May 10, 1960 L. J. LADER 2,936,369

FERRITE MICROWAVE MIXER

Filed Aug. 15, 1958 2 Sheets-Sheet 1

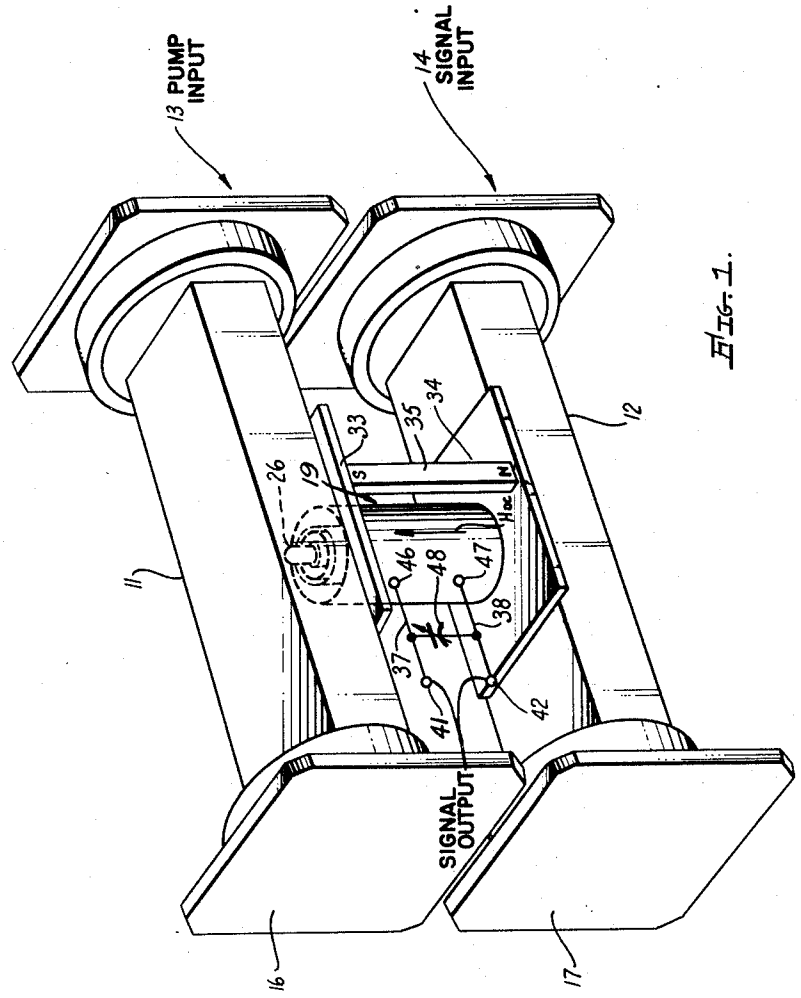


FIG. 1.

INVENTOR,
LEON J. LADER
BY Robert H. Clay
ATTORNEY

May 10, 1960 L. J. LADER 2,936,369

FERRITE MICROWAVE MIXER

Filed Aug. 15, 1958 2 Sheets-Sheet 2

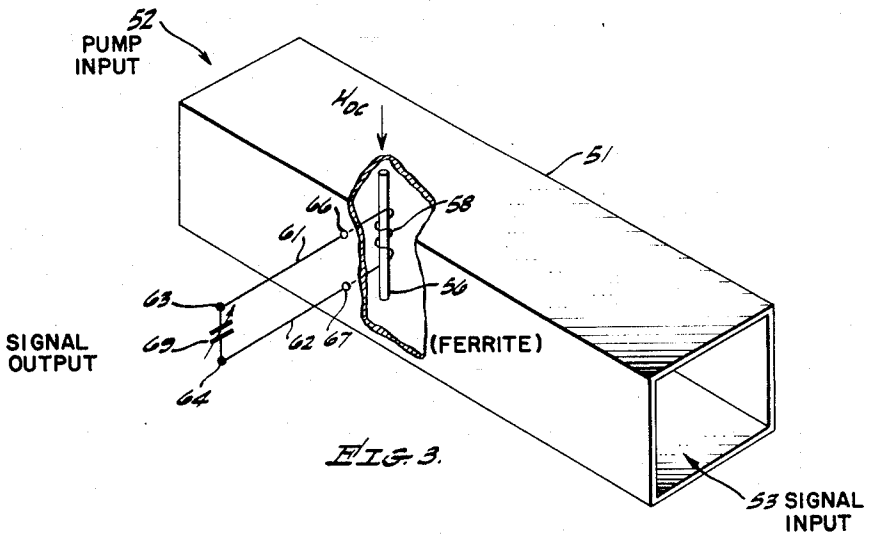


FIG. 3.

