Oct. 4, 1949. W. D. HERSHBERGER 2,483,768

MICROWAVE-ACOUSTIC WAVE TRANSLATOR

Filed June 15, 1944

Fig.1.

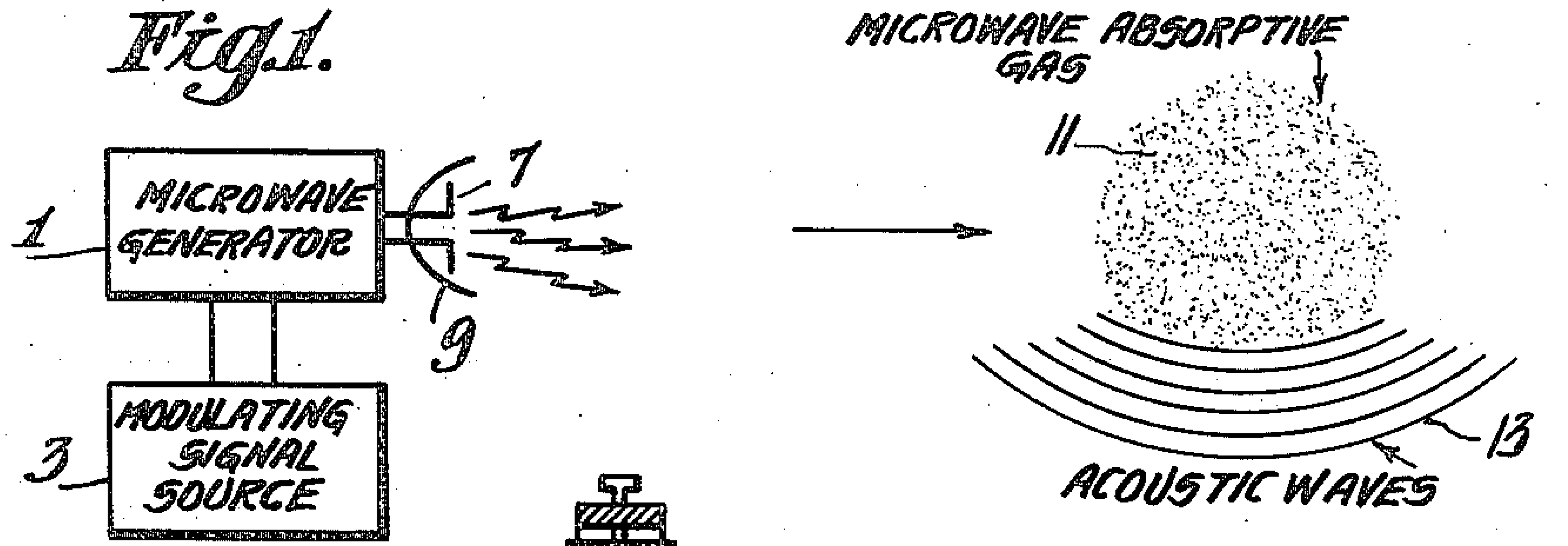


Fig.2.

