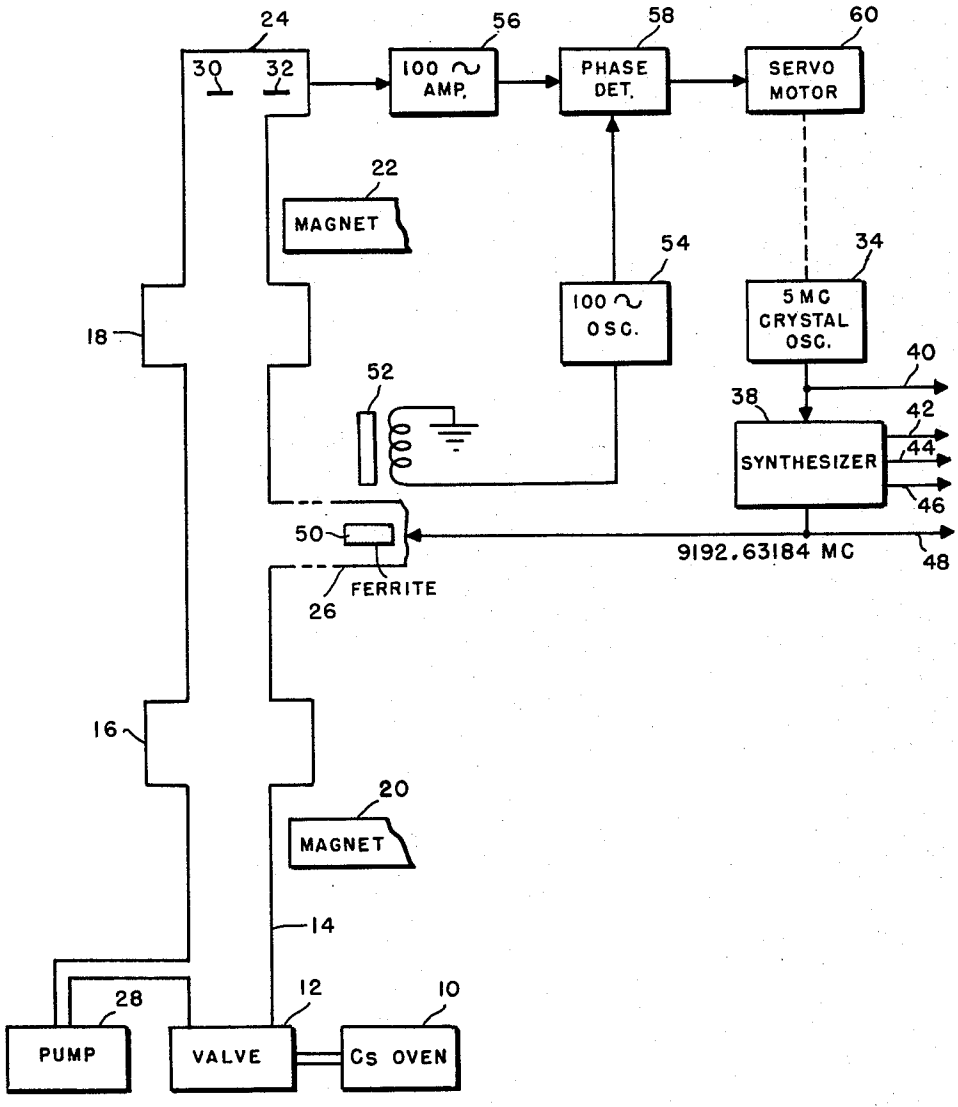
Oct. 11, 1960 F. H. REDER 2,956,238

ATOMIC RESONANCE DEVICES

Filed June 10, 1958



INVENTOR,
FRIEDRICH H. REDER
BY
Harry M. Saragovitz
ATTORNEY.

United States Patent Office 2,956,238 Patented Oct. 11, 1960

2,956,238

ATOMIC RESONANCE DEVICES

Friedrich H. Reder, Long Branch, N.J., assignor to the United States of America as represented by the Secretary of the Army

Filed June 10, 1958, Ser. No. 741,202

3 Claims. (Cl. 331—3)

(Granted under Title 35, U.S. Code (1952), sec. 266)

The invention described herein may be manufactured and used by or for the Government for governmental purposes, without the payment of any royalty thereon.

The present invention relates to atomic resonance devices, and more particularly to the devices of this type which utilize the changes of energy state of cesium atoms to produce resonance effects having a high order of stability.