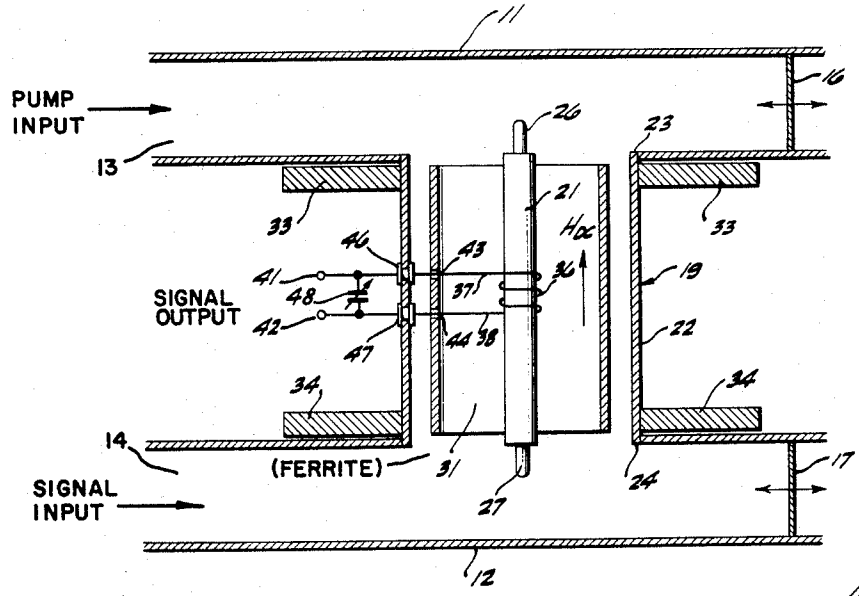


FIG. 2.

INVENTOR.
LEON J. LADER.
BY
Robert N. Clay
ATTORNEY.

United States Patent Office 2,936,369
Patented May 10, 1960

2,936,369

FERRITE MICROWAVE MIXER

Leon J. Lader, Los Angeles, Calif., assignor to Hughes Aircraft Company, Culver City, Calif., a corporation of Delaware

Application August 15, 1958, Serial No. 756,061

12 Claims. (Cl. 250—20)

The present invention relates to a microwave frequency mixer and more particularly to a ferrite microwave mixer of two signals having different frequencies for obtaining a signal with a substantially low difference frequency.

Frequency mixing is generally accomplished by crystals or vacuum diodes. The diodes have never proven satisfactory at microwave frequencies and so crystals have been depended upon for such function. Where replacement of crystals is not practical as in airborne equipment, it has been found that a more reliable device is required because crystals are frequently subject to deterioration or burnout when a small excess of power occurs. Further, elaborate systems and additional devices are frequently required to protect the crystals during operation of the equipment.

With the knowledge that has been obtained in recent years with respect to the characteristics of gyromagnetic materials at the frequency of microwave energy, many new components have been developed to simplify microwave systems and at the same time increase operational reliability thereof. There has now been developed a ferrite microwave frequency mixer that, in general, comprises a coaxial section of transmission line having a suitably magnetized ferrite cylinder coaxially mounted therein with a pickup coil wound about the center conductor or the ferrite cylinder. Microwave energy is electromagnetically coupled into the coaxial section at two different frequencies and is concentrated in the ferrite cylinder where signals at the sum and difference frequencies are developed. A signal at the difference frequency is then induced in the pickup coil and suitably and selectively coupled out for use externally of the mixer device.

It is, therefore, an object to provide a new and improved frequency mixer for microwave energies.

Another object is to provide a system for mixing microwaves in the ferrite medium to produce a useable frequency translation of the input signals.

A further object is to provide concentration of microwave fields in a ferrite element to minimize power requirements for producing frequency translations.

A still further object is to provide a ferrite microwave filter for producing a difference frequency suitable for use as an intermediate frequency in microwave systems.

A still further object is to provide a ferrite loaded microwave device for frequency mixing or amplification depending upon the relative arrangement of the inputs and the values thereof.

Other objects and advantages of the invention will be apparent in the following description and claims considered together with the accompanying drawing, in which:

Figure 1 is a perspective view of a ferrite microwave mixer;

Figure 2 is a schematic view in section of the frequency translation section of Figure 1; and

Figure 3 is a schematic perspective view of a traveling wave embodiment of the invention of Figure 1.

