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ATOMIC HYDROGEN MASER WITH ENLARGED ATOM STORAGE CONTAINER

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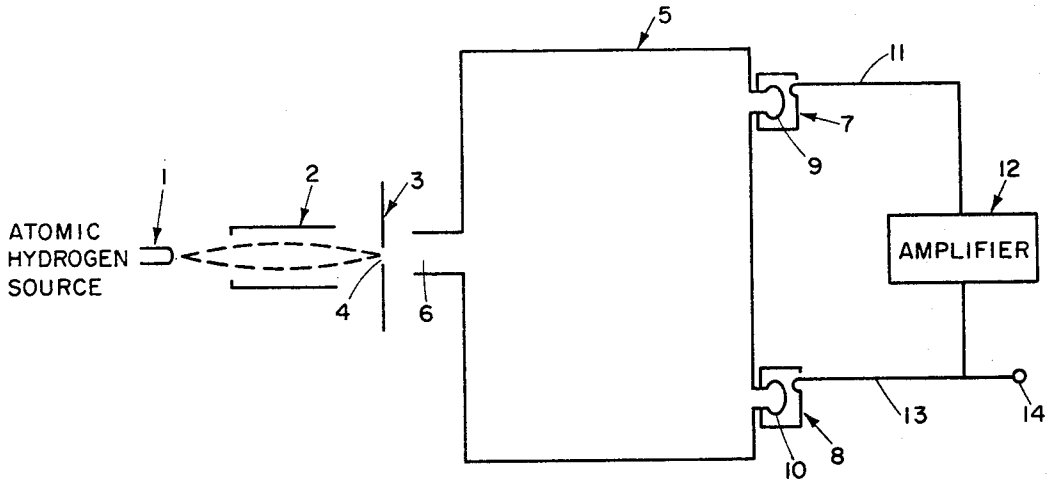


Fig. 1

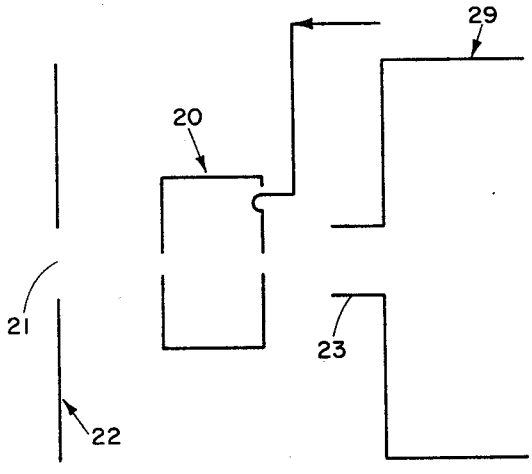


Fig. 2

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ATOMIC HYDROGEN MASER WITH ENLARGED ATOM STORAGE CONTAINER

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ABSTRACT OF THE DISCLOSURE

An atomic hydrogen maser including an atomic storage container which is made large compared to the wavelength of the hyperfine transition frequency of hydrogen to reduce undesirable wall effects. Two smaller cavity resonators which may contain atom storage bulbs are connected with the interior of the storage container, and R.F. energy from one of the resonators is amplified to produce an output signal a portion of which is applied to excite the other resonator.

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

In the hydrogen maser, atomic hydrogen from a R.F. discharge score passes through the inhomogeneous state-selecting magnetic field of a six-pole permanent magnet. This field focuses atoms in the $[F=1, m=0]$ and $[F=1, m=1]$ state onto an aperture in a specially coated dielectric bulb. This bulb is located in a region of constant-phase axial R.F. magnetic field at the center of a cylindrical cavity resonator excited in the TE_{011} mode and tuned to the $[F=1, m=1]$ $[F=0, m=0]$ hyperfine transition frequency of approximately 1420.405 mc./sec. The atoms which enter this bulb make random collisions with the coated bulb wall and eventually leave the bulb through the entrance aperture. Due to their small interaction with the wall coating, which has a particular characteristic, the atoms are not seriously perturbed even though they are retained in the bulb for more than a second and undergo more than 10^3 collisions with the wall during this period.

Since the transition time due to the storage feature just mentioned is longer than one second, the resonant line of the radiated energy is extremely narrow. Thus, self-excited maser oscillation at the hyperfine frequency may take place, and this oscillation occurs whenever the energy delivered to the R.F. cavity by the beam equals that lost by this device.

