Jan. 6, 1953 W. D. HERSHBERGER 2,624,840

MICROWAVE DETECTOR

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Fig. 1.

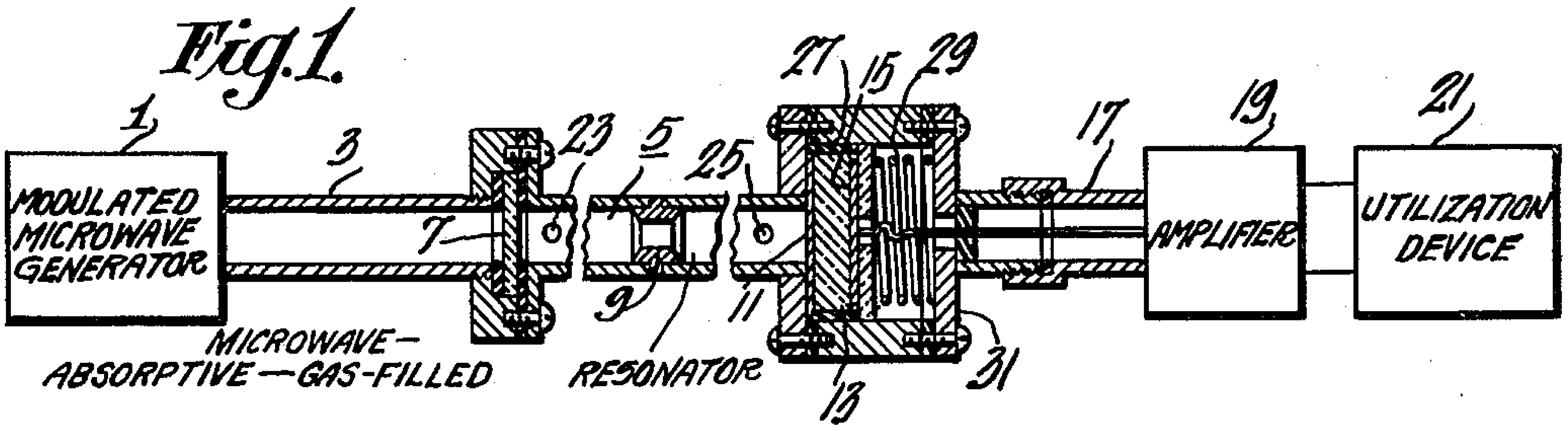


Fig. 2.

