324-77

SEARCH ROOM

Sept. 29, 1959 A. D. WHITE ET AL 2,906,954

NON-SCANNING FREQUENCY ANALYZER

Filed Aug. 22, 1955 2 Sheets-Sheet 1

Fig. 1

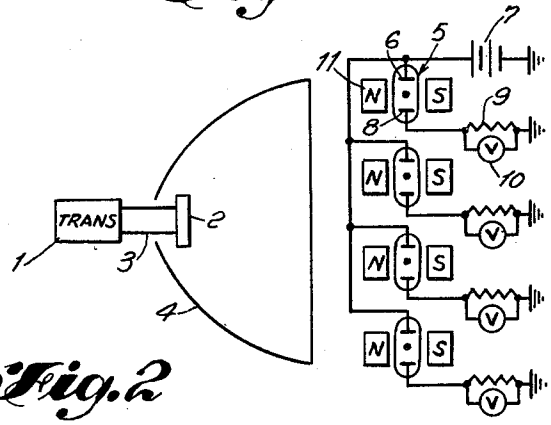


Fig. 2

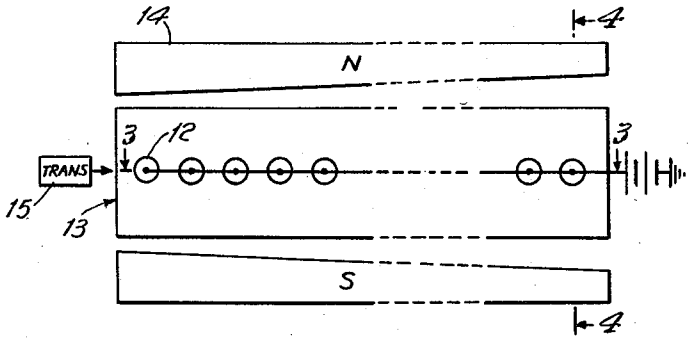


Fig. 4

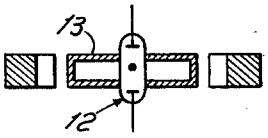


Fig. 3

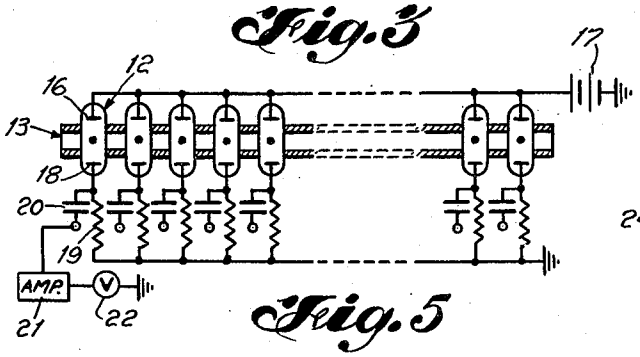


Fig. 6

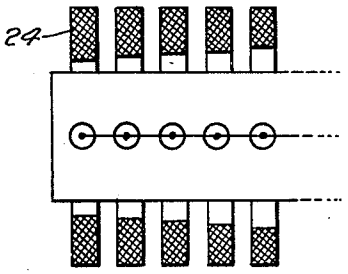
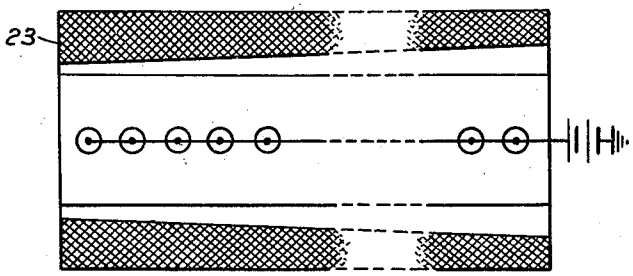