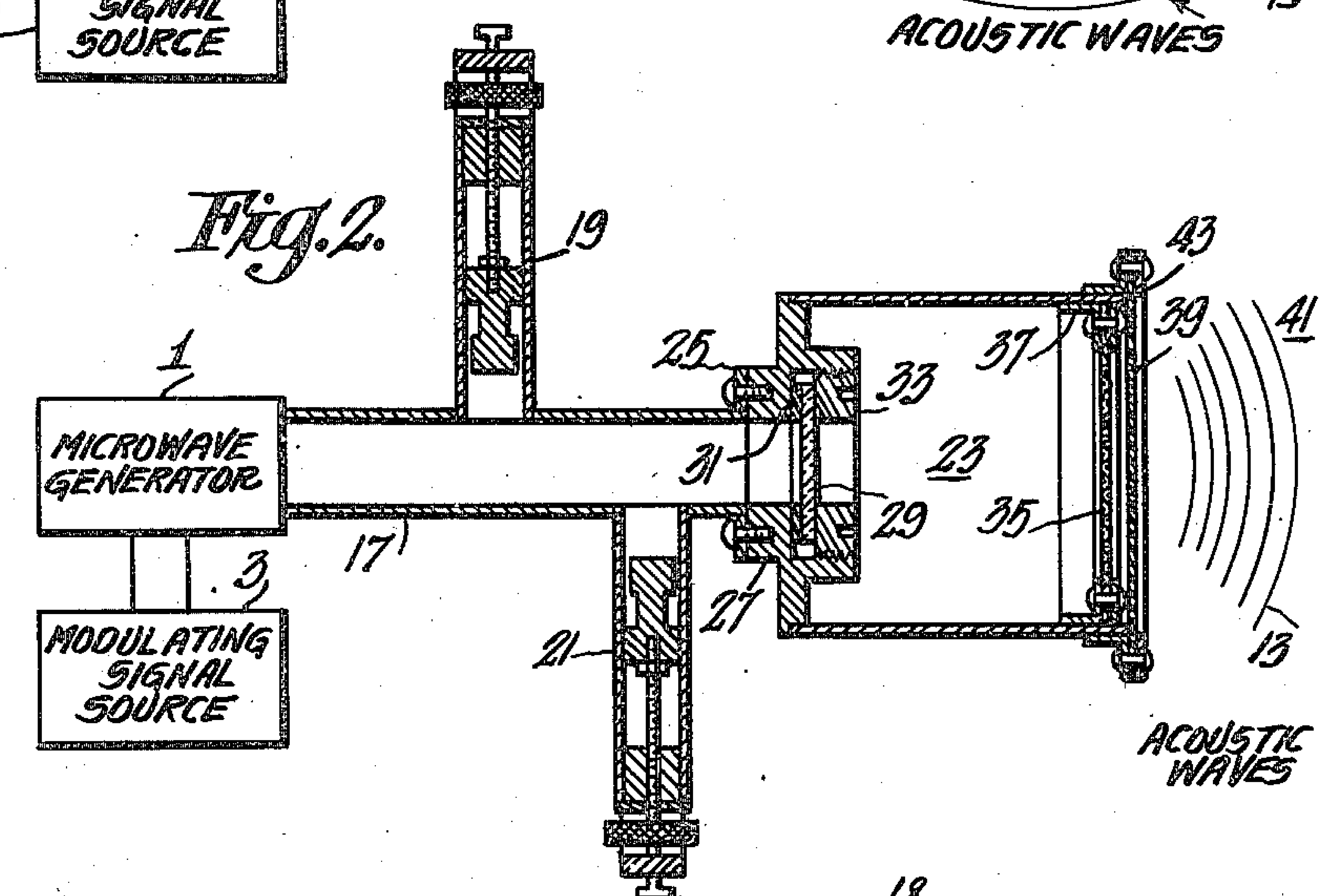


Fig.3.

