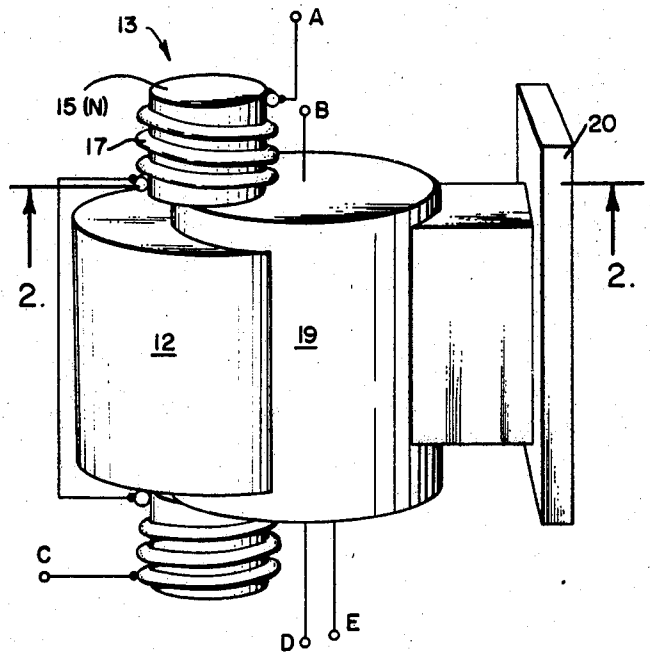
Dec. 30, 1969 I. KAUFMAN 3,487,336

FERRIMAGNETIC MICROWAVE GENERATOR OR AMPLIFIER

Filed Nov. 7, 1966 3 Sheets-Sheet 1

Fig. 1.



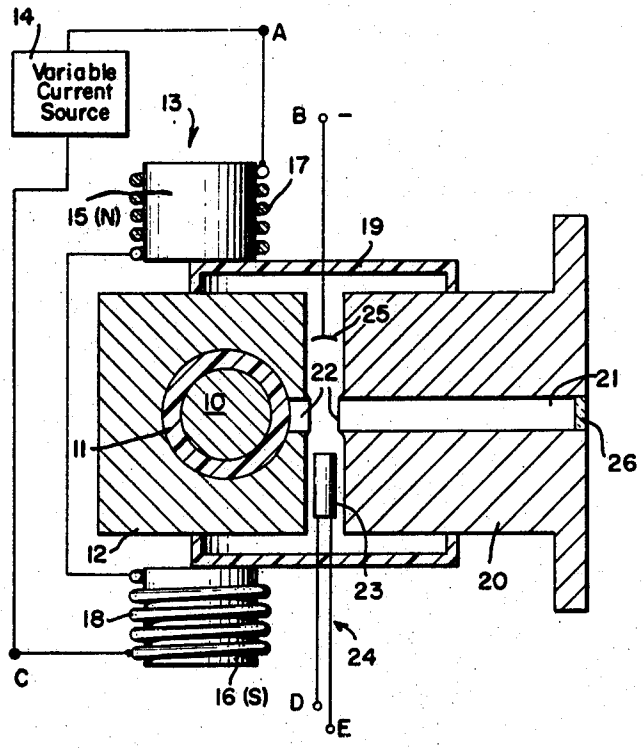


Fig. 2.

Irving Kaufman,
INVENTOR.
BY.
Edward Dugas
AGENT.

FERRIMAGNETIC MICROWAVE GENERATOR OR AMPLIFIER

Filed Nov. 7, 1966 3 Sheets-Sheet 2

Fig. 4.