Referring to Figure 1 in detail there is illustrated in

perspective a pair of rectangular input waveguides **11** and **12**, each respectively having an input port **13**, **14** at one end and a conventional adjustable short **16** and **17** at the other end. The two waveguides **11** and **12** are mounted in parallel relation with suitable brackets (not shown) to maintain such relationship and with a translation section **19** disposed intermediately and transversely between the waveguides.

As shown in Figure 2, the translation section **19** comprises a coaxial section of transmission line having a center conductor **21** and an outer conductor **22** with the ends of the latter respectively inserted into matching apertures **23** and **24** of waveguides **11** and **12**. Conventional adjustable coupling probes **26** and **27** are respectively mounted at either end of the center conductor **21** to extend into the waveguides **11** and **12**. Thus, as microwave energy is propagated through waveguides **11** and **12** in, for example, the dominant TE_{01} mode, the probes **26** and **27** electromagnetically couple to the electric fields of the modes and are excited thereby so that the amount of energy coupled is transmitted within translation section **19** in the dominant TEM mode. The adjustable shorts **16** and **17** are provided to minimize reflections and the voltage standing wave ratio of the waveguides **11** and **12**.

For frequency translation in the coaxial section **19** a hollow cylinder **31** of gyromagnetic material, such as ferrite, is suitably mounted coaxially within the section and the magnetic fields of the two energies electromagnetically coupled into the section, extend circumferentially through the cylinder. Two magnetic pole pieces **33** and **34** are respectively mounted about the coaxial section **19** at the ends thereof and a conventional static magnetic field establishing device such as a permanent magnet **35** or an electromagnet is mounted in contact with the pole pieces. In accordance with the invention the static magnetic field, indicated by an arrow labled H_{DC}, extends parallel to the longitudinal axis of the cylinder **31** and is established at a value producing gyromagnetic resonance at the higher frequency of the two energies.

Under the foregoing conditions the magnetic field vectors associated with the microwave energies within the ferrite cylinder **31** of the coaxial section **19** are perpendicular with respect to the static magnetic field vector so that precessional resonance occurs in the ferrite about the higher frequency and, because of the nonlinear characteristics of the ferrite, precessional instabilities occur about the sum and difference frequencies of the two energies. Now, it is well known that where magnetic field vectors of microwave energy are perpendicular to a static magnetic field vector in gyromagnetic material, energy is coupled from the microwave energy into modes orthogonal to the microwave magnetic field vectors. Thus, there are developed magnetic field components at the sum and difference frequencies of the two microwave energies and such components are along the direction of the static magnetic field.

To couple to the fields associated with the sum and difference frequencies within the coaxial section **19**, a pickup coil **36** is, as illustrated, suitably wound on the center conductor **21** and two leads **37** and **38** thereof are respectively extended to terminals **41** and **42** through apertures **43** and **44** of cylinder **41** and through conventional insulators **46** and **47** suitably mounted through the outer conductor **22**. It will be readily apparent that pickup coil **36** may be readily wound on the ferrite cylinder **31** where closer inductive coupling is desired. A tuning capacitor **48** is connected between the two terminals **41** and **42** to provide a resonant circuit with the inductance of coil **36** for limiting signals induced in pickup coil **36** to a single frequency at such terminals.

In operation port **13** is coupled to a source of microwave energy (not shown), which will be referenced for

convenience as a pump signal having a value of angular frequency denoted by the symbol ω_p. Similarly, port **14** is coupled to a source of microwave energy (not shown), which will be referenced merely as a signal and denoted by the angular frequency symbol ω_s. The two microwave energies are respectively propagated by waveguides **11** and **12** in the dominant TE_{01} mode. Probes **26** and **27** then electromagnetically couple to the respective electric fields of waveguides **11** and **12** to excite TEM modes in coaxial translation section **19**.

The magnetic fields of the two TEM modes extend circumferentially and are concentrated in ferrite cylinder **31** transverse to the direction of the static magnetic field H_{DC}. Energy is then coupled or translated by the ferrite material into orthogonal modes along the direction of the static magnetic field to magnetically link pickup coil **36**. An output signal is then induced in the coil **36** and connected to terminals **41** and **42**. The foregoing operation is dependent upon the value of the static magnetic field being established to provide gyromagnetic resonance or precessional resonance at the frequency ω_p of the pump signal.

