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MAGNETIC RESONANCE DEVICES

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Fig. 1.

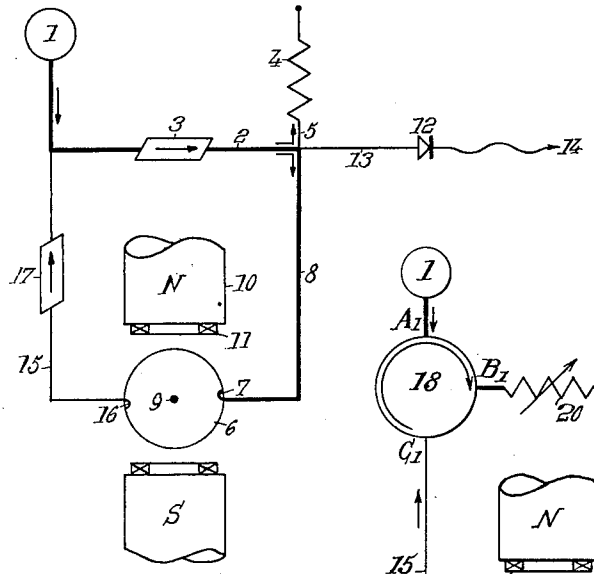


Fig. 3.

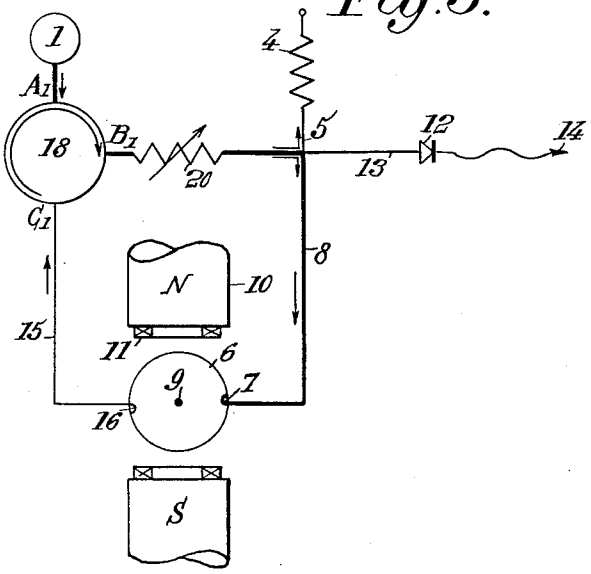
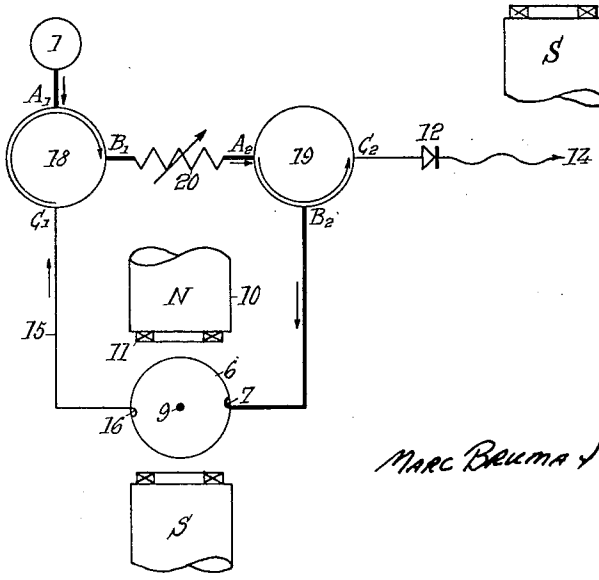


Fig. 2.