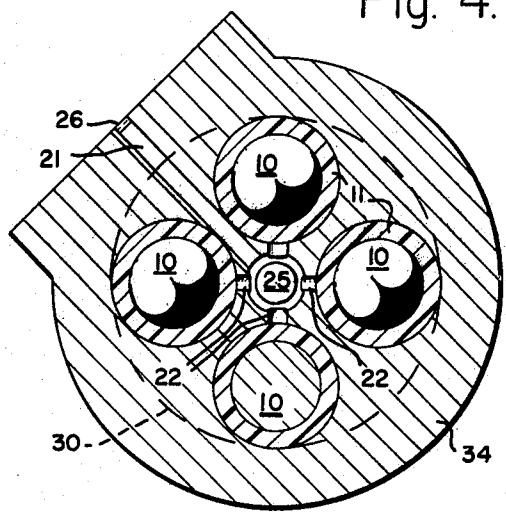
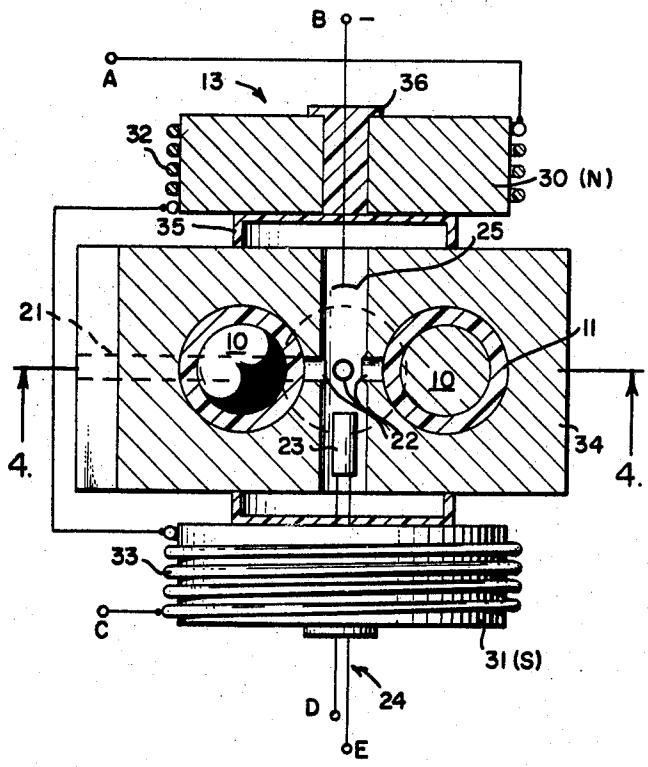


Fig. 3.