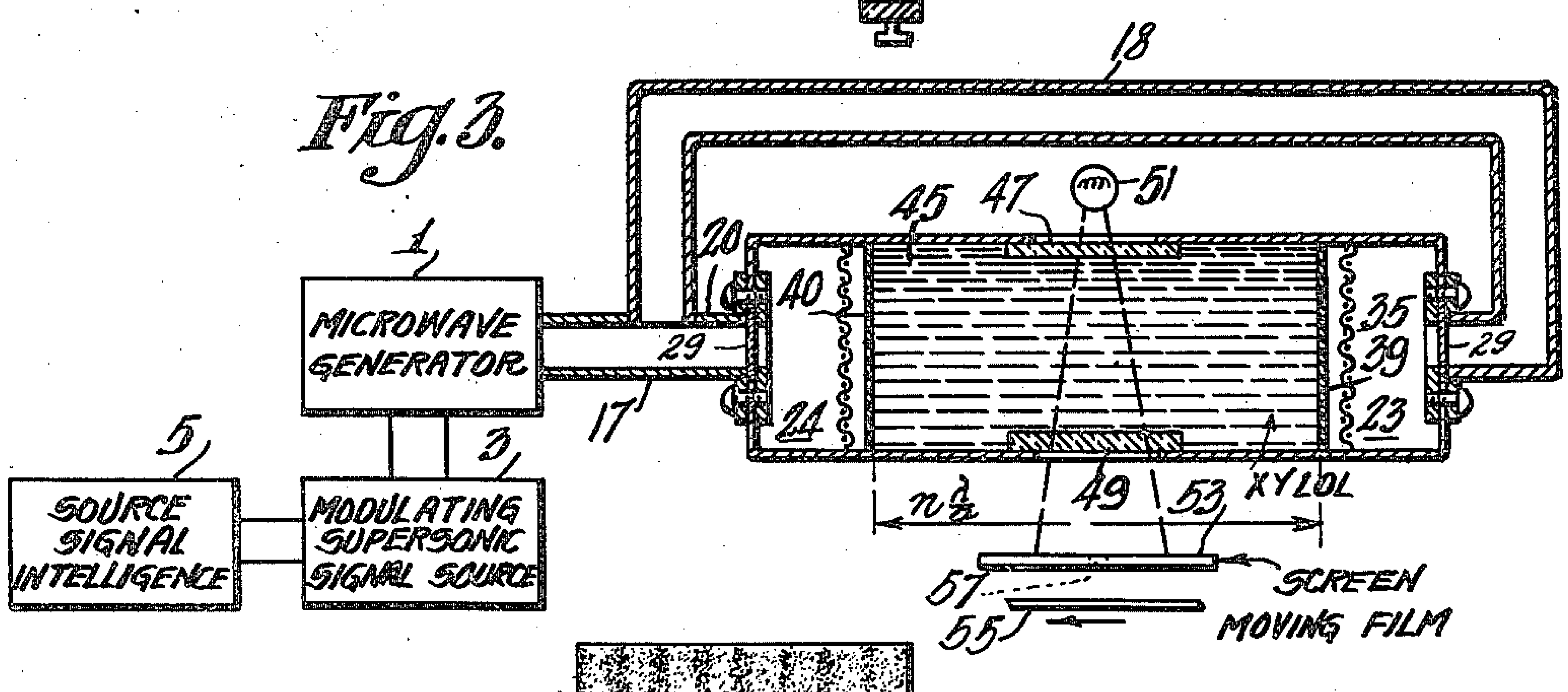
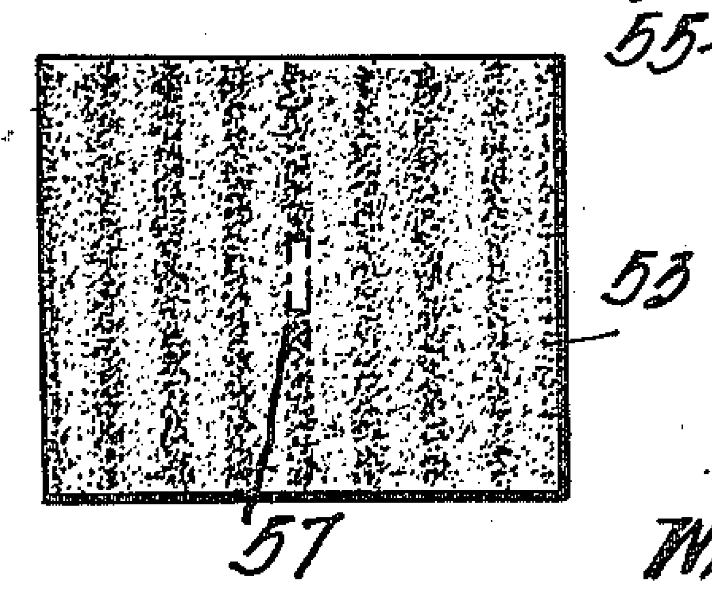


Fig.4.



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Patented Oct. 4, 1949 2,483,768

UNITED STATES PATENT OFFICE

2,483,768

MICROWAVE-ACOUSTIC WAVE TRANSLATOR

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Application June 15, 1944, Serial No. 540,429

16 Claims. (Cl. 250—6)

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This invention relates generally to microwave transmission and more particularly to improved methods of and means for generating acoustic waves in response to microwave energy absorption in certain gases.

