July 11, 1967 D. E. GIELOW 3,331,017

FREQUENCY-COMPENSATED ACCESS STRUCTURE FOR CAVITY RESONATOR

Original Filed Dec. 13, 1962 2 Sheets-Sheet 1

FIG. 1A

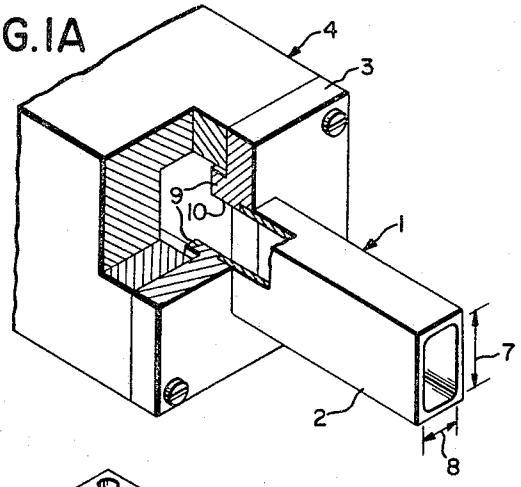
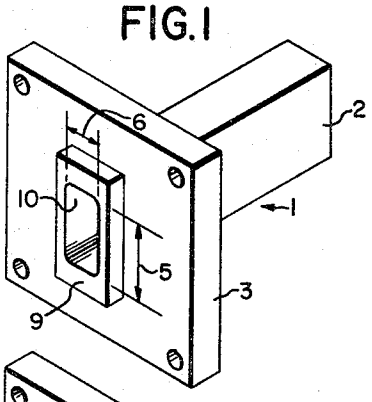


FIG. 1



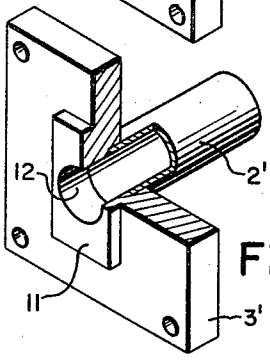


FIG. 2

FIG. 3

INVENTOR
DAVID E. GIELOW
BY J. Rosenblum
ATTORNEY

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FREQUENCY-COMPENSATED ACCESS STRUCTURE FOR CAVITY RESONATOR

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FIG.4

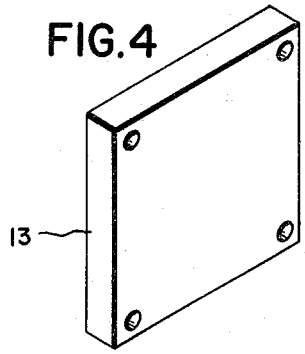


FIG.5

INVENTOR.
DAVID E. GIELOW

BY J. Rosenblum

ATTORNEY

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FREQUENCY-COMPENSATED ACCESS STRUCTURE FOR CAVITY RESONATOR

David E. Gielow, Los Altos, Calif., assignor to Varian Associates, Palo Alto, Calif., a corporation of California

Continuation of application Ser. No. 244,406, Dec. 13, 1962. This application June 14, 1966, Ser. No. 557,589

9 Claims. (Cl. 324—.5)

This application is a continuation of application Ser. No. 244,406, filed Dec. 13, 1962, by David E. Gielow and now abandoned.

The present invention relates in general to cavity resonators and in particular to novel apparatus for providing access to cavity resonators and compensating for the change of cavity resonant frequency resulting therefrom.

A difficulty with prior-art structures for providing access to a resonant cavity is that when a wall of the cavity resonator is apertured therethrough, the interior microwave field surrounding the aperture penetrates outward through the aperture so that the effective microwave length of the cavity is increased, thereby decreasing the operative microwave resonant frequency of the cavity.

In many applications, it is desirable to keep the operative microwave resonant frequency fixed regardless of whether the cavity wall structure is solid or apertured. Apertured wall structures are needed which conveniently may be substituted for solid wall structures without alteration of the cavity resonance frequency.

One object of the present invention, therefore, is provision of frequency-shift-compensated adapter means for permitting access to a cavity resonator without altering its microwave resonance frequency.

One advantage of the present invention is its usefulness in connection with cavity resonators suitable for electron paramagnetic resonance (EPR) studies. For experiments in which paramagnetic samples are exposed to the simultaneous influence of light irradiation and a microwave resonance field within a cavity resonator, unobstructed open access means are needed so that irradiation over the entire active portion of these samples may be achieved. Prior-art slotted or partitioned access means permit irradiation over only about 50 percent of the active portion of a sample.