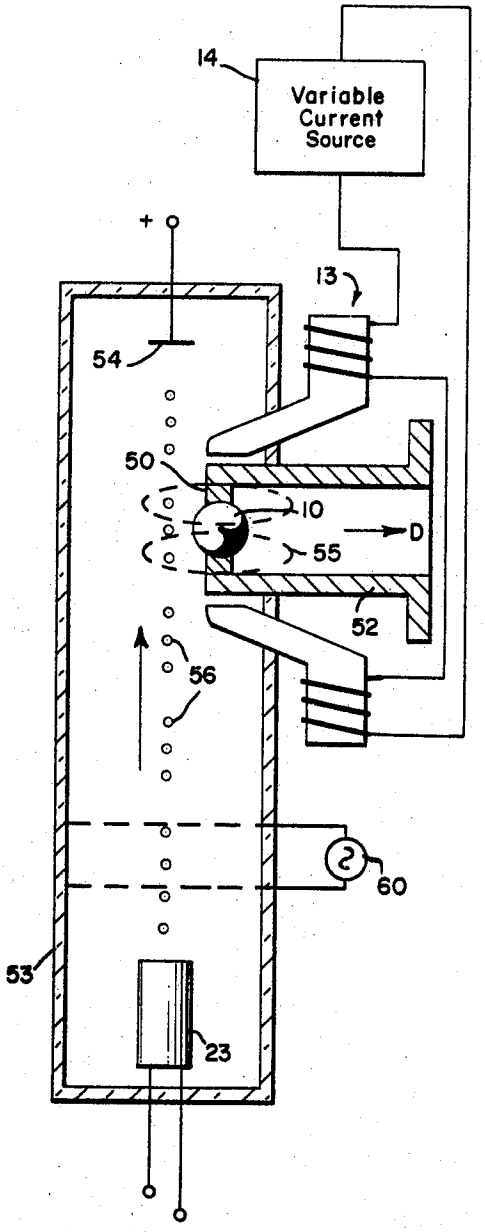


Dec. 30, 1969 I. KAUFMAN 3,487,336

FERRIMAGNETIC MICROWAVE GENERATOR OR AMPLIFIER

Filed Nov. 7, 1966 3 Sheets-Sheet 3

Fig. 6.



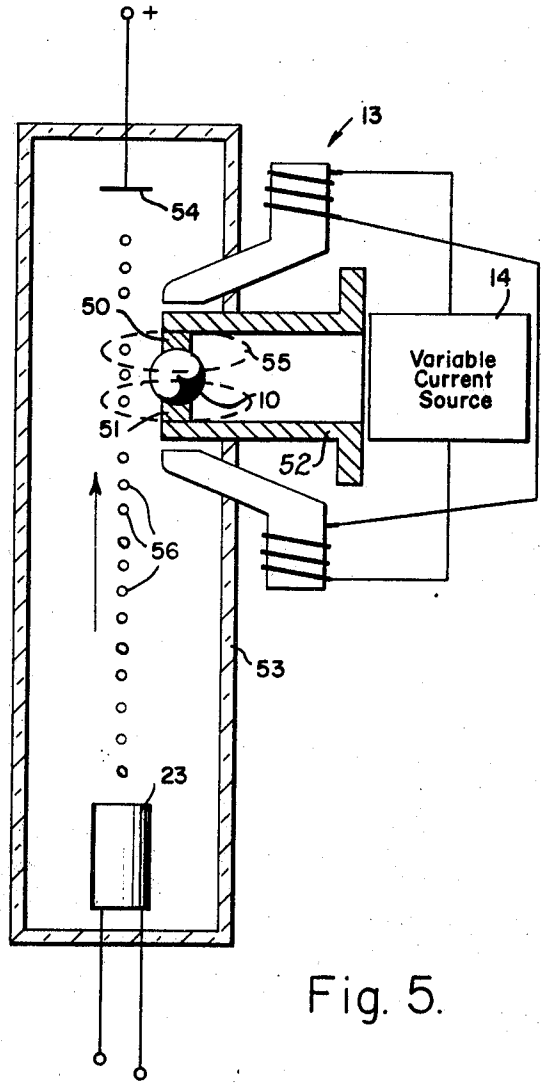


Fig. 5.

United States Patent Office 3,487,336
Patented Dec. 30, 1969

3,487,336

FERRIMAGNETIC MICROWAVE GENERATOR OR AMPLIFIER

Irving Kaufman, Tempe, Ariz., assignor to TRW Inc., Redondo Beach, Calif., a corporation of Ohio

Filed Nov. 7, 1966, Ser. No. 592,453
Int. Cl. H03c 1/28, 3/30
U.S. Cl. 332—7 11 Claims

ABSTRACT OF THE DISCLOSURE

A microwave generator or amplifier making use of ferrimagnetic resonance. The generator includes a ferrite element which may be a sphere or a disc exhibiting ferrimagnetic resonance. An electron beam is generated and is disposed adjacent to the ferrite element to interact with the electric field which appears in the vicinity of the ferrite sphere. A magnetic field is provided which preferably extends in a direction parallel to the axis of the electron beam to excite the ferrite sphere into ferrimagnetic resonance. Since there is no resonant cavity the frequency of the electric oscillations generated by the interaction between the ferrite sphere and the beam is substantially linear with the strength of the magnetic field.

This invention relates to ferrimagnetic resonant devices in general, and more particularly to devices utilizing the interaction between a beam of electrons and the electric field of a ferrite material activated into a state of ferrimagnetic resonance.