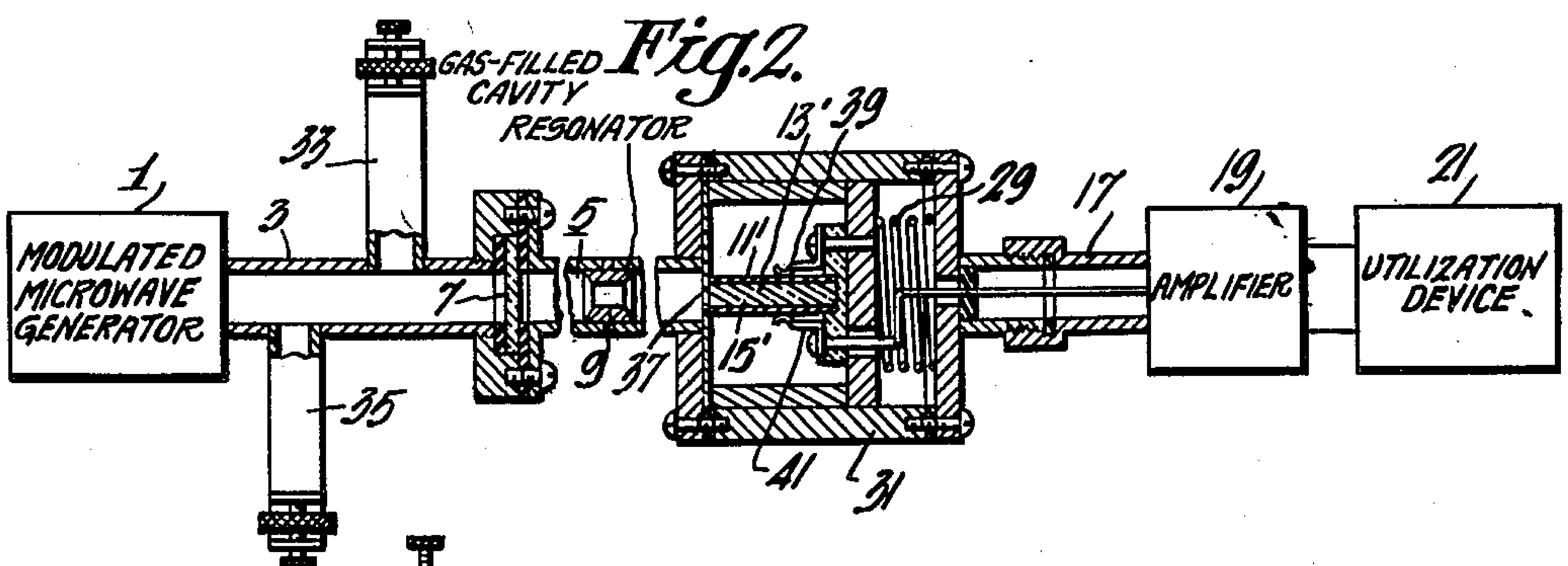
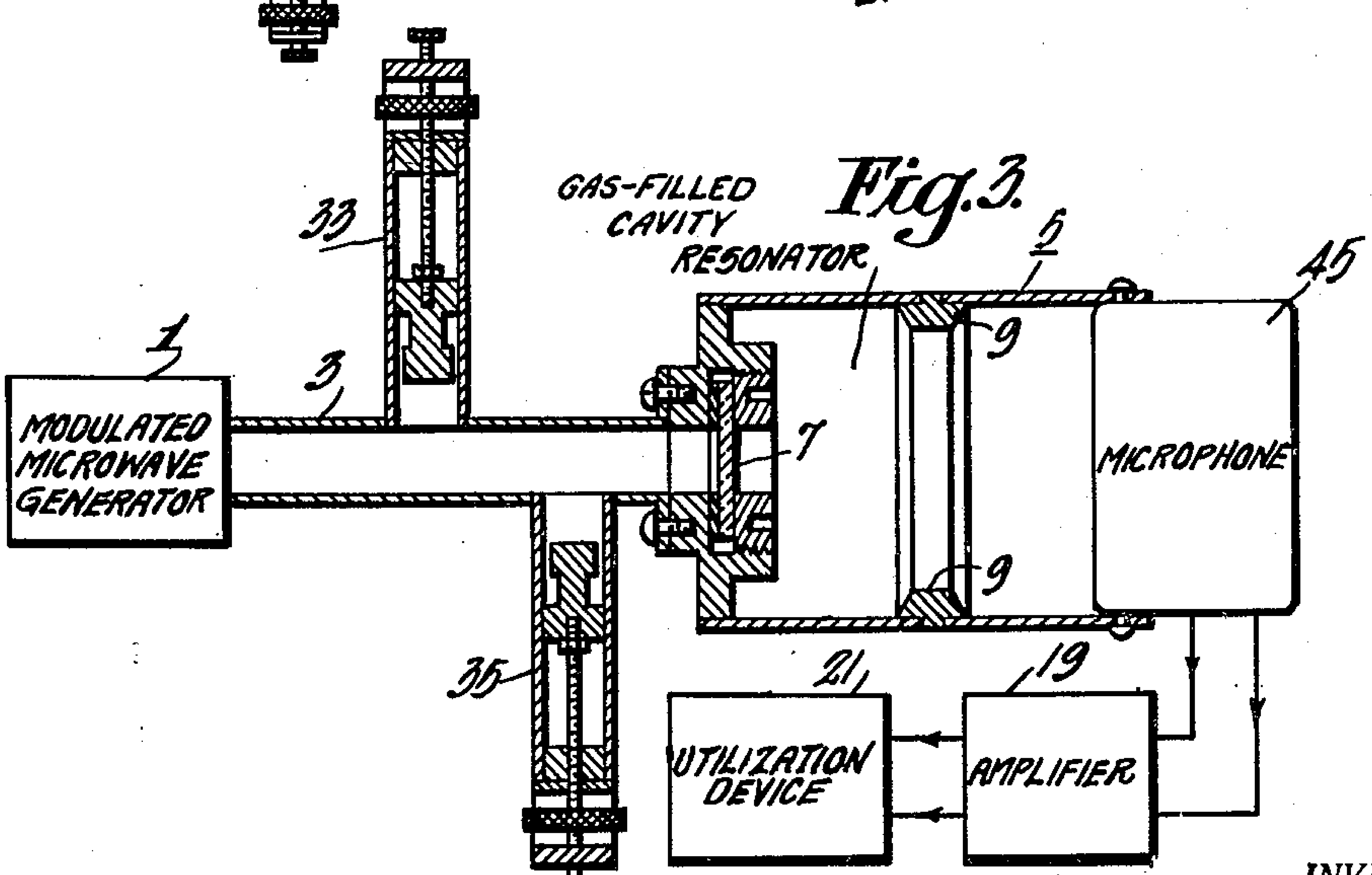


Fig. 3.



