frequency, oscillators such as magnetrons.

In one method of frequency modulating a magnetron a thermally tuned electron gun within one of the magnetron cavities has been employed. This method has a number of disadvantages; tuning is sluggish and only very low rates of frequency modulation are possible by this method.

An object of the present invention is to provide a magnetron oscillator which is mechanically tunable over a substantial range of center frequencies. Another object is to provide for electronic frequency modulation at any given center frequency, and for maintaining the degree of frequency modulation substantially constant over the range of center frequencies to which the magnetron may be tuned.

Other objects and advantages of the invention will be apparent during the course of the following description.

These objects are accomplished by coupling an external auxiliary cavity resonator, here called a magnetron pilot cavity resonator, to one of the cavity resonators of the power generating magnetron. The resonant frequency of the pilot cavity resonator is varied by mechanical adjustment and by a cloud or beam of electrons exposed to the high frequency electric field within the cavity. A change in the resonant frequency of the pilot cavity resonator couples positive or negative reactance into the power generating magnetron system, changing its resonant frequency and therewith the frequency of the generated power. A magnetic field parallel to the electron beam is superposed to concentrate and stabilize the electron flow.

In the accompanying drawing forming a part of this specification and in which like numerals are employed to designate like parts throughout the same;

Fig. 1 is a schematic view of a magnetron embodying the invention.

Fig. 2 is a cross sectional view taken on the line 2—2 of Fig. 1.

In the drawing Fig. 1, wherein for the purpose of illustration is shown a preferred embodiment of the invention, the numeral 10 designates a magnetron of the plural cavity type including a cylindrical cathode 11 surrounded by radial anode segments 12. The anode segments form the lateral walls for the individual cavities 13. Alternate anode segments are connected by straps 14 of which only one is shown.

The magnetron output may be coupled to a load in any conventional manner. For example, a loop may be provided in one of the magnetron cavities to accomplish this function.

2

The magnetron 10 is coupled to a magnetron pilot cavity resonator 15 by means of an iris coupling 16. The magnetron pilot cavity resonator 15 is a half wave length section of H-shaped wave guide.

Referring to Fig. 2 which is a cross sectional view taken through the magnetron pilot cavity resonator on the line 2—2 (Fig. 1), the numerals 20 and 21 represent opposing surfaces which cooperate to define the capacitive gap 22. The dimension h of capacitive gap 22 may be varied by regulating the position of capacitive plunger 23 by means of a hand knob 28 which is rigidly fastened to the plunger spoke 24 and turns on a threaded guide 25. Pole pieces 26 and 27 create a magnetic field substantially parallel to and between surfaces 20 and 21.

An electron gun including a filament 30, cathode 31, control grid 32, screening grid 33 and collecting anode 34 sends a beam of electrons 35 through the capacitive gap 22, said beam of electrons 35 being substantially parallel to and between surfaces 20 and 21.

The operation of the frequency modulated magnetron which is a preferred embodiment of the invention is as follows:

The magnetron 10 oscillates upon the application of the operating voltage between cathode 11 and anode segments 12. The frequency of the magnetron oscillations may be varied by varying the resonant frequency of the magnetron pilot cavity resonator 15. The stabilization factor S is a measure of the influence of the pilot cavity resonator 15 on the magnetron 10, as indicated in the following equation:

$$\frac{\Delta F}{\Delta f}=\frac{S-1}{S} \quad (1)$$

where ΔF is the frequency change of the combined system of magnetron 10 and cavity resonator 15, and Δf is the corresponding frequency change for the cavity resonator 15 alone.

The resonant frequency of the cavity 15 may be varied by mechanical tuning means (e. g., capacitive plunger 23) and by electronic means (e. g., variation of the current density of the electron beam 35 within capacitive gap 22 in the presence of the magnetic field generated by the pole pieces 26 and 27, said magnetic field being parallel to and between surfaces 20 and 21 and parallel to electron beam 35. The electron beam 35 is generated in the usual manner by cathode 31 upon heating thereof by filament 30. The density of electron beam **35** may be modulated by a voltage applied to control grid **32**. Customary plate-cathode, screen-cathode and grid-cathode direct current voltages are applied to the elements of the electron gun.