MARC BRUMA & ROZALIA MARX.
INVENTORS

BY Bailey Stephens & Huettig
ATTORNEYS

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MAGNETIC RESONANCE DEVICES

Marc Bruma, Pavillons-sous-Bois, and Rozalia Marx, nee Szanto, Paris, France, assignors to Centre National de la Recherche Scientifique, Paris, France, a state administration

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4 Claims. (Cl. 324—.5)

The present invention relates to devices which make use of phenomena of magnetic resonance, and, because it is in this case that the application of the invention appears to offer the greatest advantage, it is more particularly but not exclusively concerned with such devices employing the phenomena of electronic paramagnetic resonance for the purpose of studying certain substances by means of their magnetic properties by spectrometry or spectrography.

It will be recalled that these devices comprise essentially a generator of electromagnetic waves which supply, through a uni-directional member, the foot of a magic T, of which one of the lateral arms is formed by an impedance, while the other lateral arm is coupled to a resonant cavity containing the sample to be studied; this sample is in turn placed in the air-gap of the magnet, the uniform field of which is preferably modulated by an alternating field; a detector device is mounted in the arm of the T opposite to its foot and is connected to any desired utilization circuit.

The unit formed by the magic T and the uni-directional member referred to above can be replaced with advantage by a three-channel hyperfrequency circulator, the three channels of which would be respectively connected to the generator, to the cavity and to the detector device.

The invention has especially for its object to produce devices of the kind in question which have improved characteristics of sensitivity and stability.

The invention mainly consists in providing the said devices with means for taking from the cavity a small fraction (for example of the order of 1%) of the electromagnetic energy supplied by the generator and re-injecting this energy in suitable phase into the said generator, preferably by means of a three-channel hyperfrequency circulator interposed between the output of the generator and the magic T or the circulator which may replace it.

Preferred embodiments of the present invention will be hereinafter described with reference to the accompanying drawings, given merely by way of example and in which:

FIG. 1 diagrammatically shows an embodiment of a device made in accordance with our invention.

FIGS. 2 and 3 show two other embodiments of the invention, respectively.

The device of FIG. 1 comprises in known manner the following:

A generator 1 (FIG. 1) of electro-magnetic waves, preferably centimeter or millimeter waves (for example of the klystron or magnetron type);

A magic T, the foot 2 of which is connected to the output of the generator 1 through the medium of a uni-directional member 3;

An impedance 4 mounted on one of the lateral arms 5 of the T;

A resonant cavity 6 coupled at 7 to the other lateral arm 8 of the T and arranged to contain the sample 9 to be studied;

A magnet 10 intended to subject the sample 9 to a uniform magnetic field $H_0\rightarrow$;

Coils 11 adapted to modulate the field H_0 at low frequency while giving it the value $H_0 \pm \Delta H_0$;

Detection means 12 (silicon crystal, bolometer, thermistor . . .) arranged in the arm 13 of the magic T, opposite to its foot 2; and

Means 14 for using the signals supplied by the detector in order to form the paramagnetic spectrum of at least one substance contained in the sample 9.

The phenomenon used may be interpreted in the following way.

When subjected to the action of the uniform field $H_0\rightarrow$, an electron may be compared to a small gyroscope set in rapid rotation about its axis in the field of gravity; it is thus subjected in that field to a motion of precession, the frequency of which is given to a first approximation, equal to the Larmor frequency by the formula

$$f_0=\frac{\gamma H_0}{2} \quad (1)$$

in which γ is the gyromagnetic ratio of the electron (equal to 2.8 mHz. per gauss).

If the electron is subjected in addition to a field $H_1\rightarrow$ rotating at a speed ω_1 in a plane orthogonal to H_0 and in the same direction as the movement of precession referred to above, it can be shown that as long as ω_1 is different from $\omega_0=2\pi f_0$, the quantum threshold is not reached and the precession is not modified, but that as soon as the quality has been attained between ω_1 and ω_0, a resonance phenomenon occurs which is shown by a rocking movement of the electron: this electron then passes over to its second stable condition, inverted with respect to the first without modifying the precession.