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MICROWAVE DETECTOR

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15 Claims. (Cl. 250—27)

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This invention relates generally to microwave transmission systems and more particularly to an improved method of and means for detecting microwave energy.

The instant invention is an improvement upon and includes modifications of the device disclosed and claimed in applicant's copending application Serial No. 540,429 filed June 15, 1944, which issued October 4, 1949 as Patent No. 2,483,768, and assigned to the same assignee as the instant application. In said copending application, a microwave-absorptive-gas filled cavity resonator, which is electrically resonant to a microwave carrier frequency and acoustically resonant to a modulation frequency superimposed upon said microwaves, is employed to convert the modulation component of the microwaves to acoustic waves which are radiated from a diaphragm comprising one wall of the cavity resonator.

The various modifications of the instant invention utilize the conversion of modulated microwaves into acoustic waves in the microwave absorptive gas enclosed within the cavity resonator to apply pressure variations to a piezo crystal or to a pressure responsive diaphragm or other pressure responsive device for generating electric potentials characteristic of the microwave modulation.

A first embodiment of the invention utilizes a cavity resonator enclosing a microwave absorptive gas, wherein one of the resonator walls is an electrode of a quartz piezo crystal. Pressure variations applied to the piezo crystal electrode provide mechanical distortion of the crystal, resulting in electric potentials between the crystal electrodes characteristic of the microwave modulation. The potentials derived from the piezo crystal electrodes are amplified in any conventional manner and applied to any desired utilization device such, for example, as an oscilloscope, an indicator, a meter, a counter or other electrical utilization device. For example the instant invention provides an extremely efficient and rugged indicator for a radar receiver system. Such an indicator has the advantage that it is substantially protected against overload signals which often occur in radar systems.

A modification of the instant invention includes means for tuning the cavity resonator by means of tuning stubs located in the transmission line connecting the modulated microwave source to the cavity resonator, and a conductive diaphragm terminating one end of the resonator for applying pressure variations endwise to a Rochelle salt

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piezo crystal for deriving electric potentials from the electrodes thereof characteristic of the microwave modulation. The Rochelle salt type of piezo crystal provides much greater sensitivity to weak microwave modulated signals than the quartz-piezo crystal since the piezo activity of Rochelle salt is much greater than that of quartz.

A second embodiment of the invention utilizes a gas-filled tuned cavity resonator which is electrically resonant to a microwave carrier frequency and acoustically resonant to a modulation frequency component of said microwaves wherein the pressure variations produced in the microwave absorptive gas enclosed within the resonator actuate a microphone, or other pressure responsive device, for generating electric currents which may be amplified and applied to a utilization device of the type described heretofore. Any type of microphone may be employed which is responsive to pressure variations or to displacement of a portion of the resonator wall.

The efficiency of the conversion process from microwave energy to acoustic energy may be as high as 34 percent, depending upon the type of coupling to the acoustic device and the efficiency of the microwave irradiation of the gas enclosed within the resonator. This may be shown from the following formulas wherein an increment of heat dQ generated by microwave absorption in the gas is

(1) $$dQ=dU+pdv+vdp$$

wherein dU is the incremental change of internal energy in the gas, p is the gas pressure, and v is the volume of the gas.

Since in the instant device the volume is held constant, $dv=0$, and

(2) $$dQ=dU+vdp$$

wherein dU represents the increase in the thermal energy in the gas at constant volume. This may be expressed as

(3) $$dU=C_v\,dT$$

wherein C_v is the specific heat of the gas at constant volume and dT is the increment of absolute temperature.