Fig. 5



INVENTORS
ALAN D. WHITE
JOHN F. HENEY
BY Henry Kolin
AGENT

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Fig. 7

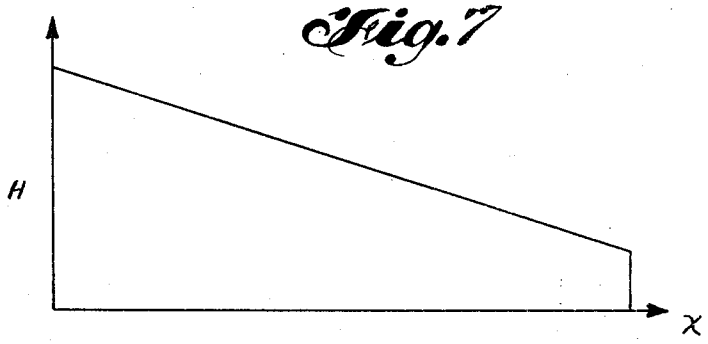


Fig. 8

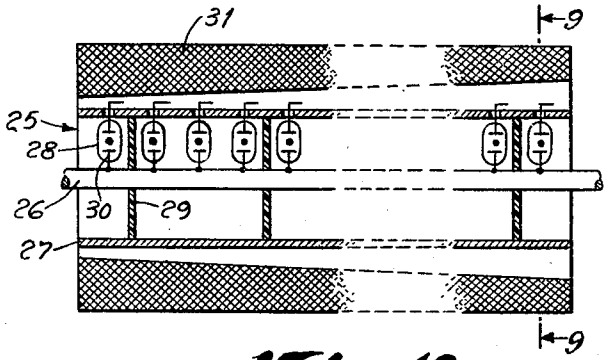


Fig. 9

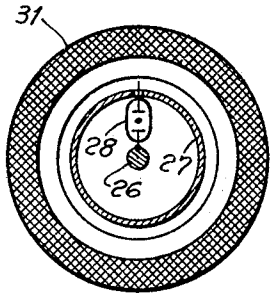
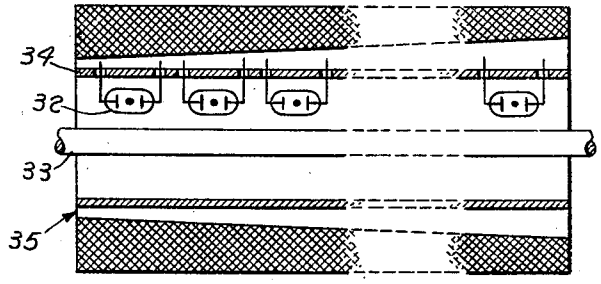


Fig. 10



INVENTORS
ALAN D. WHITE
JOHN F. HENEY
BY Henry Kolin
AGENT

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NON-SCANNING FREQUENCY ANALYZER

Alan D. White, Plainfield, and John F. Heney, Bloomfield, N.J., assignors to International Telephone and Telegraph Corporation, Nutley, N.J., a corporation of Maryland

Application August 22, 1955, Serial No. 529,648

9 Claims. (Cl. 324—77)

This invention relates to electromagnetic wave frequency analyzers and more particularly to a non-scanning analyzer utilizing the selective electromagnetic wave absorption of a gas discharge plasma immersed in a gyroresonant magnetic field.

One of the problems frequently encountered in the microwave field is the determination of the frequency of a propagated electromagnetic wave. Several devices are known for accomplishing this, both of the scanning and non-scanning types. Thus in United States Patent No. 2,704,325, a frequency scanning panoramic receiver system is used. In general, scanning devices of the mechanical or electronic type are relatively slow, i.e., non-instantaneous, and may miss a short pulse of a given frequency if that frequency is not being scanned at the time of transmission of the pulse. An instantaneous, non-scanning frequency analyzer is shown in United States Patent No. 2,598,301. In the device shown, a cyclotron effect is utilized as a frequency indicator. Such devices must be made with extreme precision, and electron beam focusing problems are always present.

In the present invention, a simple, instantaneous non-scanning analyzer is obtained by utilizing the phenomenon of absorption of energy by an electron gas plasma in a magnetic field at the gyromagnetic resonant frequency. In a gas discharge device, this absorption of energy will occur at a given frequency, the amount of absorption being a function of the electron density present and the incidence of electron collision occurring in the gas; the frequency is determined by the intensity of the magnetic field in which the gas plasma is immersed. By providing magnetic fields of different intensities immersing different ionized gaseous bodies, a different gyromagnetic resonant frequency will be obtained for each gaseous body.

It is an object of the present invention to provide a simple non-scanning frequency analyzer utilizable over a broad band of frequencies.

It is a further object to provide such a non-scanning analyzer readily adaptable for use in coaxial transmission lines and uniconductor waveguide devices.

It is still a further object to provide a non-scanning frequency analyzer wherein the frequency of the electromagnetic wave energy is determined non-destructively, i.e., without appreciably affecting the transmission of the energy.