Such a rocking action is indicated by an absorption of energy ($\Delta E=hf_0$, where h is the Planck constant), taken from the field H_1 by the electron.

If the number of electrons subjected to this swinging movement is sufficient, the disturbance of the field H_1 due to the sum of the quantities ΔE is detectable; from this detection there may be deducted the presence and/or the quantity of the said electrons.

The operation of the device described above for using the phenomenon that has just been referred to is as follows:

The generator 1 sends electro-magnetic waves of a frequency f_1 into the foot of the magic T (2, 5, 8).

One-half of this emission is lost in the impedance 4, the other half being admitted to the resonant cavity 6 in which it generates a field H_1 (which can as a first approximation be compared to the sum of two fields rotating in opposite directions at a speed ω_1.)

The wave reflected by the cavity and corresponding to the incident wave which reaches said cavity is again divided into two portions: one of these is absorbed in the member 3 of the foot 2, while the other is sent into the arm 13, in which it is detected by any suitable means (an autodyne with a single element, an autodyne with two balanced elements or a heretodyne) and is then transformed into usable indications.

As long as the sample contained in the cavity 6 does not give rise to any particular resonance, the signal detected is practically continuous.

But if the sample contains a sufficient number of paramagnetic electrons, a disturbance of the field H_1 will be caused at the moments when the field H_0, modified by ΔH_0, will fulfil the Larmor condition (1).

It is the magnitude and the form of this disturbance which is determined by the means 14.

The response of the device becomes increasingly sensitive as the signal/noise ratio increases.

Now, such a ratio is essentially dependent on the stability of the natural frequency of the generator 1: to every variation in frequency of the incident wave on the cavity there will correspond in fact variations of amplitude of the wave reflected by the cavity, which generates a "background noise."

We found that if there is taken from the cavity a small portion of the electromagnetic energy which is sent by the generator into that cavity, and if this portion is directly re-injected at a suitable phase into the generator, it becomes possible to fix the frequency of the generator, that is to say in a manner of speaking the frequency may be controlled to that which is necessary to ensure resonance in the cavity.

This experimental result, the advantage of which from the point of view of reduction of "background noise" is obvious, is also unexpected since at the moment of resonance, the amplitude and the form of the derived wave vary as a result of the change in the state of energy of the electrons.

The tapping of the energy is effected for example by a line **15** (coaxial cable or guide) by means of an auxiliary coupling system **16** (loop or hole) opening into the cavity and coupled to the generator **1** through a uni-directional member **17**.

However the signal/noise ratio may be still further improved by reducing the electro-magnetic power losses which are uselessly absorbed by the impedances **4** and/or the uni-directional members **3** and **17**.

According to this arrangement, use is made of at least one three-channel uni-directional circulator member, the channels of which are designated by A, B, and C, and which exclusively permits an almost total transmission of the hyper-frequency energy received at A towards B, of that received at B towards C and/or of that received at C towards A.

A form of embodiment of this arrangement will now be described with reference to FIG. 2, in which the members already referred to have been given the same references as the corresponding members of FIG. 1.

The unit formed by the uni-directional member **17** and the junction between the tapping line **15** and the supply line **2** is in this case replaced by a first hyper-frequency circulator with three channels A_1, B_1, C_1, and the magic T is replaced by a second hyper-frequency circulator **19** with three channels A_2, B_2, C_2, A_1 being coupled to the output of the generator **1**, B_1 through a variable attenuator **20** (the attenuation power of which can be reduced to zero at will) to A_2, C_1 to the coupling system **16**, B_2 to the coupling system **7**, and C_2 to the detector **12**.

With a circuit of this kind, it can be seen that:

On the one hand, almost the whole of the wave emitted by the generator **1** is admitted to the cavity **6** through A_1, B_1, A_2 and B_2, and then reflected towards the detector **12** through B_2 and C_2, the power used being adjustable by means of the attenuator **20**.