The principal source of error in absolute time and frequency measurements with an atomic hydrogen maser of the type just described arises from the effect of the wall of the storage bulb on the frequency of the maser. Even though this effect is small and may be measured by experiments using storage bulbs of two different diameters, it does, nevertheless, contribute a slight error. One method of minimizing this would be to resort to new wall materials which would permit the atoms to experience an even further number of wall collisions and still not undergo transitions between hyperfine energy states or any other form of relaxation which would lead to a loss of coherence.

The wall effects may be reduced, of course, by going to a larger diameter storage bulb, for the fraction of time the atom spends on the wall is inversely proportional to the storage bulb diameter. In the past, it has been necessary to limit the storage bulb to a small diameter, approximately six inches, so that it may be confined to a region of a single oscillatory phase in the R.F. cavity.

The dimensions of this cavity, of course, are invariably fixed by the wavelength of the hydrogen hyperfine radiation. This limitation is overcome in the present invention because the main storage container is effectively external to the excited R.F. cavity. The size of this container, therefore, need not be limited by the operating frequency of the atomic hydrogen maser. For example, in one proposed embodiment of the present invention, the storage container has a diameter of approximately sixty inches, and this decreases the wall effects by a factor of ten. It also increases the storage time by a similar factor. Thus, the system achieves an increase in line Q and a corresponding reduction in frequency drift due to instability of the tuned cavity.

The present invention is not only superior for absolute time and frequency measurements, but it also provides greater accuracy in the measurement of other hyperfine separations, such as, deuterium and tritium. Moreover, the present limitation in the accuracy of spin, exchange, cross-section measurements with available hydrogen masers, which is due to pressure-dependent wall effects, is reduced with the larger storage box available in the present system.

It is accordingly a primary object of the present invention to provide an atomic hydrogen maser having improved frequency accuracy and stability.

Another object of the present invention is to provide an atomic hydrogen maser having an atomic storage box whose size is unlimited by the wavelength of the hyperfine transition frequency.

Other objects, advantages and novel features of the invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings wherein:

FIG. 1 schematically depicts one embodiment of the present invention; and

FIG. 2 illustrates an alternative arrangement with the high level tuned cavity in a different location in the system.

Referring now to FIG. 1, it will be seen that an atomic hydrogen source **1** and a six-pole, state-selecting magnet **2**, both of which may be similar in construction to the apparatus disclosed in applicant's U.S. Patent No. 3,255,423 of Jan. 7, 1966, cooperate to focus atoms in the higher $F=1$ hyperfine states through the defining aperture **3** of a mask **4** and into a cylindrical storage container **5**. This container is constructed with an exterior entrance passageway **6** which acts as a collimator to permit only the axially directed atoms in the beam to enter into its interior. Since container **5**, unlike prior art devices, is not within the excited R.F. cavity, this unit need not be made of dielectric material. For the same reason, its size may be much larger than the wavelength of the hyperfine transition frequency.

Mounted on an exterior upper and lower wall portion of container **5** are a pair of R.F. cavity resonators **7** and **8**. These cavity resonators are similar to those usually employed in the conventional atomic hydrogen maser. That is, both cavities operate in the TE_{011} mode and are tuned to the hyperfine transition frequency of 1420.40 mc. Accommodated within each cavity is a dielectric storage bulb **9** and **10**. These bulbs are also the equivalent of those used in the prior art hydrogen maser. Their size is determined by the restriction mentioned hereinbefore that they be confined to a region of a single oscillatory phase of the R.F. energy in the resonant cavities. Consequently, they may be approximately six inches in diameter.

Both bulbs are in communication with the interior of the main storage box **5**. Thus, any atoms within this container may enter these smaller bulbs, remain stored therein for a short period of time and interact with any of the R.F. energy present therein. Cavity **7**, which is designated the

"low level cavity," is provided with an appropriate microwave signal output connection **11**, and the signal extracted at this location is fed to an amplifier **12** tuned to the hyperfine transition frequency. The output of this amplifier is used to excite cavity **8**, which is designated the "high level tuned cavity." This energization is accomplished by a suitable connection **13**. An output signal may be taken from this loop at point **14**, for example.