In microwave oscillators such as klystrons, energy exchange between an electron beam and a resonant cavity cause oscillations in the electron beam. The frequency of oscillation is near the resonant frequency of the cavity. To change this frequency of operation over a wide band, it is necessary to alter the dimensions of the cavity mechanically.

In prior art methods for improving the tuning characteristics of microwave oscillators, ferrite-loaded cavities have been used. A ferrite element is placed in the cavity and its resonant frequency is varied by varying the magnetic field applied to the ferrite. A device of this type is disclosed in U.S. Patent No. 2,897,455 entitled, "Magnetically Tuned Klystron," by G. R. Jones et al.

In the devices of this invention a narrow-line width ferrimagnetic specimen, such as a polished sphere of single crystal Yttrium Iron Garent (YIG) is substituted for the cavity resonator in microwave oscillators. The resonant frequency of such a specimen is the frequency of its ferrimagnetic resonance and is determined by an applied D-C magnetic field. The resonant frequency of the YIG material can, therefore, be tuned with electronic devices quickly and efficiently over a much broader frequency range without physical changes in the cavity, as the frequency of operation is determined entirely by the ferrimagnetic specimen.

It is, therefore, an object of the present invention to provide new and novel microwave oscillators and amplifiers.

It is another object of this invention to provide an electronically tunable ferrite resonator.

It is another object of the invention to provide an improved microwave oscillator utilizing ferrite resonators.

In a typical embodiment of this invention, these objects are accomplished by exciting the ferrite material into ferromagnetic resonance at a desired frequency so as to produce an oscillating electric field which is interacted with an electron beam, with the electric field causing the electron beam to be velocity modulated.

These and other objects of the present invention will become more apparent when taken in conjunction with the following description and drawings in which:

FIGURE 1 illustrates one embodiment of the present invention;

FIGURE 2 is a cross-sectional view of the embodiment of FIGURE 1 taken along the section lines 2—2;

FIGURE 3 is a cross-sectional view of the second embodiment of this invention;

FIGURE 4 is a sectional view of the embodiment of FIGURE 3 taken along the section lines 4—4;

FIGURE 5 illustrates a third embodiment of the present invention; and

FIGURE 6 illustrates a fourth embodiment of the present invention.

Referring to the drawings, like numerals represent like parts throughout.

In FIGURES 1 and 2, a spherical ferrite resonator **10** is mounted by means of an insulator **11** within a cylinder of copper **12**. The resonator **10** may take other shapes such as that of a disc or ellipse and may be made from ferrite materials such as yttrium iron garnet.

Positioned so as to interact with the ferrite resonator **10**, exciting the resonator into ferrimagnetic resonance, is magnetic means **13**. Means **13** consists of permanent magnet pole pieces **15** and **16** around which coils **17** and **18**, respectively, are wound. Terminals A and C are electrically connected to coils **17** and **18**, respectively, and to a source of variable current **14**.

The fild strength of means **13** is varied by varying the current supplied to the coils **17** and **18**.

An electron beam is generated by the electron gun **23** which is supplied with power via leads **24** by means not shown but well known to those persons skilled in the art. A repeller plate **25** is positioned so as to intercept the beam of electrons from gun **23**. A negative voltage is applied to the repeller plate **25** via terminal B to repel the electron beam back toward the gun **23** in the standard reflex klystron action. The area surrounding the gun **23** and repeller **25** is maintained at a vacuum by the envelope **19** which may be glass, metal or plastic. Wave guide **20** is positioned opposite the ferrite resonator **10** to couple microwave energy from the resonator, through cavity opening **22**, and waveguide opening **21**, to be utilized in some microwave device such as a radar set. Window **26** is positioned in waveguide opening **21** to seal the opening so as to maintain the vacuum.

In operation the D-C field from means **13**, H_o, biases the ferrite resonator **10** into ferrimagnetic resonance. The frequency of resonance ω for a spherical ferrite resonator is defined by the equation:

$$\omega = H_o \gamma$$

where γ is the gyromagnetic ratio of the ferrite.