It is a feature of this invention that a non-scanning electromagnetic wave frequency analyzer is provided wherein a plurality of bodies of ionized gaseous media are each maintained at a different gyromagnetic frequency, and means are provided to indicate which particular body of gaseous plasma is at the frequency of gyromagnetic resonance.

It is a further feature of this invention that a tapered magnetic field having a uniform gradient is maintained about a waveguide structure containing a plurality of gas discharge devices so as to provide a different field intensity for each gas discharge device.

The above-mentioned and other features and objects

of this invention and the manner of attaining them will become more apparent by reference to the following description taken in conjunction with the accompanying drawings, wherein:

Fig. 1 is a schematic view of one embodiment of a non-scanning electromagnetic wave frequency analyzer wherein the electromagnetic wave energy is radiated in the direction of a plurality of intercepting gas discharge devices;

Fig. 2 is a top plan view of gas discharge tubes in a rectangular waveguide maintained in the tapered magnetic field of a permanent magnet;

Fig. 3 is a front elevational view of the device shown in Fig. 2;

Fig. 4 is an end elevational view of the device shown in Fig. 2 taken along the lines 4—4 of Fig. 2;

Fig. 5 is a top plan view of gas discharge devices in a waveguide maintained in the tapered magnetic field of a solenoid coil;

Fig. 6 is a front elevational view of gas discharge tubes in a waveguide, each tube being immersed in a individual magnetic field;

Fig. 7 is a graphical depiction of the variation of the magnetic intensity of the tapered magnetic field with respect to the distance along the axis of the transmission line;

Fig. 8 is a sectional view partly in elevation of gas discharge tubes in a coaxial transmission line;

Fig. 9 is an end view of the device shown in Fig. 8 taken along the lines 9—9 of Fig. 8; and

Fig. 10 is a sectional view partly in elevation of another embodiment of gas discharge tubes in a coaxial transmission line.

In the embodiments hereinafter to be described, there has been provided a plurality of gas discharge devices each resonant at a different gyromagnetic frequency. This frequency is substantially determined by the intensity of the magnetic field. Any electromagnetic wave energy having an electric field distribution substantially at right angles to the magnetic field may be utilized in the practice of this invention. Although for various applications certain embodiments may be preferred, this invention may be practiced in both guided and unguided transmission systems. The term waveguide as used herein refers to waveguiding systems and is considered as including, in addition to uniconductor waveguides, such as hollow pipe rectangular waveguides, coaxial transmission lines and strip lines of the microstrip type. The use of gas discharge devices with waveguides of the microstrip type is illustrated in the copending application of M. Arditi, Serial No. 461,390, filed October 11, 1954 and assigned to the International Telephone and Telegraph Corporation which matured into Patent No. 2,760,163.

By the term "gyroresonant or gyromagnetic resonant region," reference is made herein to that state or region wherein the gyromagnetic frequency of electrons produced in the gaseous medium contained in the magnetic field is approximately equal to the frequency of the electromagnetic waves propagated through the gaseous medium. This region varies in width, i.e., broadbandedness, in accordance with the electron density and the electron collision frequency in the gas.

In Fig. 1 is shown a system embodying transmitting apparatus comprising any suitable transmitter source 1 of high frequency oscillations, such as a magnetron oscillator, which is connected to a radiator 2, such as a dipole antenna, through a transmission line 3. A reflector 4 is provided for concentrating the energy radiated from the dipole antenna 2 as a beam. The reflector 4 is preferably of a parabolic type, the dipole antenna 2 being located at or near the focal point of the reflector. Such a type of apparatus can transmit a radio beam which

is plane polarized, the plane of electric polarization being in a plane determined by the axis of the reflector and the antenna. Disposed about the reflector within the beam so as to receive the radiated energy, is a plurality of gas discharge devices **5** preferably having their anodes **6** connected to a common source of voltage **7**, the cathodes thereof **8** being connected to an appropriate resistor **9** thence to ground. It is of course immaterial as to whether the anodes or cathodes are directly connected to the voltage source **7**. Voltage indicating means **10** is used to indicate the change in voltage across the resistor **9**. The gas discharge tubes **5** are immersed each in a magnetic field of different intensity. These fields are provided by a plurality of individual permanent magnets **11** such that each tube by being immersed in a magnetic field of different intensity is thereby rendered resonant at a different gyromagnetic frequency. Thus upon radiation of electromagnetic wave energy of a given frequency, one such tube, namely that having a gyromagnetic resonant frequency corresponding to the radiated frequency, will absorb the energy. The absorbing tube is indicated by the change occurring in the display system.