In the foregoing the device of the present invention has been set forth as a frequency mixer and in this respect is defined by an output having an angular frequency ω_0 that has a substantially low value with respect to that of the pump signal ω_p. For example, where an output having a frequency of 30 mc. per second is desired and the signal frequency is 4500 mc. per second as applied to port **14**, then the frequency of the pump signal is established at 4530 mc. per second. The capacitor **48** is adjusted to resonate with the inductance of pickup coil **36** at 30 mc. per second to eliminate the sum frequency of 9030 mc. per second.

In addition to providing a microwave frequency mixing operation, two other conditions of operation exist. One occurs when a high frequency pump signal is applied as before and a low frequency signal is applied as an input to terminals **41** and **42**. In this instance, the magnetic field vector of the pump signal ω_p is transverse to the direction of the static magnetic field and the magnetic field of the low frequency signal ω_0 is along the direction of the static magnetic field. The result is a translation of energy by the ferrite material of cylinder **31** from that of the pump signal ω_p to a signal having a frequency ω_s which is the sum frequency of the two input signals.

The other condition occurs when a high frequency pump signal ω_p is again applied in the same manner and the signal ω_s of waveguide **12** has the same frequency as that of the output ω_0. The same magnetic field relationships exist and amplification of the signal ω_s occurs by energy coupling from the pump signal ω_p by the ferrite material. Because of the higher frequency of the signal under this condition of operation, the output must be electromagnetically coupled through a coaxial line.

By the concentration of the pumping power field in the ferrite material of cylinder **31** as provided by the structure set forth, the required power to produce the necessary non-linearities in the ferrite material for frequency translations and amplification is minimized. Also, it has been found in practice that the device is not subject to deterioration or burnout at substantial values of signal power and can actually withstand short duration pulses in the kilowatt range.

While the structure has been described as having two rectangular waveguides **11** and **12** coupled to the coaxial section **19** at opposite sides thereof, it will be apparent that coaxial lines could be readily used in place of the waveguides with suitable modification with respect to the probes **26** and **27**. Also the two energies may be coupled by a single waveguide at one end of the coaxial section with a suitable termination provided at the other end.

Substantially the same operation, based upon the same principles as set forth in the foregoing for the device of Figures 1 and 2, can be obtained from a traveling wave structure as illustrated in Figure 3. Thus, in the perspective view of the latter figure, there is shown a section of rectangular waveguide **51** having respective input ports **52** and **53** at either end. Such waveguide **51** is dimensioned to propagate microwave energies of two different frequencies in the same type of mode, which have magnetic fields polarized along planes parallel to the broad walls of the waveguide.

Frequency translation is accomplished within the waveguide by a cylindrical post **56** of gyromagnetic material, such as ferrite, suitably mounted transversely between the broad walls. A static magnetic field, indicated by an arrow H_{DC}, is established by conventional structure (not shown) to extend along the longitudinal axis of the post **56** with a value resulting in gyromagnetic resonance in the ferrite material at the higher frequency of the two energies.

The energy at the resultant translated frequency is picked up by an induction coil **58** wound about the ferrite post **56**. Two leads **61** and **62** of the coil **58** are respectively extended to external terminals **63** and **64** through suitable side wall apertures **66** and **67**. To eliminate undesired frequency components at terminals **63** and **64** a variable tuning capacitor **69** is connected between such terminals to form a resonant circuit with the inductance of coil **58**.

As previously stated, operation of the embodiment of Figure 3 is substantially the same as set forth for the device of Figure 1. Thus, with port **52** coupled to a conventional high frequency source (not shown) and port **53** coupled to a conventional lower frequency source (not shown), two waves of energy are propagated by the waveguide. Both of the waves have the same mode, such as the TE_{01}, with plane polarized magnetic fields parallel to the broad walls. At the ferrite post **56**, which is not critical with respect to location in the waveguide **51**, the components of the magnetic fields of both modes are transverse to the longitudinal axis of the post **58** and, therefore, to the static magnetic field H_{DC}. Gyromagnetic precession then occurs and energy is coupled to orthogonal modes at the sum and difference frequencies. The magnetic fields of these orthogonal modes than link pickup coil **58** to induce signals and, by suitable control of tuning capacitor **69**, a signal at a single frequency is developed between terminals **63** and **64**. The several operating conditions set forth with respect to the embodiment of Figures 1 and 2 are equally applicable to the present embodiment for frequency translations and also for amplification.