As shown in Fig. 2, the screening grid **33** and collecting anode **34** are both electrically connected to the walls of the cavity resonator **15**. Inasmuch as these walls are customarily grounded, the cathode **31** will be operated at some negative voltage (with respect to ground) to maintain the required potential differences between cathode **31**, screening grid **33** and collecting anode **34**. Although the screening grid **33** and collecting anode **34** are here shown as being at the same potential, the screen grid **33** may be operated at a somewhat higher or lower potential than that of the collecting anode **34** if desired.

The modulation of the density of electron beam **35** by the voltage applied to control grid **32** will electrically modulate the frequency of said cavity **15** by variation of the electron loading in the capacitive gap **22**. Furthermore, by proper design of relations between the stabilization factor S and the magnetic field intensity, as will appear more in detail hereafter, it is possible to maintain the degree of frequency modulation substantially constant over the range of mechanical frequency adjustment of the cavity resonator **15**, said mechanical frequency adjustment being made by movement of the capacitive tuning plunger **23**.

The electron loading effected by the electron beam **35** within the capacitive gap **22** is augmented as a result of the complex helical motion which the electrons describe under the influence of the combined magnetic field (generated by pole pieces **26** and **27**) and the electric field between surfaces **20** and **21** (the electric field being the alternating electric field of frequency corresponding to the frequency of the magnetron **10** and cavity **15**). The magnetic field created by pole pieces **26** and **27** is parallel to the electron beam **35**. The alternating electric field generated between surfaces **20** and **21** is at right angles to the magnetic field. Under the action of the combined electric and magnetic field, the electrons describe a complex motion, which is that of a helix of constantly increasing diameter to some maximum diameter, thence of constantly decreasing diameter to a zero diameter point or node, thence to the maximum diameter again maintaining this sequence of motion while passing between the surfaces **20** and **21**. Alternatively, the motion may be termed an increasing and decreasing "Archimedean spiral helix," in analogy to the customary circular helix. Two frequencies are relevant in the discussion of this motion. They are F, the frequency of the alternating electric field between surfaces **20** and **21**, and F′, the "cyclotron frequency," (frequency of rotation of an electron of charge e and mass m in a magnetic field of intensity B).

(2) $$F'=\frac{B}{2\pi}\cdot\left(\frac{e}{m}\right)$$

The frequency of the electrons within the "Archimedean spiral helix" is

$$\frac{F+F'}{2}$$

the frequency of the zero diameter nodes is $F-F'$.

The effect of this complex motion of the electrons is to increase the effective alternating current electron density within the capacitive gap **22**. The variation of the electron density within the gap **22** by means of the control grid **32** results in a frequency modulation of the cavity **15** and of the magnetron **10**.

That the design shown in Figures 1 and 2 will permit the frequency modulation of the cavity **15** to remain substantially constant over the tuning range of the cavity **15** caused by the adjustment of the mechanically adjusted tuning plunger **23** will now be shown.

A table of the various symbols used in the discussion follows:

k_1, k_2, etc., are constants.

$$j\equiv\frac{I}{h}$$

where I is the current and h the gap spacing in gap **22**. (The symbol "≡" means "is equivalent to.")

$$\beta\equiv\frac{B}{H}$$

where B is the magnetic field strength generated by poles **26** and **27** and H is the "cyclotron field strength."

$$H=\frac{2\pi F}{e/m}$$

e/m is ratio of charge to mass for the electron.

F is the center frequency of the magnetron-cavity combination.

f is the resonant center frequency of cavity resonator **15** alone.

F and f are adjusted to be equal at the center of the mechanical tuning range.

To a first approximation the equation governing the electronically produced frequency change ΔF_e (caused by electronic loading alone) is given below:

(3) $$\Delta F_e=k_1\cdot\frac{j}{\beta-1}$$

The adjustment of the height h of gap **22** by the mechanical tuning control **23** results in a mechanically produced frequency change of the resonant frequency of cavity **15** as indicated in the following equation.