In Fig. 2 is shown a top plan view of a plurality of gas discharge devices **12** arranged passing through the broad face of a rectangular waveguide **13**. These tubes are immersed in a tapered magnetic field provided by a permanent magnet **14** having a trapezoidal-shaped longitudinal cross section. Thus, as illustrated, an electromagnetic wave entering the waveguide will pass from a region of high magnetic intensity to a region of lower magnetic intensity because of the tapered nature of the magnetic field provided by the shaped permanent magnet. By a tapered magnetic field or a uniform gradient magnetic field reference is made to a magnetic field that is constant in time but increases in intensity at successive points along the longitudinal axis of the waveguide. The absence of a magnetic field, i.e., a field having zero intensity, is not to be considered as a uniform gradient magnetic field.

A polarized wave will be launched by transmitter **15** of Fig. 2 through the rectangular waveguide in the direction shown. This waveguide is preferably responsive to only a single mode, such as the TE_{10} mode. The electromagnetic wave energy will be selectively absorbed by one of the gas discharge devices having a gyromagnetic frequency corresponding to that of the frequency of the launched wave. Indicating means are provided, as shown in Figs. 1 and 3 to determine which is the absorbing gas discharge device. Thereby, the frequency of the launced wave is readily determinable.

In Fig. 3 is shown a front elevational view of the embodiment of the non-scanning frequency analyzer illustrated in Fig. 2. As seen from this figure, each discharge tube **12** has its anode **16** connected to a common voltage source **17**. The cathode **18** of each discharge tube is connected through a series resistor **19** to a common voltage source **17** and also through a coupling capacitor **20** to a pulse amplifier **21** and thence to a non-swept display system **22**.

For purposes of illustration, and without being restricted thereto, the operation of the analyzer illustrated in Fig. 3 will be described. A microwave pulse of frequency W incident on the array of discharge tubes will traverse the waveguide, a small portion of the energy being absorbed by a tube located in the region of the tapered magnetic field wherein

$$W_o=\frac{e}{m}\times H$$

where e/m represents the ratio of charge to mass of the electron, W_o is the gyromagnetic resonant frequency, and H represents the intensity of the magnetic field. Inasmuch as for all practical purposes the ratio of e to m is substantially constant, the resonant frequency W_o is determined only by the value of H. By maintaining e/m constant, the gyromagnetic frequency is readily calculated from the following formula: $0.357\ W_o=H$, where W_o represents the gyromagnetic frequency in megacycles and H represents the magnetic field intensity in oersteds. For the air or vacuum case, H is essentially the same as the flux density B, expressed in gauss. Thus, as is apparent from the foregoing, where the frequency of the input signal source is the same as the gyromagnetic frequency, a condition of resonance will be established in the gas discharge plasma. As a result of the selective power absorption by the gas discharge plasma, the direct-current power input to the discharge, which is required to maintain the electron and ion density in the plasma against losses, undergoes a change. As a result, the direct voltage across resistor **19** changes during the radio-frequency pulse interval. This output pulse from the discharge tube is amplified and displayed on a non-swept display system **22** which may be calibrated to read frequency directly. An annular beam display tube may be used for this purpose. Where the incoming signal is not modulated, coupling capacitor **20** is eliminated and the change in voltage across resistor **19** is directly determined.

In Fig. 4 is shown an end elevational view of the device of Fig. 2. The gas discharge tube **12** is shown as occupying a substantial portion of the volume of the waveguide **13**. As shown in this figure, the direction of propagation of the radio-frequency energy and that of the magnetic field and of the electric field associated with the electromagnetic wave are all orthogonally related. For the purposes of this invention, it is only required that the electric field of the propagated electromagnetic wave and the magnetic field thereabout be in orthogonal relation. Thus the magnetic field may be transverse to or in substantially parallel alignment to the longitudinal axis of the waveguide.