Thus, there have been described two ferrite microwave devices which operate in substantially the same manner, but differ substantially in structure, to accomplish the objects and advantages of the invention as set forth. While the salient features of the invention have been described in detail with respect to such devices, it will be readily apparent that many modifications may be made within the spirit and scope of the invention and it is, therefore, not desired to limit the invention to the exact details except insofar as they may be defined in the following claims.

What is claimed is:

1. A microwave device comprising structure for supporting electromagnetic energy of two different frequencies in similar modes having parallel magnetic field components, an element of gyromagnetic material mounted in said structure and extended transverse to said magnetic field components whereby such components are concentrated in said material, means for establishing a static magnetic field through said material transverse to said magnetic field components at a value producing gyromagnetic resonance at the higher frequency of energy whereby energy is coupled by said material into modes at the sum and difference frequencies orthogonal to

said similar modes, and means electromagnetically coupled to fields of said sum and difference frequencies with tuning means included for selecting a signal at one such frequency.

2. A microwave device comprising structure for supporting electromagnetic energy of two different frequencies in similar modes having parallel magnetic field components, a ferrite element mounted in said structure and having an axis disposed transverse to said magnetic field components, means for establishing a static magnetic field axially through said ferrite element of a value producing gyromagnetic resonance at the higher frequency of energy whereby energy is coupled by said ferrite element into modes at the sum and difference frequencies orthogonal to said similar modes, a pick-up coil having its longitudinal axis mounted along the axis of said ferrite element within said structure, and a tuning capacitor connected in parallel with said coil for selecting a signal at one of said sum and difference frequencies.

3. A ferrite microwave device comprising structure for supporting electromagnetic energy of two different frequencies, microwave energy propagating means coupled to said structure for exciting two similar modes having parallel magnetic field components at said two different frequencies, a ferrite element mounted in said structure and having an axis disposed transverse to said magnetic field components, means for establishing a static magnetic field axially through said ferrite element of a value producing gyromagnetic resonance at the higher frequency of energy whereby energy is coupled by said ferrite element into modes at the sum and difference frequencies orthogonal to said similar modes, a pick-up coil mounted with its axis along the axis of said ferrite element within said structure, and a tuning capacitor connected in parallel with said coil to provide a circuit resonant at one of said frequencies for eliminating all but said one frequency.

4. A microwave device comprising structure for supporting electromagnetic energy of two different frequencies in similar modes having parallel magnetic field components, a hollow cylinder of gyromagnetic material having a longitudinal axis mounted transverse to said magnetic field components within said structure, means for establishing a static magnetic field axially through said material at a value producing gyromagnetic resonance at the higher frequency of energy whereby energy is coupled into modes orthogonal to said similar modes, and means electromagnetically coupled to said orthogonal modes for providing an output.

5. A microwave device comprising structure for supporting energy of two different frequencies in similar modes having parallel magnetic field components coaxial with respect to an elongated conductor within said structure, a hollow cylinder of gyromagnetic material mounted in said structure and having a longitudinal axis disposed along the axis of said conductor whereby said magnetic field components are concentrated in said material, means for establishing a static magnetic field axially through said material to produce gyromagnetic resonance at the higher frequency of energy whereby energy is coupled into modes orthogonal to said similar modes, and a pick-up coil wound on said conductor whereby said orthogonal modes link said coil to induce an output voltage.

6. A ferrite microwave device comprising a coaxial section having a center conductor and outer conductor for supporting energy of two different frequencies in similar modes having parallel magnetic field components coaxial with respect to said center conductor, a ferrite cylinder mounted in said section coaxially with respect to said center conductor whereby said magnetic field components are concentrated therein, means for establishing a static magnetic field through said ferrite cylinder parallel to the axis thereof at a value to produce gyromagnetic resonance at the higher frequency of energy whereby energy is coupled into modes orthogonal to said similar modes, a coil wound on said center conductor whereby said orthogonal modes link said coil to induce voltages, and a tuning capacitor connected in parallel with said coil to provide a resonant circuit at one frequency of induced voltage.

7. A ferrite microwave device comprising a coaxial section having a center conductor and outer conductor for supporting energy of two different frequencies, microwave energy propagating means coupled to said structure for exciting two similar modes having parallel magnetic field components at said two different frequencies, a ferrite cylinder mounted in said section coaxially with respect to said center section whereby said magnetic field components are concentrated therein, means for establishing a static magnetic field through said ferrite cylinder parallel to the axis thereof at a value producing gyromagnetic resonance at the higher frequency of energy whereby energy is coupled into modes orthogonal to said similar modes, a pick-up coil wound on said center conductor whereby said orthogonal modes link said coil to induce voltages, and a tuning capacitor connected in parallel with said coil to provide resonance with the inductance of said coil at the frequency of one of said induced voltages.