One feature of the present invention, therefore, is provision of waveguide access means in combination with frequency-compensated adaptor means which may be attached to a resonant cavity for permitting external irradiation over substantially all of the active portion of a sample disposed within the cavity resonator without altering the microwave resonant frequency at which the cavity operates.

A further advantage of the present invention is that it conveniently permits light to be transmitted through a cavity resonator and permits optical transmission changes in a paramagnetic sample disposed within the cavity to be detected so that a cavity resonator may be adapted for operation at the same fixed frequency in optical transmission resonance studies as in other microwave resonance experiments.

One feature of the present invention, therefore, is provision of waveguide access means and apertured adaptor means which, in combination with a half-wavelength cavity coupling section on top of which a microwave coupler and a waveguide assembly are mounted, comprise an accessory apparatus suitable for opening a cavity resonator having closed end walls without altering its resonant frequency in order that light may be transmitted therethrough.

These and other features and advantages of the present invention will be more apparent after a perusal of the

following specification taken in connection with the accompanying drawings wherein the same numeral is used in the various figures for the same or analogous element, and:

FIG. 1 is an isometric view of a frequency-shift-compensated adaptor assembly having rectangular waveguide access means in accordance with the present invention.

FIG. 1A is an isometric view, partially broken away, of a cavity resonator, at one end of which the adaptor assembly shown in FIG. 1 is attached.

FIG. 2 is an isometric view partially broken away, of a frequency-shift-compensated adaptor assembly having a cylindrical waveguide access means in accordance with the present invention.

FIG. 3 is an isometric view, partially broken away, of an adaptor assembly and cavity resonator combination, adapted to be disposed between the pole pieces of external magnet means and suitable for permitting microwave resonant samples contained in a sample tube holder disposed within the resonator, to be exposed to the simultaneous influence of light irradiation and a microwave resonance field, in accordance with the present invention.

FIG. 4 is an isometric view of a solid rectangularly shaped end-closing structure which is interchangeable with the adaptor assembly of FIG. 3.

FIG. 5 is an isometric view, partially broken away, of frequency-shift-compensated adaptor assemblies in combination with a rectangular cavity resonator, which combination is adapted to be disposed between the pole pieces of external magnet means and is suitable for transmitting light at one or more frequencies through microwave resonant samples disposed within the cavity or for detecting optical transmission changes within said samples while simultaneously observing electron resonances.

Referring now to FIG. 1, frequency-shift-compensated adaptor assembly **1** consists of rectangular waveguide access means **2** having an interior hollow chamber which has a cut-off frequency beyond the frequency of the cavity resonator, and adaptor **3**. Adaptor assembly **1** may be connected to a cavity resonator **4** as shown in FIG. 1A. In this embodiment, a rectangular aperture extends through the central portion of adaptor **3**, this aperture having dimensions **5** and **6** equal to the interior dimensions **7** and **8**, respectively, of waveguide access means **2**. On the side of adaptor **3** disposed exterior to the cavity, this aperture widens, having dimensions equal to the outer dimensions of waveguide access means **2**, so that access means **2** may be inserted into adaptor **3** and soldered or brazed thereto.

Waveguide access means **2**, the hollow interior of which opens into the interior of cavity resonator **4**, will not propagate microwaves at the microwave resonance frequency of cavity resonator **4**. Thus cavity resonator **4** is opened without any appreciable attenuation of the interior microwave field, so that, for example, microwave resonant samples disposed within the cavity may be simultaneously exposed to external irradiation and microwave resonance fields therein.

Adaptor **3** provides for frequency compensation throughout the operative frequency range of cavity resonator **4** so that it remains resonant at the frequency at which it is intended to be operated. Frequency compensation is achieved by virtue of the effect upon the cavity microwave fields of metallic member **9**, a rectangular lip-like portion of adaptor **3** which projects axially into cavity resonator **4** as shown in FIG. 1A. Metallic member **9** counteracts the fringing effects of the interior microwave field in the vicinity of aperture **10**, reducing the effective microwave length of cavity resonator **4** by an amount equal to the increase of the effective microwave length due to opening the resonator to the exterior.