The operation of the overall system is as follows: Hydrogen atoms emanating from source **1** encounter an energy gradient within state-selecting magnet **2** which causes those atoms in the $[F=1, m=1]$ and $[F=1, m=0]$ states to converge along the longitudinal axis of symmetry of the magnet, and those atoms in the $[F=1, m=1]$ and $[F=0, m=0]$ states to be directed radially outward from this axis. Mask **4** with its central aligned aperture **4** focuses the former atoms into the tubular extension **6** of storage box **5**, and this collimator further insures that only atoms in the $[F=1, m=1]$ and $[F=1, m=0]$ states reach the interior of the box.

The atoms which enter container **5** are stored for a time interval which may last as long as ten seconds. During this time, they may pass several times through each of the two small storage bulbs **9** and **10** and be stored therein for a smaller interval of time. In the low level tuned cavity **7**, these atoms give up sufficient energy to maintain a low level maser oscillation at the hydrogen hyperfine frequency. That is, the atoms undergo transitions to the $[F=0, m=0]$ state, and the radiation accompanying this transition establishes a weak, self-sustained oscillation in cavity **7** tuned to this frequency.

The microwave signal excited from cavity **7**, after amplification in amplifier **12**, is coupled to cavity **8**. Consequently, a relatively strong state of oscillation at the hyperfine transition frequency is present within this cavity. Atoms which enter bulb **10**, therefore, are subjected to a sufficiently intense R.F. field at the hyperfine transition value so that they are placed in a phase coherent, radiant state after a few passages through this bulb. Hence, they are in condition to contribute to the continued excitation of cavity **7** when and if they subsequently enter this portion of the apparatus.

Storage box **5** and the state-selection portion of the system, it will be appreciated, are evacuated by appropriate vacuum pumps, not shown. Also, the main storage box **5** and both tuned cavities **7** and **8** are surrounded by concentric moly permalloy shields to insure a sufficiently low and uniform magnetic field within these components so that induced Zeeman transitions are not serious during the relatively extensive storage time.

The interior wall surfaces of main storage box **5** and bulbs **9** and **10** are coated with materials of the class described in applicant's above-described patent for the reasons mentioned therein. The preferred compounds as noted are the hydrogen-saturated hydrocarbons, the hydrogen-saturated silicons, the silanes, and halogen-saturated compounds such as Teflon.

If the diameter of storage box **5** is ten times that of bulbs **9** and **10** and if the storage times in this box is ten times longer and the beam intensity ten times greater, then oscillations can be obtained in the above system over the same fraction of range of source pressures as those encountered in the prior art atomic hydrogen maser if the amplification provided by amplifier **12** is such as to maintain the energy level in the high cavity **8**, 60 db over that in the low cavity **7**.

FIG. 2 shows an alternative arrangement in which the high level, tuned cavity **20** is relocated to a position between the defining aperture **21** of mask **22** and the entrance **23** of the large storage container **29**. This cavity is again energized with a signal derived from the low level cavity mounted on a wall of storage container **29**. Since the atoms in the beam now pass through cavity **20** only once, instead of several times, the radio frequency field within it must be appreciably greater than that within the corresponding high level, tuned cavity **8** of FIG. 1. Consequently, in this modification the amplifier interconnecting the high and low level cavities must have a greater amplification factor. Also, cavity **20** should have appropriate aligned apertures to allow the atoms to enter this portion of the system and continue on into the main storage container. Because the atoms do not require prolonged interaction with the high intensity radio frequency field within this cavity, they may be permitted to pass directly through this device without any interim storage in a dielectric bulb of the type employed in the system of FIG. 1.

The arrangement of FIG. 2 should provide slightly greater stability of the output signal since the atoms are in a phase coherent radiant state during the entire time that they are in the large storage container **29**.

It might appear that unknown phase shifts in the amplifier would lead to an erroneous output frequency. However, the usual hydrogen maser procedure of tuning the cavity such that the frequency is independent of the beam intensity assures that the cavity mistuning, the phase shift in the amplifier, and the spin exchange collisions will all be mutually balanced so that the maser oscillates at the true hyperfine frequency.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. A maser oscillator comprising, in combination,

a storage container having an inside dimension which is large compared to the wavelength of the radio frequency energy radiated by a gaseous atom which undergoes a magnetic dipole transition between an upper and a lower hyperfine energy state;

means for directing a beam composed of such gaseous atoms into the interior of said storage container, the predominant number of atoms in said beam being in said upper hyperfine energy state;

a pair of cavity resonators in communication with the interior of said storage container;

means for extracting the radio frequency signal developed within one of said cavity resonators by gaseous atoms which leave the interior of said storage container, enter the interior of said cavity resonator and there undergo a magnetic dipole transition from said upper to said lower hyperfine energy state;

means for amplifying said radio frequency signal; and

means for exciting the other cavity resonator of said pair with said amplified radio frequency signal whereby gaseous atoms which leave the interior of said storage container and enter the interior of this cavity resonator and which are in said lower hyperfine energy state are excited to said upper hyperfine energy state.