For a perfect gas

(4) $$pv=RT$$

wherein R is the universal gas constant or

(5) $$pdv+vdp=R\,dT$$

but since

(6) $$dv=0$$

then

$$dT=\frac{vdp}{R} \tag{7}$$

and

$$dU=C_v dT=\frac{C_v}{R}vdp=\frac{C_v}{\gamma R}vdp \tag{8}$$

wherein C_p is the specific heat at constant pressure, and γ is the ratio of specific heats

$$\frac{C_p}{C_v}$$

Therefore,

$$dQ=dU+vdp=\left(\frac{C_v}{\gamma R}+1\right)vdp \tag{9}$$

wherein *vdp* represents the potential energy of the acoustic standing wave in the interior of the cavity resonator. The efficiency E of the device is

$$E=\frac{vdp}{dQ}=\frac{1}{\frac{C_v}{\gamma R}+1} \tag{10}$$

which for ammonia (NH_3) is 34 percent.

The high frequency response limits of the devices disclosed herein may be determined either by the mechanical constants of the crystal and resonant acoustic cavity system, which may be partially controlled by proper design, or by the time limitations for the exchange of energy between the internal degree of freedom of the gas responsible for microwave absorption and the external degrees of freedom of the gas. The latter limitation is fundamental in devices of this type and may limit the high frequency response to from 10^5 to 10^7 cycles per second, depending on the lifetime of the excited state of the molecules of the gas.

Among the objects of the invention are to provide an improved method of and means for detecting microwave energy. Another object in the invention is to provide an improved microwave detector for modulated microwave energy. An additional object of the invention is to provide an improved microwave detector for modulated microwave energy wherein the modulated microwaves are converted to acoustic pressure variations which actuate a pressure responsive detector. A further object of the invention is to provide an improved microwave detector comprising a cavity resonator which is electrically resonant to a microwave frequency and which is acoustically resonant to a modulation component of said microwave frequency.

Additional objects of the invention include improved means for detecting modulated microwaves comprising a cavity resonator enclosing a microwave absorptive gas for generating pressure variations therein characteristic of the modulation of said microwaves. Another object is to provide an improved microwave detector employing a piezo crystal for generating electric potentials responsive to pressure variations induced in a microwave absorptive gas subjected to modulated microwave irradiation. An additional object is to provide an improved microwave detector for modulated microwave energy comprising a cavity resonator enclosing a microwave absorptive gas subjected to modulated microwave irradiation, and a microphone or other pressure or translational responsive device actuated by pressure variations induced in the microwave absorptive gas. A further object of the invention is to provide improved means for coupling modulated microwave energy into a cavity resonator which is electrically resonant to the microwave frequency and acoustically resonant to the modulated microwave frequency for deriving pressure variations characteristic of the microwave modulation component.

The invention will be described in greater detail by reference to the accompanying drawing of which Figure 1 is a cross-sectional, partially-schematic view of a first embodiment of the invention; Figure 2 is a cross-sectional, partially-schematic view of a modification of said first embodiment of the invention; and Figure 3 is a cross-sectional, partially-schematic view of a second embodiment of the invention. Similar reference characters are applied to similar elements throughout the drawing.

Referring to Figure 1 a modulated microwave generator 1 is coupled through a waveguide 3 into one end of a cavity resonator 5 having a microwave permeable window 7 opening into the waveguide 3. The cavity resonator 5 is proportioned to be electrically resonant to the carrier frequency of the microwaves and acoustically resonant to the microwave modulation frequency. Conductive projections 9 extending from opposite walls of the cavity resonator intermediate the ends of the resonator provide for electrical resonance in the portion of the resonator adjacent the waveguide window while substantially reducing microwave coupling to the remaining portion of the cavity resonator. However, the opening between the projecting elements 9 provides efficient acoustic coupling between the two end portions of the resonator.

The end of the resonator 5 remote from the microwave permeable window 7 is terminated by one electrode 11 of a quartz-piezo crystal having its electric axis parallel with the longitudinal axis of the cavity resonator 5. The piezo crystal 13 also includes a second electrode 15 on the opposite crystal face from the first electrode 11. The crystal electrodes may be plated or evaporated upon the opposite faces of the crystal. The crystal electrode 11 terminating the cavity resonator 5 is grounded thereto and the other crystal electrode 15 is connected through a transmission line 17 to the input of an amplifier 19. The amplifier 19 amplifies the modulation component of the modulated microwaves for applying operating potentials to a utilization device 21 of any of the types described heretofore.

Input potentials applied to the amplifier 19 are generated between the crystal electrodes 11 and 15 due to mechanical pressure variations applied to the crystal in response to acoustic pressure variations established in the cavity resonator 5 due to microwave irradiation of a microwave absorptive gas enclosed therein. A sample of the microwave absorptive gas, for example ammonia, may be confined within the resonator at suitable pressure, or the gas may be continuously circulated through the resonator 5 by means of an inlet port 23 and an outlet port 25.