Referring now to FIG. 2, another embodiment of the

invention is shown in which waveguide access means 2' has cylindrical symmetry instead of rectangular symmetry. Adaptor 3' is cylindrically apertured through the central portion of rectangular lip-like metallic member 11, which is adapted to slidably fit into rectangular cavity resonator 4. The diameter of aperture 12 is equal to the interior diameter of access means 2'. The use of this combination is advantageous in connection with applications requiring a very short waveguide section. Where, however, maximal access cross sectional area is sought as, for example, in experiments in which it is desired to shine light through the hollow access chamber into a cavity resonator, the embodiment shown in FIG. 1 is preferred because the rectangular symmetry provides the maximum access cross sectional area consistent with the requirement that the hollow access chamber have a cut-off frequency beyond the frequency of the cavity resonator.

Referring now to FIG. 3, a cavity resonator assembly 14 is shown consisting of a rectangular cavity resonator 15, a frequency-shift-compensated adaptor assembly 1 comprising a rectangular adaptor 3 and rectangular waveguide access means 2, a cavity coupling section 16, and a rectangular waveguide assembly 17 for transmitting energy to and from resonator 15.

A hollow sample cell 18 may be introduced centrally into cavity 15 through sample access means 19. In one embodiment, the sample cell advantageously comprises a quartz tube having a pancake-shaped central portion lying in a nodal plane of electric field, a position of maximum microwave magnetic field in cavity resonator 15. The sample tube may contain a microwave resonant sample in solid form or in solution, the sample being simultaneously exposed to the influence of the cavity microwave magnetic field and external irradiation without appreciable attenuation of the interior microwave field. The solution, for example, may flow through the sample tube thereby permitting process control measurements determinative of the nature and amount of various materials in the sample solution. Moreover, solutions containing different samples may be mixed within a tubular mixing chamber (not shown) which may be inserted into the sample cell, whereby steady state intermediates may be observed and reaction rates determined. Alternatively, electrodes (not shown) may be disposed within the sample tube and an electrolytic reaction may be produced in a sample solution, which is simultaneously exposed to the influence of a cavity microwave magnetic field and external irradiation, electron resonances of reaction products being observed and reaction rates being measured.

A static D.C. magnetic field generated between the pole pieces 20 of external magnet means is superimposed on cavity resonator 15 substantially at right angles to the microwave magnetic field therein, coils 20' being provided on the cavity wall to impose an A.-C. modulation on the static D.C. field in order to use A.-C. detection means as is well known in the art. A beam of light emanating from light source 21 is directed through hollow waveguide access means 2 into resonator 15 so that substantially all of the active portion of the sample contained within sample cell 18 is irradiated, whereby the effect of irradiation upon electron resonances is substantially enhanced.

It is desirable, moreover, that cavity resonator 15 be suitable for use in connection with other resonance experiments as well as those involving light irradiation. For this reason adaptor assembly 1 is detaachable and may be replaced, for example, by a solid end-closing end-plate 13. The substitution of such an end-plate for adaptor 1 may be accomplished expeditiously without altering the resonant frequency of the cavity. Since the frequency shift associated with fringing field effects occurring whenever a closed cavity is opened is eliminated within adaptor assembly 1, assembly 1 may be detached from cavity resonator 15, being replaced by end-closing metallic structure 13, and similarly may be reattached to the cavity without detuning the cavity.

Referring now to FIG. 5, a cavity resonator assembly 22 is shown in which two frequency-shift-compensated adaptors are used. The assembly shown in FIG. 3 conveniently may be adapted to permit light transmission experiments by the addition of a frequency-shift-compensated adaptor and a half wavelength coupling section on top of which a waveguide transmission line is mounted. Half wavelength cavity coupling section 23 is attached to one end of cavity resonator 15, waveguide assembly 17 and cavity coupling section 16 having been removed. A microwave coupler 24 is mounted on top of this half wavelength section for coupling energy between waveguide transmission line 25 and cavity resonator 15. A coupler which is especially suitable for this purpose is the coupler of John C. Everitt which is the subject of a copending patent application, Ser. No. 228,113, filed Oct. 3, 1962, now Patent No. 3,214,684 and assigned to applicant's assignee. An additional frequency-shift-compensated adaptor assembly 26 is connected to half wavelength section 23 thereby permitting light from light source 21 to be transmitted through a sample disposed centrally within cavity resonator 15. A detector 27 is adapted to receive light transmitted through the resonator, whereby measurements of optical absorption may be made while simultaneously observing the electron resonances of the sample. Alternatively, detector 27 may be replaced by another light source so that, for example, light at two different frequencies may be transmitted through the interior of the resonator while electron resonances are observed.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