(4) $$f=k_2h^{1/2}$$

The variation of the mechanical tuning control **23** in addition to varying the center frequency F about which the electronic frequency modulation takes place will also vary β since

(5) $$\beta\equiv B\cdot\frac{e/m}{2\pi F}$$

and would result in a change of ΔF_e, the degree of frequency modulation (Equation 3). However, the variation of h likewise causes a counterbalancing change in j since

(6) $$j\equiv\frac{I}{h}$$

such that the ratio of $j/\beta-1$ tends to remain unchanged. This criterion (ratio

$$\frac{j}{\beta-1}$$

constant as h varies) is expressed as follows:

(7) $$\Delta\frac{\Delta\frac{(\beta-1)}{j}}{\Delta h}=0$$

Taking differentials in Equation 7

$$\frac{1}{j}\frac{\Delta\beta}{\Delta h}-\frac{(\beta-1)}{j^2}\frac{\Delta j}{\Delta h}=0 \quad (8)$$

or

$$\frac{\Delta j}{j}=\frac{\Delta\beta}{\beta-1} \quad (9)$$

From Equation 6

$$\frac{\Delta j}{j}=-\frac{\Delta h}{h} \quad (10)$$

$$\frac{\Delta\beta}{\beta-1}=\frac{\beta}{\beta-1}\cdot\frac{\Delta\beta}{\beta} \quad (11)$$

From Equation 5

$$\frac{\Delta\beta}{\beta}=-\frac{\Delta F}{F} \quad (12)$$

$$\frac{\Delta F}{F}=\left(\frac{\Delta F}{\Delta f}\right)\left(\frac{\Delta f}{f}\right)\left(\frac{f}{F}\right) \quad (13)$$

From Equation 4

$$\frac{\Delta f}{f}=\frac{1}{2}\frac{\Delta h}{h} \quad (14)$$

Substituting in Equation 13, the equivalents determined from Equations 1 and 14 and remembering that

$$\frac{f}{F}=1$$

at the center of the mechanical tuning range.

$$\frac{\Delta F}{F}=\frac{S-1}{S}\cdot\frac{\Delta h}{2h} \quad (15)$$

Substituting Equation 15 in Equation 12

$$\frac{\Delta\beta}{\beta}=\frac{-\Delta h}{2h}\cdot\left(\frac{S-1}{S}\right) \quad (16)$$

Substituting Equations 16, 11 and 10 in Equation 9

$$\frac{-\Delta h}{h}=\frac{-\beta}{\beta-1}\cdot\left(\frac{\Delta h}{2h}\right)\cdot\left(\frac{S-1}{S}\right) \quad (17)$$

Simplifying

$$\frac{\beta}{\beta-1}=\frac{2S}{S-1} \quad (18)$$

By substituting the equivalent of β from Equation 5, and solving for B.

$$B=\frac{4\pi F}{e/m}\cdot\left(\frac{S}{S+1}\right) \quad (19)$$

Equations 18 and 19 hold exactly only at one value of h, since β varies with h. However, the variation of the ratio

$$\frac{j}{\beta-1}$$

with h is minimized by satisfying Equation 18 at the center value of h.

In the customary design problem for a frequency modulated magnetron according to the present invention, S is known (usually in the range of 1.25–2.00), and the magnetic field intensity B is designed to satisfy equation 19 at the center frequency of the tuning range. (Adjustment of B rather than F in Equation 19 is chosen since F is predetermined.) It is desirable to make B variable over a slight range (in the completed device) to more accurately satisfy the requirement of Equation 19.

In the alternative event that β must have a certain value (to secure a required tuning range), S may be designed to satisfy Equation 18.

For the special case of the cavity resonator alone, (i. e. disconnected from the magnetron) Equation 19 reduces to:

$$B=\frac{4\pi F}{e/m} \quad (20)$$

By satisfying Equation 20 at the midfrequency of the cavity resonator, a substantially constant degree of electronic frequency modulation of the cavity resonator frequency over the range of the mechanical tuning is possible (in complete analogy to the case of the magnetron-resonator combination).

It is obvious that the cavity resonator embodying the principle of the present invention is not limited solely to combination with magnetron oscillators, but may be used to control the frequency of various other radio frequency oscillators, the frequency of which correspond to the frequency of said cavity resonator.