The invention utilizes the characteristics of various gases which are substantially perfect dielectrics at most radio frequencies but which absorb considerable energy at certain other predetermined microwave frequencies. For example, in an article by Cleeton and Williams in Physical Review 45, 234 (1934), observations on microwave absorption in ammonia gas indicated that radiation having a wavelength of 1.25 centimeters will lose approximately 63 percent of its initial energy upon passing through 1.1 meters of ammonia gas in a non-metallic container at atmospheric pressure. It was noted further that the absorption frequency band is relatively wide since the absorption coefficient falls to approximately one-half of its maximum value at wavelengths of 1 centimeter and 1.5 centimeters. The observations described in the article identified heretofore were inspired by earlier general theoretic work on the energy levels of the ammonia molecule together with observations on the infra-red spectrum of this gas, but in all such prior experiments no attempt was made to determine, explain, or utilize the effect upon the gas of microwave absorption by said gas.

The instant invention relates to applicant's copending application, Ser. No. 537,960, filed on May 29, 1944, now Patent No. 2,471,744, wherein a microwave absorptive gas, enclosed within a cavity resonator which is coupled to a microwave transmission system, is heated by absorbed microwave energy to provide direct indications of transmitted microwave power as a function of the variation in gas pressure provided by the absorbed microwave energy. In said copending application, the microwave absorptive gas also comprises the thermometric medium whereby the gas pressure may be ascertained.

The present invention also relates to applicant's invention described in his copending application Ser. No. 540,428, filed June 15, 1944, now Patent No. 2,451,732, wherein the absorption of microwave energy of predetermined frequency by certain gases is employed to provide an adjustable light valve which comprises a gas prism providing variable refraction of a light beam directed through said light valve. The variable refractive properties of the gas prism comprising the light valve are due to the variations in pressure within predetermined regions of the enclosed mi-

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crowave absorptive gas in response to the irradiating microwave energy.

It is believed that the temperature and pressure changes in the microwave absorptive gas, due to selective dissipation therein of the irradiated microwave energy, is the result of molecular resonance effects incidental to excitation of the energy levels of the gas molecules. As employed herein, the term "molecular resonance" defines the characteristics or properties of an aggregation of gas molecules which give rise to the selective absorption of electromagnetic microwaves of a definite frequency or frequencies. The microwave energy absorption in the gas proper increases as the gas pressure is increased.

The instant invention depends upon applicant's observations that microwave absorptive gas when irradiated by modulated microwaves provides sonic or supersonic waves characteristic of the microwave modulation. Therefore, a source of microwaves modulated at audible or supersonic frequencies may be employed as an indicating device for indicating the presence of various microwave absorptive gases since any appreciable quantity of said gas present will generate corresponding audible or supersonic waves.

Another embodiment of the instant invention comprises a cavity resonator including a microwave absorptive gas and having a microwave-opaque, acoustic wave-permeable window for transmitting acoustic waves generated in the enclosed gas to a surrounding medium. This embodiment of the invention provides a convenient and relatively efficient loud speaker, or sound generator, wherein the enclosed microwave absorptive gas is irradiated by microwaves modulated at the desired acoustic frequency.

A third embodiment of the invention comprises means for employing one or more such acoustic wave generators to provide standing or traveling supersonic waves in an enclosed supersonic responsive medium such as, for example, xylol. The variation in pressure in the supersonic responsive medium provides corresponding variations in the light transmitting characteristics thereof which may be employed to provide an extremely efficient, flexible and convenient light valve for oscillographic or sound film recording purposes.

It should be understood that the terms "acoustic" or "supersonic" as employed herein includes all vibrations in gases, liquids, or solids which occur in either the audible or supersonic frequency spectra.

Among the objects of the invention are to provide an improved method of and means for employing modulated microwave energy to provide acoustic waves of frequencies corresponding to the microwave modulation. Another object of the invention is to provide an improved method of and means for indicating the presence of predetermined gases. A further object of the invention is to provide an improved acoustic wave generator. Another object is to provide an improved method of and means for converting supersonically modulated microwaves to supersonic waves in a desired elastic medium.

Other objects of the invention include an improved method of and means for modulating a light beam as a function of the modulation characteristics of a source of modulated microwaves. An additional object of the invention is to provide an improved method of and means for making oscillographic measurements. Another object is to provide an improved method of and means for measuring microwave power.