Due to the magnetic behavior of the resonator, a strong electric field appears in the immediate vicinity of the sphere. This electrical field is explained by the fact that in resonance a ferrite specimen is considered to be two oscillating magnetic dipoles of very strong dipole moment; since the natural resonance is a precession, which resolves into two magnetic dipoles that are space-wise orthogonal and 90° out of phase. An oscillating magnetic dipole corresponds to an oscillating current loop, which has electric field lines parallel to the loop.

The ferrite resonator **10** has an inherent resonant frequency "built in" by its geometry. With just a D-C biasing field applied to the ferrite resonator, no R.F. fields will be generated. But at any real temperature (i.e., above absolute zero), there are noise fields of finite amplitude. The electron beam from gun **23** can interact with these noise fields, through cavity opening **22**, deliver energy to them and therefore build up the R.F. electric and magnetic fields to large magnitudes. The interaction of the electric field with the beam velocity modulates the beam.

After the beam has traveled some distance past the opening **22**, the beam's velocity modulation is converted into density modulation. The density modulated beam is then returned to the vicinity of the opening **22** by means of the negative potential on the repeller plate **25**. If the electric field of the resonator **10** is in such a direction as to slow down a bunched group of returned electrons, energy will be transferred to the resonator **10** where it can be extracted by radiation through the waveguide opening **21**.

In practice the D-C magnetic field H_0 should be parallel to the electron beam as the magnetic field will tend to direct the beam from the gun **23** to the repeller **25**.

Gun **23** may be replaced by a field-emitting cathode device having a low temperature of operation so as to minimize temperature effects which may be coupled to the ferrite resonator.

To enhance the interaction between the electron beam and the ferrite resonator, the Q of the resonator should be as large as possible in order to create a large electric fields. In practice, since the Q of the ferrite is inversely proportional to the line width, a ferrite with a small line width like yttrium iron garnet should be used. The Q of the coupling means, on the other hand, should not be too high if wide band tuning is desired.

Referring to FIGURES 3 and 4, a plurality of ferrite resonators **10** are positioned circumferentially around the electron beam from gun **23** in a plane perpendicular to the beam path. Each of the resonators are mounted by means of insulators **11** within a copper cylinder like member **34**.

Positioned so as to interact with the ferrite resonator is electromagnetic means **13**. Means **13** consists of pole pieces **30** and **31** around which coils **32** and **33**, respectively, are wound. Terminals A and C may be connected to the source of variable current **14** shown in FIGURE 2. An insulator **36** passes through pole piece **30** and insulates the lead form repeller **25** to the terminal B from the pole piece.

The operation of the device of FIGURES 3 and 4 is identical to the operation of the device of FIGURES 1 and 2 but the power output of the device is higher because of the plurality of ferrite resonators.

In FIGURE 5, a vacuum envelope **53**, which may be glass, plastic or other similar material, houses an electron gun **23**, plate **54**, a ferrite resonator **10** which is mounted to the envelope **54** by means of insulator **51**. The means **13** provides the D-C field H_0, which interacts with the ferrite resonator **10**. A waveguide **52** couples the R'F' energy from the ferrite resonator to a utilization device not shown. In this embodiment an electron beam from the gun **23** is velocity modulated by interaction with the electric field of resonator **10**. Some of the electrons that pass through the R.F. fields in the immediate vicinity of the ferrite resonator **10** are accelerated by the field, others are decelerated. The latter have a longer time to interact with the field and the ferrite resonator receives more energy than it gives up. This is the energy that maintains the fields **55** in and around the ferrite resonator and that is supplied in the form of R.F. power to the output waveguide **52**.