On the other hand, almost the whole of the wave taken at **16** from the cavity is re-injected through C_1 and A_1 into the generator **1** instead of having its half branched off towards the foot of the magic T, as in the case of the circuit arrangement of FIG. 1.

It is of course possible to include any desired adaptation members in the devices described.

FIG. 3 shows a third embodiment of our invention, wherein the magic T of FIG. 1 has been kept, but the energy re-injection means make use of a circulator **18** such as that shown by FIG. 2.

A device according to our invention has a great number of advantages as compared with those existing up to the present time, especially as regards the sensitivity and the stability of the measurements which can be effected by the device.

Thus, the device permits of the detection of a quantity of paramagnetic substance of the order of 10 to 100 times smaller than that which can be detected by devices of the kind in question known at the present time, and in which there is no tapping of power followed by a re-injection as in the present invention.

In one form of embodiment of the invention which has given complete satisfaction, and which is cited purely by way of illustration and naturally in a non-limitative manner, the numerical data selected were as follows: H_0=2,500 gausses, f_1=7,000 mHz. (corresponding to a wavelength of 4.2 cm.), which makes the values of ω_0 and ω_1 substantially equal, the desired resonance being produced for example one hundred times per second by modulating H_0 at a frequency of 50 cycles or once every 8 seconds by sweeping H_0 by suitable triangular wave.

In a general manner, while we have, in the above description, disclosed what we deem to be practical and efficient embodiments of our invention, it should be well understood that we do not wish to be limited thereto as there might be changes made in the arrangement, disposition and form of the parts without departing from the principle of the present invention as comprehended within the scope of the accompanying claims.

What we claim is:

1. A device for utilizing the phenomenon of magnetic resonance of a substance, comprising a cavity generator of high-frequency electro-magnetic waves, a resonant cavity containing a sample constituted at least in part by said substance, means for applying a uniform magnetic field to the said sample, means for modulating said field with an alternating field at low frequency, a detector device, means for utilizing the output of said detector, a uni-directional member, a magic T having its foot coupled to the output of said generator through said uni-directional member, an impedance constituting one of the lateral arms of said T, means for coupling the other lateral arm of said T to the resonant sample containing cavity means for coupling the arm of said T opposite to its foot to the said detector device, means for taking-off from said sample containing cavity a small fraction, of the order of 1%, of the electro-magnetic energy in said last mentioned cavity, and means for directly re-injecting said small fraction at a suitable phase into said cavity of said generator.

2. A device according to claim 1, in which the said reinjection means comprise a three-channel hyper-frequency circulator, the three channels of which are connected respectively to a conductor forming part of said energy-extraction means, to the output of said generator, and to said uni-directional member.

3. A device for utililing the phenomenon of magnetic resonance of a substance, comprising a cavity generator of high-frequency electro-magnetic waves, a resonant cavity containing a sample constituted at least in part by the said substance, means for applying a uniform magnetic field to said sample, means for modulating said field with an alternating field at low frequency, a detector device, means for utilizing the output of said detector, a three-channel hyper-frequency circulator, the three channels of which are coupled respectively to the output of said generator, to said sample containing cavity and to said detector device, energy extraction means for taking-off from said sample containing cavity a small fraction, of the order of 1%, of the electro-magnetic energy in said last mentioned cavity, and means for directly re-injecting said small fraction at a suitable phase into said cavity of said generator.

4. A device according to claim 3, in which said reinjection means comprise a three-channel hyper-frequency circulator interposed between a conductor forming part of said energy-extraction means, the output of said generator and the first-mentioned hyper-frequency circulator.

References Cited in the file of this patent

UNITED STATES PATENTS

2,677,051 Smith ---------- Apr. 27, 1954

OTHER REFERENCES

Portes: Physical Review, vol. 91, No. 5, September 1953, pp. 1071 to 1078.

Arams et al.: Proceedings of the I.R.E., May 1958, pp. 912 to 914.