The structure of the crystal support may be varied in any conventional manner providing the crystal electrode 11 is maintained in good contact with the adjacent end of the cavity resonator 5. For example an insulating ring or plate 27 may surround the ends of the crystal, and the crystal electrode 15 may be subjected to pressure by means of a coiled spring 29 enclosed within the crystal housing 31.

A modification of the device described by reference to Figure 2 includes microwave tuning plugs 33 and 35 mounted on the transmission waveguide 3 adjacent to the microwave permeable window 7, for tuning the resonator 5 through the window 7 for matching the resonator to the microwave transmission system. Also the quartz-piezo crystal 13 may be replaced by a Rochelle salt crystal 13' which is end-driven by a flexible conductive diaphragm 37 closing the end of the cavity resonator 5 remote from the microwave permeable window 7. The crystal electrodes 11' and 15' are plated upon or supported against the wide opposite faces of the crystal normal to the driving diaphragm 37. The crystal is supported in position and electrical contact is made to the crystal electrodes by means of spring contacts 39 and 41. The entire crystal contact and electrode assembly is maintained in contact with the diaphragm 37 at suitable pressure by means of the coil spring 29 enclosed within the crystal casing 31.

The output of the Rochelle salt piezo crystal is coupled through an amplifier to a utilization device in the same manner as described heretofore with respect to Figure 1. The Rochelle salt type of piezo crystal provides much higher output potentials in response to mechanical deformation of the crystal and hence provides a much more sensitive microwave detector than the quartz crystal type. However, the Rochelle salt type of piezo crystal is subject to wide operating variations due to absorption of moisture from the atmosphere. Such types of crystals also are easily damaged by mechanical shock and hence require much more careful handling than piezo crystals of the quartz type.

The tuning plugs 33, 35 may be of the type described in my copending application Serial No. 537,960 filed May 29, 1944, providing vernier adjustment of the position of the tuning piston with minimum noise signal introduction due to erratic sliding contact resistance between the piston and the tuning plug wall.

The device illustrated in Figure 3 is similar in all respects to the devices illustrated in Figures 1 and 2 with the exceptions that the resonator 5 is constructed of sufficient cross-sectional area to accommodate the translational element of any conventional type of microphone 45 which is supported by the resonator side walls to form one end wall of the resonator remote from the microwave permeable window 7. The microphone 45 may be of the pressure-responsive or translational-responsive type actuated by the pressure variations produced in the microwave absorptive gas confined within the resonator 5 due to modulated microwave irradiation. Currents or voltages derived from the microphone 45 are applied through the amplifier 19 to the utilization device 21 to actuate said device in response to the microwave modulation component of the irradiating microwaves.

Thus the invention disclosed comprises a cavity resonator confining a microwave absorptive gas for detecting the modulation component of modulated microwave signals. The modulated microwaves produce pressure variations in the microwave absorptive gas which actuate a piezo crystal, a microphone or other pressure- or translational-responsive device to generate electric potentials characteristic of the microwave modulation.

I claim as my invention:

1. A microwave detector comprising a cavity resonator enclosing a microwave absorptive gas, means for introducing microwave energy to be detected into said resonator to vary the pressure of said gas therein, and an electrical translating device subjected to said gas pressure within said resonator for directly converting said pressure variations into electrical energy characteristic of said microwave energy.

2. A microwave detector comprising a cavity resonator enclosing a microwave absorptive gas, means for introducing microwave energy to be detected into said resonator to vary the pressure of said gas therein, and a piezoelectric device subjected to said gas pressure within said resonator for directly converting said pressure variations into electrical energy characteristic of said microwave energy.

3. A microwave detector comprising a cavity resonator enclosing a microwave absorptive gas, means for introducing microwave energy to be detected into said resonator to vary the pressure of said gas therein, and an electro-acoustical device subjected to said gas pressure within said resonator for directly converting said pressure variations into electrical energy characteristic of said microwave energy.

4. A microwave detector comprising a cavity resonator enclosing a microwave absorptive gas, means for introducing microwave energy to be detected into said resonator to vary the pressure of said gas therein, and a piezoelectric device having one electrode disposed coincidentally with the inner wall of said resonator and subjected to said gas pressure for directly converting said pressure variations into electrical energy characteristic of said microwave energy.