In Fig. 5 is shown a gas discharge device similar to that shown in Fig. 2, identical numbers being used for similar components. In place of the permanent magnet **14** of Fig. 2, a solenoid **23** is used. This solenoid provides a uniform gradient magnetic field in which the depth of windings about the solenoid core increases uniformly along its longitudinal axis to present a conical cross section. Other types of windings may also be used to provide a uniform gradient magnetic field. As illustrated, the magnetic field is in a direction which is substantially parallel to the direction of propagation of the polarized electromagnetic wave. However, this magnetic field is still in orthogonal relation to the electric field associated with the electromagnetic wave. In Fig. 6 is shown a front elevational view of a device similar to that illustrated in Fig. 5 with similar components bearing identical numbers. However, individual solenoids **24** have been provided about each gas discharge tube in place of the shaped solenoid **23** of Fig. 5 which provides a tapered magnetic field. By provision of individual solenoids, different and highly specific discrete values of gyromagnetic resonant frequencies may be obtained within the waveguide structure for specialized applications instead of having a uniform gradient continuous magnetic field as provided in the device of Fig. 5.

In Fig. 7 is shown a schematic representation of the variation in the magnetic field intensity H along the longitudinal axis x of the transmission line. While a linear variation has been shown, such as readily given by the equation $H=-mx+b$, m and b being constants, other types of tapered fields such as those following a logarithmic, exponential or harmonic function may be employed.

In addition to the applicability of the non-scanning frequency analyzer for use with electromagnetic wave energy propagated in hollow-pipe and microstrip waveguide structures, this device may also be used in coaxial transmission lines. In Fig. 8 is shown a coaxial line **25** having an inner conductor **26** and an outer conductor **27**

in which gas discharge tubes **28** have been disposed. Dielectric spacers **29** may be used, for example, to maintain the center conductor in alignment with the outer conductor. For convenience, all of the anodes **30** of the gas discharge devices may be connected to the inner conductor **26**, thereby furnishing a common voltage link. A tapered magnetic field is provided by a solenoid **31** wound in a manner similar to that previously described. In Fig. 9 is shown an end view of the coaxial structure of Fig. 8.

For small-size coaxial lines, it may be preferable, as illustrated in Fig. 10, to arrange the longitudinal axes of the gas discharge devices **32** in substantially parallel alignment to the inner conductor **33** and the outer conductor **34** of the coaxial transmission line **35**. With such an arrangement, both lead wires for each electrode of the gas discharge device are passed through the outer conductor. The magnetic fields for the coaxial transmission lines may be provided by solenoids, as illustrated, or by permanent magnets.

The present invention finds application in an extremely wide frequency range. When used with a uniconductor hollow-pipe waveguide, frequencies from below 100 megacycles per second to above 100,000 per second may be employed, a preferred range being from 1,000 to 20,000 megacycles per second.

As will be recognized by those skilled in the art, the waveguide section may have either fast or slow wave propagating characteristics and may be either closed or open. For fast propagation, the guide should have smooth boundaries although they may be ridged. For slow propagation, the guide may be periodically corrugated or provided with helical, foraminous or grid-like walls. The length of the gas envelope may be widely varied depending upon the magnitude of the effect desired. Roughly speaking, this effect is proportional to the length of the electron gas medium.

It is particularly desirable that for a hollow-pipe waveguide the lowest mode of propagation in the waveguide be nondegenerate in nature. Most commonly and preferably, the waveguide will be of rectangular cross section and the polarized electromagnetic wave will be linearly polarized. The sealed-off tube containing the gas fills all or part of the guide cross section.

Suitable gases that may be used in the practice of this invention are appropriate pure gases or gas mixtures preferably of the non-electronegative type, such as neon, helium, argon, krypton, xenon and hydrogen. Gas pressures between 0.1 and 100 millimeters of mercury may be used. It has been found that magnetic field intensities ranging from 10 gauss to 15,000 gauss are suitable. The non-electronegative gases mentioned are preferred for use in these electron devices because of their chemical inertness and because these gases provide relatively high free-electron densities for a given input power. Thermionic as well as cold-cathode discharges may be used for providing the required electron density.

As seen from the foregoing, it is apparent that many modifications may be made without departing from the basic idea of this invention, namely that of providing a non-scanning microwave frequency analyzer wherein a plurality of bodies of ionized gaseous media are maintained at different gyromagnetic frequencies and indicating means are employed to determine which particular body is at a given gyroresonant frequency. Thus while a tapered magnetic field having a uniform gradient is preferable, for certain applications individual magnetic fields maintained about the gas discharge device may also be used. A frequency resolution of one percent is readily obtainable by careful control of the available magnetic field. Depending upon the size of the transmission structure, the number of gas discharge devices used, the steepness of the magnetic field gradient, etc., frequency resolution may be made as fine or coarse as desired. In addition, this frequency analyzer is particularly useful for

applications where the frequency of the electromagnetic wave energy is to be determined without interfering with the transmission of the energy through the waveguide.