The invention will be described with reference to the accompanying drawings of which Figure 1 is a schematic block diagram of one embodiment thereof suitable for indicating the presence of predetermined gases, Figure 2 is a cross-sectional, elevational, partly-schematic view of a second embodiment of the invention providing an acoustic wave generator, Figure 3 is a cross-sectional, elevational, partly-schematic view of a third embodiment of the invention providing means for modulating a light beam, and Figure 4 is a plan view of the light screen forming a portion of said third embodiment of the invention. Similar reference characters are applied to similar elements throughout the drawing.

Referring to Figure 1, an efficient, flexible, and convenient detector for microwave absorptive gases comprises a microwave generator **1** having an output frequency corresponding to the absorption frequency of the gas to be detected. The microwave generator **1** is modulated by any conventional audible or supersonic signal source **3** coupled thereto. The modulated microwaves derived from the generator **1** are applied to a conventional microwave antenna such, for example, as a dipole **7** which may include, if desired, a wave reflector **9**.

The modulated microwave energy radiated from the antenna **7** is directed toward a space in which the microwave absorptive gas **11** is believed to be present. If any appreciable quantity of said microwave absorptive gas is subjected to the modulated microwave radiation, acoustic waves **13** will be generated, and may be detected either by ear or by any known acoustic wave detecting apparatus having the required sensitivity. It should be understood that the microwave generator, the modulating signal source, and the microwave radiating means may be combined in a suitably portable structure to provide convenient irradiation of any desired external region.

Referring to Figure 2, the modulated microwave output of the generator **1** is coupled to the input of a waveguide **17**, which includes reactive tuning plugs **19**, **21**, for matching the surge impedance of the waveguide to the impedance of a cavity resonator **23** which is coupled to the output end of the waveguide. A flange **25** on the output end of the waveguide **17** is bolted or otherwise fastened to a complementary collar **27** on one side of the cavity resonator **23**. The opening from the waveguide **17** into the cavity resonator **23** is sealed by a microwave-permeable, gas-tight window **29** which is maintained under pressure against a rubber gasket **31** by means of a

threaded annular ring **33**. The end of the cavity resonator remote from the window **29** includes a substantially microwave-opaque, acoustic wave-permeable screen **35** clamped in a supporting frame **37** secured to the ends of the walls of the cavity resonator **23**.

Immediately adjacent to, parallel with, and externally of the screen **35**, is secured a flexible diaphragm **39**, of suitable plastic material for transmitting acoustic waves from the gas enclosed within the cavity resonator **23** to a surrounding medium **41**. A convenient construction for supporting the diaphragm **39** comprises a second clamping frame **43** also supported by the ends of the cavity resonator walls.

It is is desired to generate supersonic vibrations of a single frequency in response to corresponding supersonic modulation of the microwave source, the cavity resonator **23** may be proportioned to resonate at said supersonic frequency in any manner known in the art. Alternatively, the cavity resonator **23** may be proportioned to resonate to the microwave carrier frequency to provide a substantially perfect termination for the waveguide transmission system thereby providing maximum absorption of microwave energy in the microwave absorptive gas enclosed within said resonator. Two tuning plugs **19**, **21**, coupled to the waveguide **17**, may be adjusted to match the terminating impedance of the cavity resonator **23** to the surge impedance of the waveguide **17** in order substantially to eliminate wave reflections from the cavity resonator. A further modification of the device comprises a cavity resonator proportioned so that a plurality of overlapping microwave modes are excited therein, and also proportioned so that no serious resonance effects are obtained at the desired acoustic modulation frequency.

The cavity resonator may be rectangular, or of any other convenient shape, and if rectangular, may be excited so that its resonant frequency f_{em} will be

$$(1) \qquad f_{em} = \frac{v_{NH_3}}{2}\left[\left(\frac{n_x}{l_x}\right)^2 + \left(\frac{n_y}{l_y}\right)^2 + \left(\frac{n_z}{l_z}\right)^2\right]^{1/2}$$

where v_{NH_3} is the speed of electromagnetic waves in the gas enclosed within the cavity resonator, n_x, n_y and n_z are the modal indices defining the modes of oscillation, and l_x, l_y, and l_z are the linear dimensions of the rectangular enclosure.