5. A microwave detector comprising a cavity resonator enclosing a microwave absorptive gas, means for introducing microwave energy to be detected into said resonator to vary the pressure of said gas therein, a piezoelectric device having one electrode disposed coincidentally with an inner wall of said resonator and subjected to said gas pressure and having another electrode disposed outside of said resonator for directly converting said pressure variations into electrical energy characteristic of said microwave energy, and an amplifier responsive to said piezoelectric device.

6. A microwave detector comprising a cavity resonator enclosing a microwave absorptive gas, means including a microwave permeable window in said resonator for introducing microwave energy to be detected into said resonator to vary the pressure of said gas therein, a piezoelectric device having one electrode disposed coincidentally with an inner wall of said resonator and subjected to said gas pressure and having another electrode disposed outside of said resonator for directly converting said pressure variations into electrical energy characteristic of said microwave energy, and an amplifier responsive to said piezoelectric device.

7. A microwave detector comprising a cavity resonator enclosing a microwave absorptive gas, means for introducing modulated microwave energy to be detected into said resonator to vary the pressure of said gas therein at the modulation frequency, and an electrical translating device subjected to said gas pressure within said resonator for directly converting said pressure variations into electrical energy characteristic of said microwave modulation.

8. A microwave detector comprising a cavity resonator electrically resonant to a microwave carrier frequency and acoustically resonant to a carrier modulation frequency, said resonator enclosing a microwave absorptive gas, means for introducing modulated microwave energy to be detected into said resonator to vary the pressure

of said gas therein at said modulation frequency, and an electrical translating device subjected to said gas pressure within said resonator for directly converting said pressure variations into electrical energy characteristic of said microwave modulation.

9. A microwave detector comprising a cavity resonator electrically resonant to a microwave carrier frequency and acoustically resonant to a carrier modulation frequency, said resonator enclosing a microwave absorptive gas, means including a microwave permeable window in said resonator for introducing modulated microwave energy to be detected into said resonator to vary the pressure of said gas therein at said modulation frequency, means for tuning said window, and an electrical translating device subjected to said gas pressure within said resonator for directly converting said pressure variations into electrical energy characteristic of said microwave modulation.

10. A microwave detector comprising a cavity resonator acoustically resonant to a microwave carrier modulation frequency, said resonator enclosing a microwave absorptive gas, means including a microwave permeable window enclosing one end of said resonator for introducing modulated microwave energy to be detected into said resonator to vary the pressure of said gas therein at said modulation frequency, a conductive diaphragm enclosing another end of said resonator, and a piezoelectric device coupled to said diaphragm for directly converting said pressure variations into electrical energy characteristic of said microwave modulation.

11. A microwave detector comprising a cavity resonator electrically resonant to a microwave carrier frequency and acoustically resonant to a carrier modulation frequency, said resonator enclosing a microwave absorptive gas, means including a microwave permeable window enclosing one end of said resonator for introducing modulated microwave energy to be detected into said resonator to vary the pressure of said gas therein at said modulation frequency, a conductive diaphragm enclosing another end of said resonator, and a piezoelectric device end-coupled to said diaphragm for directly converting said pressure variations into electrical energy characteristic of said microwave modulation.

12. Apparatus according to claim 1 including means intermediate the ends of said resonator providing substantial electrical attenuation and close acoustic coupling between the portions of said resonator on opposite sides of said last-mentioned means.

13. A microwave detector comprising a waveguide enclosing a microwave absorptive gas, means for introducing microwave energy to be detected into said waveguide to vary the pressure of said gas therein, and an electrical translating device subjected to said gas pressure within said resonator for directly converting said pressure variations into electrical energy characteristic of said microwave energy.

14. A microwave detector comprising a waveguide having a gas-tight section therein enclosing a microwave absorptive gas, means for introducing microwave energy to be detected into said waveguide to vary the pressure of said gas within said gas-tight section, and an electrical translating device subjected to said gas pressure within said resonator for directly converting said pressure variations into electrical energy characteristic of said microwave energy.

15. A microwave detector comprising a wave conduit enclosing a microwave absorptive gas, means for introducing microwave energy to be detected into said conduit to vary the pressure of said gas therein, and an electrical translating device subjected to said gas pressure within said resonator for directly converting said pressure variations into electrical energy characteristic of said microwave energy.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,123,242	Hollman	July 12, 1938
2,372,193	Fisk	Mar. 27, 1945

OTHER REFERENCES

"Ammonia Absorption Measurements with Guided Waves and the Shape of a Special Line," by H. S. Howe.