I claim:

1. A microwave apparatus comprising, in combination:

(a) a microwave cavity assembly comprising a cavity resonator, at least three walls of which are apertured therethrough, and sample access means forming a hollow interior chamber having a cut-off frequency beyond the frequency of said resonator, said sample access means extending through two oppositely-disposed apertured walls of said resonator and being adapted to support a sample cell within said resonator, and said sample cell being adapted to contain a microwave resonant sample therein,

(b) at least one frequency-shift-compensated adaptor assembly comprising:

(1) a short hollow waveguide section forming a hollow chamber having a cut-off frequency beyond the resonant frequency of said cavity resonator, for providing access to the interior of said resonator through a wall adjacent said oppositely disposed walls while producing total attenuation of interior microwave fields extending from said resonator into said waveguide section, and

(2) an end-closing adaptor means comprising a solid member having a central portion projecting axially into said resonator and apertured therethrough, the projecting portion of said member being productive of a decrease in the microwave length of said cavity and a corresponding increase in the resonant frequency of said cavity, said decrease in microwave length and said increase in frequency being equal and opposite respectively to the increase in said microwave length and the corresponding decrease in said frequency due to fringing effects

of said interior microwave fields about said aperture,

(c) a cavity coupling section being attached at one end of said cavity resonator opposite said adaptor assembly,

(d) a waveguide assembly adapted for transmission of microwave energy coupled to said resonator,

(e) at least one light source disposed in coaxial alignment with the interior longitudinal axis of said short waveguide section and adapted for energization by external power supply means, for transmitting light through said waveguide section into said resonator whereby said microwave resonant sample may be irradiated therein.

2. A microwave apparatus according to claim **1** wherein said cavity resonator, said cavity coupling section, and said waveguide assembly are rectangularly shaped, said waveguide assembly being attached to said cavity coupling section adjacent one end of said cavity coupling section.

3. A microwave apparatus according to claim **2** wherein said projecting portion of said solid member is rectangularly shaped.

4. A microwave apparatus according to claim **3** wherein said hollow waveguide section is rectangularly shaped and said solid member is rectangularly apertured therethrough.

5. A microwave apparatus according to claim **3** wherein said hollow waveguide section is cylindrically shaped and said solid member is cylindrically apertured therethrough.

6. A microwave apparatus according to claim **1**, wherein said cavity coupling section comprises a rectangular half-wavelength cavity section, a microwave coupler being mounted upon the top thereof, said coupler being adapted to couple microwave energy between said resonator and said waveguide assembly, said assembly and said resonator being rectangularly shaped, and said waveguide assembly being disposed on top of said coupling section.

7. A microwave apparatus according to claim **6** and further including a light detector adapted for energization by external power supply means and disposed in coaxial alignment with said light source, for measuring the optical absorption occurring in said microwave resonant sample when light is transmitted therethrough.

8. A microwave apparatus for use in gyromagnetic resonance studies comprising:

a cavity resonator having a detachable adaptor wall with an unobstructed aperture therein;

waveguide means coupled to said adaptor wall so that unrestricted optical radiation may be directed through said waveguide and said aperture to the interior of said cavity resonator;

said adaptor wall having a rectangular lip-like portion surrounding said aperture and projecting into such cavity resonator for reducing the effective microwave length of the cavity resonator by an amount substantially equal to the increase of effective microwave length resulting from said aperture whereby the resonant frequency of said cavity resonator is not varied by said adaptor wall.

9. A microwave apparatus comprising, in combination, a cavity resonator and at least one adaptor means comprising a short hollow waveguide section and a metallic field-displacing rectangular lip-like member projecting axially into said resonator for connecting the interior of said waveguide section with the interior of said resonator through at least one wall aperture in said resonator, whereby access is provided to the interior of said cavity; a cavity coupling section adjacent to one end of said resonator, and a waveguide assembly connected to said coupling section for transmitting microwave energy to and from said resonator; at least one light source disposed coaxially with the interior longitudinal axis of said hollow waveguide section for transmitting light through said waveguide section into the resonator; and a sample tube that is centrally contracted to form a pancake-shaped capillary disposed in the nodal plane of the electric field of said resonator, said capillary being adapted to contain a paramagnetic sample in aqueous solution therein, the face of said pancake capillary being disposed in the path of the transmitted light.

No references cited.

WALTER L. CARLSON, *Primary Examiner.*

M. J. LYNCH, *Assistant Examiner.*