While we have described above the principles of our invention is connection with specific apparatus, it is to be clearly understood that this description is made only by way of example and not as a limitation to the scope of our invention as set forth in the objects thereof and in the accompanying claims.

We claim:

1. An electromagnetic wave frequency analyzer comprising a plurality of gas discharge devices, each of said devices containing a gas capable of providing a high density of electrons upon ionization of said gas, means to ionize said gas, means to provide a magnetic field of different intensity for each of said ionized gas discharge devices, means to propagate an electromagnetic wave through said ionized gas discharged devices according to a polarized mode of propagation which has an electric field distribution substantially at right angles to said magnetic field, said field providing in said ionized gas discharge devices selective absorption of electromagnetic wave energy at different gyromagnetic resonant frequencies, and indicating means responsive to the absorption of wave energy by said ionized gas discharge devices.

2. An electromagnetic wave frequency analyzer comprising an electromagnetic waveguide structure, a plurality of gas discharge devices disposed within said structure, each of said devices containing a gas capable of providing a high density of electrons upon ionzation of said gas, means to ionize said gas, means to provide a uniform gradient magnetic field immersing said structure and said ionized gas discharge devices so that the magnetic field strength is different in different ones of said ionized gas discharge devices, means to propagate an electromagnetic wave through said ionized gas discharge devices according to a polarized mode of propagation which has an electric field distribution substantially at right angles to said magnetic field, said gradient field providing in said ionized gas discharge devices selective absorption of electromagnetic wave energy at different gyromagnetic resonant frequencies, and means to indicate an absorbing ionized gas discharge device.

3. A frequency analyzer according to claim 2, wherein said means to provide a uniform gradient magnetic field comprises a permanent magnet having a trapezoidal-shaped longitudinal cross section.

4. A frequency analyzer according to claim 2, wherein said means to provide a uniform gradient magnetic field comprises a solenoid wherein the depth of winding about the solenoid core increases uniformly along the longitudinal axis thereof.

5. An electromagnetic wave frequency analyzer comprising a rectangular waveguide, a plurality of spaced apart gas discharge devices disposed within said waveguide each of said devices containing a gas capable of providing a high density of electrons upon ionization of said gas, means to ionize said gas discharge devices, means to provide a uniform gradient magnetic field immersing said waveguide and said devices so that the magnetic field strength is different in different ones of said devices, means to propagate an electromagnetic wave through said waveguide according to a linearly polarized mode of propagation which has an electric field distribution substantially at right angles to said magnetic field, said field providing in said devices selective absorption of electromagnetic wave energy at different gyromagnetic resonant frequencies, and means to indicate an absorbing gas discharge device.

6. A frequency analyzer according to claim 5, wherein said gas discharge devices are spaced apart in substantially uniform alignment to provide in coaction with said uniform gradient magnetic field and said propagated electromagnetic wave a series of gas discharge devices having uniformly varying gyromagnetic resonant frequencies.

7. An electromagnetic wave frequency analyzer comprising a coaxial transmission line having inner and outer conductors, a plurality of gas discharge devices disposed within said transmission line each of said devices containing a gas capable of providing a high density of electrons upon ionization of said gas, means to ionize said gas discharge devices, means to provide a uniform gradient magnetic field immersing said transmission line and said devices so that the magnetic field strength is different in different ones of said devices, means to propagate an electromagnetic wave through said transmission line according to a polarized mode of propagation which has an electric field distribution substantially at right angles to said magnetic field, said field providing in said devices selective absorption of electromagnetic wave energy at different gyromagnetic resonant frequencies, and means to indicate an absorbing gas discharge device.

8. A frequency analyzer according to claim 7, wherein one terminal of each said gas discharge device is connected to the inner conductor of said transmission line.

9. A frequency analyzer according to claim 7, wherein the longitudinal axes of said gas discharge devices are disposed within said transmission line in substantially parallel alignment to said inner and outer conductors, lead wires for each terminal of said devices passing through the outer conductor.

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