Among the objects of the invention are to reduce the amount of cesium wasted when the device is not in operation, to provide improved means for frequency modulating the output, and to decrease the physical height of the equipment and increase the signal to noise ratio thereof.

The features of the invention which are believed to be novel are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and method of operation, together with further objects and advantages thereof, may best be understood by reference to the following description taken in conjunction with the accompanying drawing, which is a schematic diagram of the invention applied to a cesium beam frequency standard, although it is applicable to other types of atomic frequency standards. A commercial example of this type of frequency standard is marketed under the trademark "Atomichron."

Such a standard comprises an oven **10** where cesium is vaporized and passed through a manually operated, high-vacuum valve **12** into a beam tube **14**. This valve is kept closed when the apparatus is not in operation to prevent loss of cesium, which is used up when the temperature is above 35° centigrade.

Along tube **14** are positioned two spaced cavity resonators **16** and **18**, known as Ramsey cavities. Positioned above and below these cavities are permanent focusing magnets **20** and **22**. Above magnet **22** is positioned a detector **24**.

The atoms in the cavities **16** and **18** are excited by a wave applied thereto in like phase through a branch **26** opening into the main tube **14** midway between the cavities. The frequency of this wave should be as near as possible to the frequency of the cesium resonance, viz., 9192.63184 megacycles.

A vacuum pump **28**, connected to the tube **14**, immediately above the valve **12** keeps the gas at the required low pressure. Heretofore, this pump was positioned above the detector **24** so that all the gas with any impurities therein traversed the entire length of the tube. By connecting the pump immediately above the source, most of the impurities introduced into the beam tube are pumped out close to their source, with a resultant improvement in the signal to noise ratio. In addition, by positioning the pump at the side of the gas generating oven, the overall height of the equipment can be reduced about a foot.

In operation, the beam of cesium atoms enters into the tube **14** and travels toward the cavities. The energy state of the atoms depends upon the orientation of their dipole moments. If it is assumed that the atoms of the beam

are of two energy states then as they pass the first focusing magnet **20**, because of the orientation of its magnetic field, the atoms of the higher energy state will be deflected toward the wall of the tube, while those of lower energy state will pass on toward the cavities, where they are excited by the radio frequency field injected into the cavities. The atoms absorb energy from this field and as a result are raised to the higher energy state. A maximum number of atoms are thus transformed if the frequency of the radio frequency exciting field is exactly equal to the transition frequency of the atom. These atoms now travel past the second focusing magnet **22**, which is so oriented that atoms in the lower energy state will be deflected away from the beam and those in the higher energy state will pass on to detector **24**.

The number of atoms which are converted to the higher energy state, and hence the number of such atoms which reach detector **24**, depends upon the closeness of the injected signal frequency to the frequency of cesium resonance. These atoms strike the ionizing target **30** and then are attracted by means of a mass spectrometer to the cathode **32** of an electron multiplier. The output of latter varies with the number and rapidity of impingement of cesium atoms on the cathode. The detected output can therefore be used to lock the frequency of the external oscillator which supplies this injected signal.

The external oscillator is a five megacycle crystal oscillator **34** having a control element therein to precisely adjust its frequency to a small extent. The output of this oscillator is applied to a conventional frequency synthesizer which converts the 5 mc. output to a plurality of harmonics and subharmonics which are combined in various ways to provide a number of frequencies to be utilized at leads **40—48**.

One of these frequencies is 9192.62184 mc., the exact frequency of cesium resonance, which is applied to branch **26** of tube **14**. To provide locking information this frequency is frequency modulated at a low rate by means of a ferrite modulator within branch **26**. This comprises a piece of ferrite **50**, subjected to the varying magnetic field of a permanent magnet **52** having a coil to which is applied a sinusoidal modulating current from a 100 cycle modulating oscillator **54**. Permanent magnet **52** provides a predetermined steady magnetic bias on the ferrite element **50**. The 100 cycle signal modulates the phase of the R.F. exciting wave, and this produces a concomitant frequency modulation thereof. Since any departure of the frequency of the R.F. exciting wave from the frequency of cesium resonance effects the output of detector **24**, the amplitude of said output is a measure of said departure, and the direction of phase displacement of said output, relative to the phase of the modulating signal, is a measure of the direction of departure. The 100 cycle detector output signal is amplified by a tuned amplifier **56** and applied, together with the signal from modulating oscillator **54** to a phase comparing detector **58** where the phase of the two signals are compared. If the exciting frequency departs from the frequency of cesium resonance, the phase detector will yield an output having an amplitude which is a function of the extent of the departure of the frequency of the exciting wave from the frequency of cesium resonance, and a direction which is a function of the direction of said departure. This operates a servo motor **60** which rotates the frequency controlling elements of oscillator **34** until the output of the phase detector is zero or minimum, at which time said departure is minimized.