For the same rectangular cavity resonator, the frequencies f_s of the supersonic modes of oscillation are given by

$$(2) \qquad f_s = \frac{V_{NH_3}}{2}\left[\left(\frac{m_x}{l_x}\right)^2 + \left(\frac{m_y}{l_y}\right)^2 + \left(\frac{m_z}{l_z}\right)^2\right]^{1/2}$$

where V_{NH_3} is the speed of sound in the gas enclosed in the rectangular enclosure, m_x, m_y and m_z are the modal indices defining the acoustic mode of operation, and l_x, l_y, and l_z have the same significance as in Formula 1.

Since the microwave frequency in the enclosed gas is of the order of 10^6 times as large as the acoustic frequency in said gas, the acoustic frequency may be conveniently selected so that the cavity resonator resonates at both the microwave and acoustic frequencies. For example, a carrier frequency of 2.3 times 10^{10} cycles (corresponding to a wavelength of 1.3 centimeters) may, by reference to Formulas 1 and 2, be modulated by an acoustic frequency of the order of twenty-three thousand cycles if both types of waves are excited in the 1, 1, 0 mode. It should be understood that a large variety of other combinations of exciting frequencies and resonant characteristics are possible by proper choice of n_x, n_y and n_z, and m_x, m_y and m_z.

Thus it will be seen that the cavity resonator **23**, confining a microwave absorptive gas such as ammonia, may be resonated either to the irradiating microwave frequency, to the modulating supersonic or audible frequencies, or both, thereby providing an extremely flexible source of audible or supersonic acoustic waves having a single acoustic frequency, or extending over any desired band of acoustic frequencies as is desirable in a loud speaker.

Furthermore, the flexible membrane **39** may comprise either an acoustic wave-permeable material which does not vibrate substantially with the exciting acoustic waves, or it may comprise a vibrating diaphragm which vibrates sympathetically with the waves generated in the cavity resonator to generate corresponding acoustic waves in the surrounding medium.

Figure 3 comprises an embodiment of the invention which may be employed for modulating a source of light for oscillographic or acoustic-wave recording purposes. The output of the modulated generator **1** is coupled to the input of the waveguide **17** which includes branches **18** and **20**. The branch **18** transmits modulated microwave energy to a first cavity resonator **23** and the branch **20** transmits the remainder of the microwave energy to a second similar cavity resonator **24**. Both cavity resonators may be proportioned and designed substantially as described heretofore in Figure 2, whereby they resonate simultaneously to both the microwave carrier frequencies and a supersonic modulated frequency.

A source of desired signal intelligence **5** is connected to modulate a supersonic signal source **3** which in turn modulates the microwave generator **1**. The diaphragms **39**, **40**, of the cavity resonators **23**, **24** respectively, preferably are located any integral number of wavelengths apart at the operating supersonic modulating frequency. These diaphragms form the end walls of a supersonic trough **45** enclosing a supersonic-responsive fluid such as, for example, any type of xylol. Thus, standing, or if desired, travelling supersonic waves will be excited in the xylol confined within the supersonic trough **45** which will provide therein regions of varying fluid density.

Fluid-tight windows **47**, **49** in opposite side walls of the supersonic trough **45** provide means whereby a light beam derived from a light source **51** may be directed through the xylol to an image screen **53**.

If standing waves are established within the xylol in the supersonic trough **45**, the light beam directed through the xylol medium will provide a pattern of varying density on the light sensitive screen **53** as indicated in Figure 4.

If the supersonic signal source **3** is unmodulated by signal intelligence, the pattern on the light sensitive screen **53** will comprise stationary vertical lines which vary gradually from black to white. However, if the supersonic signal source **3** is modulated by signal intelligence such, for example, as audible sound waves, the pattern on the light sensitive screen **53** will comprise lines which rapidly vary in intensity. The signal intelligence modulation characteristics however, may be recorded upon a moving photographic film **55** disposed behind the image screen **53**, and illuminated through an aperture **57** at some predetermined point on the screen **53**.

Thus the third embodiment of the invention may be employed for recording sound, or other signal intelligence, on a moving photographic film by applying the signal intelligence to modulate the supersonic signal source which further modulates the microwave carrier source.