8. A ferrite microwave device comprising a first rectangular waveguide for propagating energy in a plane polarized mode at a selected frequency, a second rectangular waveguide for propagating energy in a plane polarized mode at a lower frequency than said selected frequency, said first and second waveguides mounted with respective broad walls in parallel relation, a section of coaxial line having a center conductor and outer conductor mounted transversely between adjacent broad walls of said waveguides with adjustable coupling probes respectively extended from the ends of said center conducter into said waveguides whereby said center section is excited in two similar modes having parallel magnetic field components at said different frequencies, a ferrite cylinder mounted in said section coaxially with respect to said center conductor whereby said magnetic field components are concentrated therein, means for establishing a static magnetic field through said ferrite cylinder parallel to the axis thereof at a value producing gyromagnetic resonance at said selected frequency whereby energy is coupled into modes orthogonal to said similar modes at sum and difference frequencies, a pick-up coil wound on said center conductor and having leads extended through said cylinder and outer conductor whereby said orthogonal modes link said coil to induce voltages at said sum and difference frequencies, and a tuning capacitor connected between said leads to provide resonance with the inductance of said coil at the frequency of one of said sum and difference frequencies.

9. A microwave device comprising structure for supporting electromagnetic energy in two similar plane polarized modes having parallel magnetic field components and different frequencies, a gyromagnetic element mounted within said structure and having a longitudinal axis transverse to said magnetic field components, means for establishing a static magnetic field axially through said element at a value producing gyromagnetic resonance at the higher frequency of said energies whereby energy is translated to modes orthogonal to said similar modes, and means electromagnetically coupled to said orthogonal modes for deriving an output.

10. A microwave device comprising a section of rectangular waveguide for propagating energy in two similar plane polarizing modes having parallel magnetic field components at two different frequencies, a gyromagnetic element mounted within said waveguide with an axis transverse to the broad walls and to said magnetic field components, means for establishing a static magnetic field axially through said element at a value producing gyromagnetic resonance at the higher frequency of said energies whereby energy is translated to modes orthog-

onal to said similar modes, and means electromagnetically coupled to said orthogonal modes for deriving an output.

11. A ferrite microwave device comprising a section of rectangular waveguide for propagating energy in two similar modes having parallel magnetic field components parallel to the broad walls of said waveguide at two different frequencies, a ferrite post mounted in said waveguide with an axis disposed transversely of the broad walls, means for establishing a static magnetic field through said post along said axis at a value producing gyromagnetic resonance at the higher frequency of energy whereby energy is translated to modes orthogonal to said similar modes, and means electromagnetically coupled to said orthogonal modes for deriving an output.

12. A ferrite microwave device comprising a section of rectangular waveguide for propagating energy in two similar plane polarized modes having parallel components of magnetic field parallel to the broad walls of

said waveguide at two different frequencies, a cylindrical ferrite post mounted in said waveguide with an axis disposed transversely of the broad walls, means for establishing a static magnet field through said post along the axis at a value producing gyromatic resonance at the higher frequency of energy whereby energy is translated to modes orthogonal to said similar modes, a pick up coil wound on said post whereby said orthogonal modes link said coil to induce voltages with leads extended through apertures in said waveguide, and tuning capacitor connected between said leads to provide a circuit resonant only to one of said induced voltages.

References Cited in the file of this patent

UNITED STATES PATENTS

2,802,183 Read ---------- Aug. 6, 1957

FOREIGN PATENTS

777,341 Great Britain ---------- June 19,1957

Disclaimer

2,936,369.—*Leon J. Lader*, Los Angeles, Calif. FERRITE MICROWAVE MIXER. Patent dated May 10, 1960. Disclaimer filed June 30, 1961, by the assignee, *Hughes Aircraft Company*.

Hereby enters this disclaimer to claims 1, 9, and 10 of said patent.

[*Official Gazette August 15, 1961.*]

Disclaimer

2,936,369.—*Leon J. Lader*, Los Angeles, Calif. FERRITE MICROWAVE MIXER. Patent dated May 10, 1960. Disclaimer filed June 30, 1961, by the assignee, *Hughes Aircraft Company*.

Hereby enters this disclaimer to claims 1, 9, and 10 of said patent.

[*Official Gazette August 15, 1961.*]