The advantageous features of this invention are summarized as follows:

a. Mechanical tuning of center frequency.

b. Electronic frequency modulation of frequency.

c. Substantially constant degree of electronic frequency modulation over the mechanical tuning range.

While there has been described what is at present considered to be the prefered embodiment of this invention, it will be obvious to those skilled in the art that various changes and modifications may be mode therein without departing from the scope of the invention as set forth in the appended claims.

What is claimed is:

1. A magnetron pilot cavity resonator coupled to a magnetron, said resonator having an adjustable capacitive gap formed by surfaces therein, electron means for varying the resonant frequency of said resonator, said means including a cathode, an anode and a control grid adjacent said gap and adapted to pass an electron beam therethrough substantially parallel to said surfaces and to vary the flow of electrons in said beam, and means for generating a magnetic field substantially parallel to and including said electron beam whereby the density of said electron beam may be modulated thereby modulating the resonant frequency of said resonator and introducing a corresponding frequency modulation in the output of said magnetron.

2. A magnetron pilot cavity resonator coupled to a magnetron, said resonator comprising, a wave guide closed at one end and open at the other to one of the magnetron cavity resonators, said wave guide having surfaces therein defining a capacitive gap, adjustable mechanical tuning means for varying the spacing of said surfaces whereby the center frequency of said resonator may be varied, electron means adapted to pass an electron beam through said gap substantially parallel to said surfaces, said electron means including a cathode, an anode and a control grid adjacent said gap, and means for generating a magnetic field substantially parallel to and including said electron beam whereby voltages applied to said control grid will vary the electron density of said electron beam thereby varying the resonant frequency of said resonator and the frequency of said magnetron.

3. A magnetron pilot cavity resonator having a capacitive gap formed by surfaces therein, means for adjusting the spacing between said surfaces, means positioned to pass an electron beam of

variable intensity through said gap substantially parallel to said surfaces to vary the resonant frequency of said resonator, and means for generating a magnetic field substantially parallel to and including said electron beam to stabilize and concentrate said electron beam.

4. A magnetron pilot cavity resonator having a capacitive gap formed by surfaces therein, mechanical tuning means for adjusting the spacing of said surfaces for varying the center frequency of said resonator, electronic means for varying the resonant frequency of said resonator, said means including a cathode, an anode, and a grid adjacent said capacitive gap and adapted to pass an electron beam therethrough substantially parallel to said surfaces and to vary the intensity of said beam, and means for generating a magnetic field substantially parallel to and including said electron beam.

5. A magnetron pilot cavity resonator, said resonator having a capacitive gap formed by surfaces therein across which high frequency electric fields are impressed, electron means for varying the effective capacity of said gap, said means including a cathode, an anode, and a grid adjacent said capacitive gap and adapted to pass an electron beam therethrough substantially parallel to said surfaces whereby the control of the density of said electron beam may be utilized to vary the resonant frequency of said resonator, and means for generating a magnetic field substantially parallel to and including said electron beam.

6. A magnetron pilot cavity resonator, said

resonator having a capacitive gap formed by surfaces therein across which a high frequency electric field is impressed, electron means adjacent said capacitive gap for varying the effective capacity of said gap, said electron means including a cathode, an anode, and a control grid, said electron means adapted to pass a beam of electrons through said gap at right angles to said electric field whereby the electron density of said electron beam within said gap may be varied, and a pair of magnet poles for producing a magnetic field parallel to the axis of and including said electron beam whereby said electron beam is stabilized and concentrated in said gap.

WILLIAM V. SMITH.

REFERENCES CITED

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

UNITED STATES PATENTS

Number	Name	Date
2,241,976	Blewett et al.	May 13, 1941
2,282,856	Engbert	May 12, 1942
2,320,860	Fremlin	June 1, 1943
2,407,706	Shulman et al.	Sept. 17, 1946
2,408,409	Bowen	Oct. 1, 1946
2,412,372	Usselman	Dec. 10, 1946
2,413,385	Schmidt	Dec. 31, 1946
2,415,962	Okress	Feb. 18, 1947
2,459,791	Chevigny	Jan. 25, 1949
2,472,200	Everhart	June 7, 1949