It should be understood that various modifications of the invention disclosed may be employed in accordance with known microwave and acoustic wave technique, and that the invention may be utilized for any desired type of oscillographic, television, or other light modulating apparatus. For example, since the acoustic wave amplitudes are a function of the microwave modulation characteristics, an acoustic wave amplitude measuring device may be employed in combination with the device of Figure 2 to indicate directly microwave power or microwave modulation percentage characteristics. Similarly, such measurements may be derived by optical or electrical analysis of the modulated light beam of the device of Figure 3.

Various other microwave absorptive gases have been tested and found to be satisfactory for microwave applications in apparatus of the type described heretofore. The following table indicates the microwave frequencies at which some of these various gases have been found to absorb considerable micromave energy as indicated by the absorption coefficients which have been measured:

Gas	Wave length	Power Absorption Coefficient per cm.
	Cm.	
Ethyl Chloride	1.25	25×10^{-4}
Ethylene Oxide	1.25	35×10^{-4}
Freon 22	1.25	17×10^{-4}
Monoethylamine	1.25	6.7×10^{-4}
Ammonia	1.25	84×10^{-4}
	3.2	16×10^{-4}

Thus the invention discloses several modifications of an improved method of and means for irradiating predetermined microwave absorptive gases by means of modulated microwaves of a predetermined frequency to generate acoustic waves in said irradiated gases. The invention may be employed, as described heretofore, for indicating the presence of certain gases, for generating acoustic waves characteristic of microwave modulation, or for modulating a light beam in accordance with said microwave modulation.

I claim as my invention:

1. The method of indicating the presence of a microwave absorptive gas in a space comprising generating modulated microwave energy, irradiating said space with said modulated energy to excite molecular resonance in said gas, and indicating the presence of said gas as a function of the magnitude of sonic waves characteristic of said modulation frequency which are generated by any of said gas present in response to said microwave energy absorbed thereby.

2. A reproducer for providing sonic vibrations in a surrounding medium in response to applied modulated microwave energy including a chamber for confining a microwave absorptive gas, means for irradiating said gas by said modulated energy to excite selective molecular resonance and thus to provide pressure variations in said gas characteristic of said microwave modulation, and means forming a portion of said

chamber for transmitting said pressure variations to said surrounding medium.

3. Apparatus of the type described in claim 2 characterized in that said chamber is proportioned to resonate electrically to said applied microwave energy.

4. Apparatus of the type described in claim 2 characterized in that said chamber is proportioned to resonate electrically to said applied microwave energy and simultaneously to resonate acoustically to said microwave modulation.

5. In a system including a microwave energy absorptive gas confined within a substantially gas-tight enclosure, the method of generating elastic vibrations in a fluid medium comprising irradiating said gas with acoustically modulated microwave energy to excite molecular resonance in said gas to generate heat therein in response to said energy absorbed by said gas, said generated heat providing pressure variations in said gas characteristic of said acoustic modulation of said irradiating microwave energy, and acoustically coupling said gas to said fluid medium to transfer said pressure variations thereto.

6. In a system including a source of microwave energy and a microwave energy absorptive gas confined within a substantially gas-tight enclosure, the method of generating elastic vibrations in a fluid medium comprising modulating said microwave energy source in accordance with signal intelligence, applying said modulated microwave energy to irradiate said gas to generate heat therein in response to said energy absorbed by said gas, said generated heat providing pressure variations in said gas characteristic of said microwave energy modulation, and acoustically coupling said gas to said fluid medium to transfer said pressure variations thereto.

7. Apparatus for generating elastic vibrations in a fluid medium including a substantially gas-tight enclosure for confining a microwave energy absorptive gas, means for irradiating said gas within said enclosure with acoustically modulated microwave energy to excite molecular resonance in said gas to generate heat in said gas in response to microwave energy absorbed thereby, said generated heat providing pressure variations in said gas characteristic of said acoustic modulation of said irradiating microwave energy, and means operative through said enclosure for acoustically coupling said gas to said fluid medium to transfer said pressure variations to said medium.