2. In an arrangement as defined in claim **1**,

means accommodated within each cavity resonator for storing said gaseous atoms for an interim period of time and thereafter redirecting said gaseous atoms back into the interior of said storage container.

3. In an arrangement as defined in claim **2**, wherein said means for storing said gaseous atoms and redirecting them back into the interior of said storage container comprises

a dielectric bulb in which cavity resonator, each dielectric bulb having an entrance passageway leading into the interior of said storage container and having its inner wall surfaces made of a nonrelaxing material whereby gaseous atoms which enter these bulbs from the interior of said storage container may collide a multiplicity of times with said inner wall surfaces without being disturbed appreciably from their hyperfine energy state.

4. An atomic hydrogen maser comprising, in combination,

a storage container having a size which is large compared to the wavelength of the radio frequency energy

radiated by a hydrogen atom which undergoes a magnetic dipole transition between an upper and lower hyperfine energy state;

means for directing a beam of hydrogen atoms, the predominant number of which are in said upper hyperfine energy state, into said storage container,

said storage container having its inner wall surfaces made of a nonrelaxing material which permits said hydrogen atoms to collide repeatedly with said surfaces without experiencing any appreciable change in their hyperfine energy state;

a pair of radio frequency cavity resonators coupled to said storage container,

each of said cavity resonators being tuned to the frequency of said radio frequency energy;

a dielectric storage bulb accommodated within each of said cavity resonators,

each of said bulbs having an entrance passageway which communicates with the interior of said storage container whereby any of the hydrogen atoms present within said storage container may enter each of said storage bulbs,

each of said bulbs having its inner wall surfaces made of a nonrelaxing material whereby the hydrogen atoms which enter these storage bulbs may collide repeatedly with these wall surfaces without experiencing any appreciable change in their hyperfine energy state;

means for extracting the radio frequency signal available in one of said cavity resonators as a result of the excitation of that cavity resonator by hydrogen atoms which enter its storage bulb and there undergo radiative transitions between said upper and lower hyperfine energy states;

means for amplifying said radio frequency signal; and means for exciting the other cavity resonator with said amplified radio frequency signal whereby those hydrogen atoms which enter its storage bulb and are in the lower hyperfine energy state as a result of having previously undergone a radiative transition to this state from said upper hyperfine energy state are quickly excited to said upper hyperfine energy state.

5. An atomic hydrogen maser comprising, in combination,

a storage container having a size which is large compared to the wavelength of the radio frequency energy produced by a hydrogen atom which undergoes a radiative transition between an upper and lower hyperfine energy state;

a first cavity resonator tuned to the frequency of said radio frequency energy;

means for directing a beam of hydrogen atoms, the predominant number of which are in said upper hyperfine energy state, through said cavity resonator and into said storage container,

said storage container having its inner wall surfaces made of a nonrelaxing material which permits said hydrogen atoms to collide repeatedly with said surfaces without experiencing any appreciable change in their hyperfine energy state;

a second cavity resonator tuned to the frequency of said radio frequency energy and coupled to said storage container;

a dielectric storage bulb accommodated within said said second cavity resonator,

said bulb having an entrance passageway which communicates with the interior of said storage container whereby any of the hydrogen atoms present within said storage container may enter said storage bulb,

said storage bulb having its inner wall surfaces made of a nonrelaxing material whereby the hydrogen atoms which enter this storage bulb may collide repeatedly with these wall surfaces without experiencing any appreciable change in their hyperfine energy state;

means for extracting the radio frequency signal available in said second cavity resonator as a result of the excitation of that cavity resonator by hydrogen atoms which enter its storage bulb and there undergo radiative transitions between said upper and lower hyperfine energy state;

means for amplifying said radio frequency signal; and means for exciting said first cavity resonator with said amplified radio frequency signal whereby those hydrogen atoms in said beam which pass through said first cavity resonator and are in said lower hyperfine energy state encounter a high intensity radio frequency field and are excited to said upper hyperfine energy state.

No references cited.

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ROY LAKE, *Primary Examiner.*