While there has been described what is at present considered to be a preferred embodiment of the invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, aimed

in the appended claims to cover all such changes modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A cesium beam frequency standard comprising an oven for vaporizing cesium, an atomic beam tube into which a beam of cesium atoms is introduced from said oven, a high vacuum valve between said oven and said beam tube for controlling the flow of cesium into said tube; said beam tube having positioned therealong, in the order named, a first focusing magnet, a pair of spaced Ramsey cavity resonators tuned to the frequency of cesium resonance, a second focusing magnet, and a detector; a vacuum pump connected to said beam tube at a point near said oven and positioned beside said oven; a branch connected to said beam tube substantially midway between said cavities for injecting into said cavities radio frequency energy of like phase and of a frequency in the vicinity of cesium resonance to cause a change of energy state of atoms in said cavity; a source of said radio frequency energy connected to said branch, a magnetic ferrite modulator in said branch, a source of low frequency current coupled to said modulator for frequency modulating said radio frequency energy and thereby periodically varying the amplitude and phase of the output of said detector, and means responsive to said output and said low frequency current for reducing any departure of the frequency of said radio frequency energy source from the frequency of cesium resonance.

2. An atomic frequency standard comprising a source of atoms, an atomic beam tube into which a beam of said atoms is introduced from said source; a first focusing magnet, a pair of spaced cavity resonator means tuned the frequency of cesium resonance, a second focusing magnet, and a detector arranged in said tube in the order named, a vacuum pump connected to said beam tube at a point near said source, whereby impurities in said beam are removed close to said source, a branch connected to said beam tube substantially midway between said cavities for injecting into said cavities radio frequency energy of like phase and of a frequency in the vicinity of the transition frequency of said atoms to cause a change of energy state of atoms in said cavity, a source of said radio frequency energy connected to said branch, a modulator in said branch, a source of low frequency current coupled to said modulator for frequency modulating said radio frequency energy and thereby periodically varying the amplitude and phase of the output of said detector, and

means responsive to said output and said low frequency current for reducing any departure of the frequency of said radio frequency energy source from said transition frequency.

3. A cesium beam frequency standard comprising an elongated atomic beam tube, said beam tube having positioned therealong, in the order named from one end to the other, a first focusing magnet, first and second spaced Ramsey cavity resonators tuned to the frequency of cesium resonance, a second focusing magnet, and a detector; an oven for vaporizing cesium at said one end of the beam tube whereby a beam of cesium atoms is introduced into said tube, a high vacuum valve at said one end connecting the output of said oven to said beam tube for controlling the flow of cesium into said tube, a vacuum pump connected to said beam tube at a point immediately above said valve and positioned beside said oven; a branch connected to said beam tube substantially midway between said cavities for injecting into said cavities radio frequency energy of like phase and of a frequency in the vicinity of cesium resonance to cause a change of energy state of atoms in said cavity; a source of said radio frequency energy connected to said branch, a magnetic ferrite modulator in said branch, a source of low frequency current coupled to said modulator for frequency modulating said radio frequency energy and thereby periodically varying the amplitude and phase of the output of said detector, and means responsive to said output and said low frequency current for reducing any departure of the frequency of said radio frequency energy source from the frequency of cesium resonance.

References Cited in the file of this patent

UNITED STATES PATENTS

2,770,729	Dicke	Nov. 13, 1956
2,831,974	Wright et al.	Apr. 22, 1958
2,836,722	Dicke et al.	May 27, 1958
2,894,209	Chodorow et al.	July 7, 1959

OTHER REFERENCES

Literature from Polytechnic Research and Development Co., Inc., 202 Tillery Street, Brooklyn 1, N.Y., on a portable Ammonia Maser Oscillator Tube.

Article: "Solid-State Maser Amplifier," Physical Review, Jan. 15, 1958, vol. 109, No. 2, pp. 312–318.

Radio and Television News, January 1957, pp. 63, 120, "Atomichron—World's Most Accurate Clock."