8. A receiver for translating modulated microwave energy to sonic vibrations in a fluid medium, including a substantially gas-tight enclosure, a microwave absorptive gas confined within said enclosure, means for microwave irradiating said confined gas by said modulated microwave energy to generate heat in said gas in response to the microwave energy absorbed thereby, said generated heat providing pressure variations in said gas at the modulation frequency of said irradiating microwaves, and means operable through said enclosure for translating said gas pressure variations to sonic vibrations in said fluid medium.

9. A sonic wave generator including a source of microwave energy, means for modulating said microwave energy in accordance with signal intelligence, a substantially gas-tight enclosure, a microwave absorptive gas confined within said enclosure, means including a microwave permeable window in said enclosure for microwave irradiating said gas by said modulated microwave energy to generate heat in said gas in response to the microwave energy absorbed thereby, said generated heat providing pressure variations in said gas at the modulation frequency of said irradiating microwaves, and means including a substantially microwave opaque-pressure responsive window in said enclosure for transmitting said pressure variations through said enclosure in the form of sonic waves.

10. A sonic wave generator including a source of microwave energy, means for modulating said microwave energy in accordance with signal intelligence, a substantially gas-tight cavity resonator proportioned to resonate to said microwave energy, a microwave absorptive gas confined within said cavity resonator, means including a microwave permeable window in said cavity resonator for microwave irradiating said gas by said modulated microwave energy to generate heat in said gas in response to the microwave energy absorbed thereby, said generated heat providing pressure variations in said gas at the modulation frequency of said irradiating microwaves, and means including a substantially microwave opaque-pressure responsive window in said cavity resonator for transmitting said pressure variations through said cavity resonator in the form of sonic waves.

11. A sonic wave generator including a source of microwave energy, means for modulating said microwave energy in accordance with signal intelligence, a substantially gas-tight cavity resonator proportioned to resonate electrically to said microwave energy and simultaneously to resonate acoustically to said modulation signals, a microwave absorptive gas confined within said cavity resonator, means including a microwave permeable window in said cavity resonator for microwave irradiating said gas by said modulated microwave energy to generate heat in said gas in response to the microwave energy absorbed thereby, said generated heat providing pressure variations in said gas at the modulation frequency of said irradiating microwaves, and means including a substantially microwave opaque-pressure responsive window in said cavity resonator for transmitting said pressure variations through said cavity resonator in the form of sonic waves.

12. Apparatus of the type described in claim 10 including variable reactive means for matching the impedances of said modulated microwave source and said cavity resonator to minimize wave reflections from said resonator to said source.

13. A sonic wave generator including a source of microwave energy, means for modulating said microwave energy in accordance with signal intelligence, a substantially gas-tight cavity resonator proportioned to resonate to said microwave energy, a microwave absorptive gas confined within said cavity resonator, means including a microwave permeable window in said cavity resonator for microwave irradiating said gas by said modulated microwave energy to generate heat in said gas in response to the microwave energy absorbed thereby, said generated heat providing pressure variations in said gas at the modulation frequency of said irradiating microwaves, an acoustically-permeable substantially microwave-opaque grid forming a second window in said enclosure, and a substantially gas-tight membrane covering said second window for transmitting said pressure variations through said enclosure in the form of sonic waves.

14. The method of employing modulated microwave energy for generating acoustic waves in a

microwave absorptive gas comprising irradiating said gas with said modulated microwave energy to excite molecular resonance in said gas to provide temperature variations therein and deriving acoustic wave energy characteristic of said microwave modulation in response to said temperature variations in said gas.

15. A method of radio communication employing a microwave absorptive gas comprising generating microwave energy, modulating said energy in accordance with signal intelligence, irradiating said gas by said modulated microwave energy to excite molecular resonance in said gas to provide temperature variations therein, and deriving sonic wave energy characteristic of said microwave modulation in response to said temperature variations in said gas.

16. In combination, a cavity resonator proportioned to resonate simultaneously to electromagnetic waves of a first predetermined frequency and to acoustic waves of a second predetermined frequency, a microwave energy selectively absorptive gas confined within said resonator, and means for introducing into said resonator electromagnetic wave energy of said first frequency, said energy being modulated at said second frequency, to excite selective molecular resonance and thus to provide pressure variations in said gas characteristic of said second frequency microwave modulation.

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