The embodiment of FIGURE 6 includes a prebuncher **60**, which may be a conventional microwave cavity, or a second ferrite resonator. The velocity modulation impressed on the beam by this prebuncher turns into density modulation, as in the conventional two-cavity klystron. And as in that device, the interaction of the now bunched beam with the fields of the output resonator produces R.F. power of an intensity far greater than that required to bunch the electric beam; so the device is an amplifier. Again, as in that device, by feeding back from output to input resonator, the equivalent of a two-cavity klystron oscillator results. In practice, and to make use of the tunability of the ferrimagnetic device, it will generally be of advantage to use two ferrimagnetic resonators instead of one conventional cavity resonator followed by a ferrimagnetic resonator.

The velocity modulation of the electron beam in this embodiment is coupled via the ferrite resonator through the waveguide **52** along the path designated D. The waveguide **52** may be a circular guide operated in the TM_{01} mode.

What is claimed is:

1. A ferrimagnetic microwave generator or amplifier comprising:

means for generating an electron beam;

a ferrite element exhibitng ferrimagnetic resonance disposed adjacent to said beam; and

means for generating a magnetic field for biasing said ferrite element, whereby said ferrite element interacts with said electron beam and solely determines the frequency of an oscillating electric field set up by the interaction of said element with said beam, there being a linear relationship between said frequency and the magnitude of said magnetic field, and said oscillating electric field interacting with said beam to modulate the velocity thereof.

2. A microwave generator or amplifier as defined in claim **1** wherein said means for generating a magnetic field includes a permanent magnet and an electromagnet for developing a magnetic field interacting with said ferrite element, and a variable current source for providing said electromagnet with a controlled electric current, thereby to control the strength of said magnetic field.

3. A microwave generator or amplifier as defined in claim **1** wherein said magnetic field is disposed substantially parallel to the axle of said electron beam.

4. A microwave generator or amplifier as defined in claim **1** wherein said means for generating an electron beam includes a field emission device.

5. A microwave generator or amplifier as defined in claim **1** wherein said ferrite element consists of a single crystal.

6. A microwave generator or amplifier wherein said ferrite element consists of a disc of yttrium iron garnet.

7. A microwave generator or amplifier wherein said ferrite element consists of a disc of yttrium iron garnet.

8. A microwave generator or amplifier as defined in claim **1** wherein a repeller is positioned in the path of the velocity modulated electron beam, thereby to return said electron beam to again interact with said oscillating electric field to couple again energy to said ferrite element, and means positioned adjacent said ferrite element for receiving said coupled energy.

9. A ferrimagnetic microwave generator or amplifier comprising:

means for generating an electron beam;

a plurality of ferrite elements, each exhibiting ferrimagnetic resonance and each being disposed adjacent to said beam; and

means for generating a magnetic field extending through and for biasing said ferrite elements, whereby said ferrite elements interact with said electron beam to set up an oscillating electric field, there being a linear relationship between the frequency of said oscillating field and the magnitude of said magnetic field, said frequency being determined solely by the ferrimagnetic resonance of said ferrite element and by the magnitude of said magnetic field, and said oscillating electric field modulating the velocity of said electron beam.

10. A microwave generator or amplifier as defined in claim **9**, wherein said ferrite elements are positioned circumferentially about and in any plane perpendicular to the axis of said electron beam, thereby to excite said ferrite elements into ferrimagnetic resonance, and a repeller positioned in the path of said electron beam to return said beam to interact again with said oscillating electric field.

11. A microwave generator or ampilfier as defined in claim **9** wherein each of said ferrite elements is composed of a single crystal ferrite.

References Cited

UNITED STATES PATENTS

2,897,455	7/1959	Jones et al.	332—7
3,235,819	2/1966	Carvelas et al.	
3,353,118	11/1967	Olson et al.	332—51 X

OTHER REFERENCES

Cacheris et al.: "Magnetic Tuning of Klystron Cavities"—I.R.E. Proceedings, p.1017.

ALFRED L. BRODY, Primary Examiner

U.S. Cl. X.R.

315—5.18, 3; 332—51; 333—24