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E. H. JACOBSEN

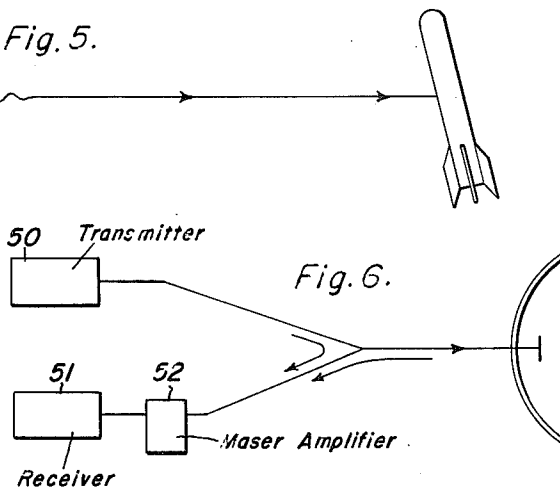
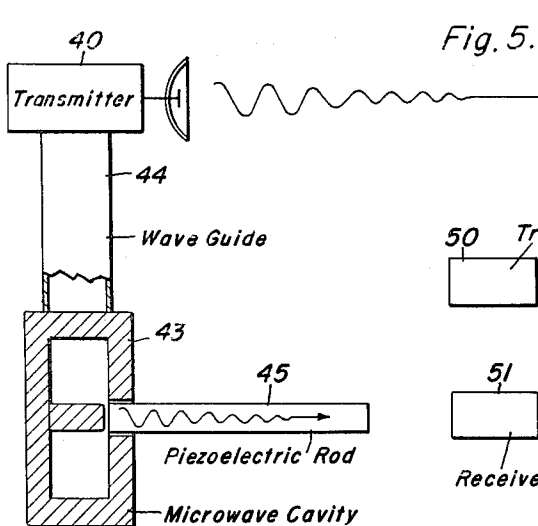
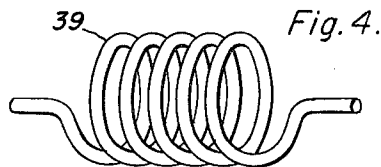
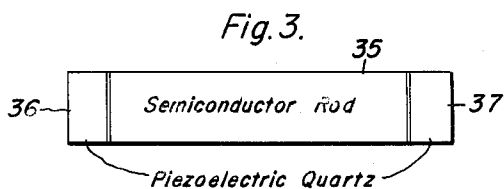
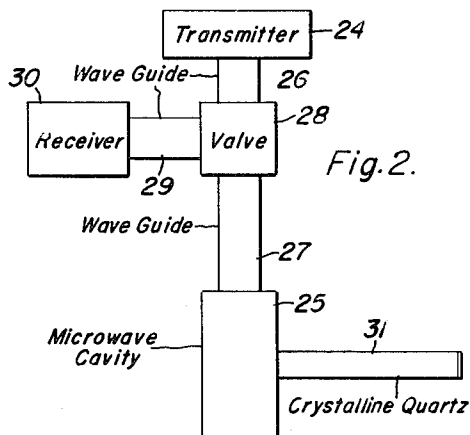
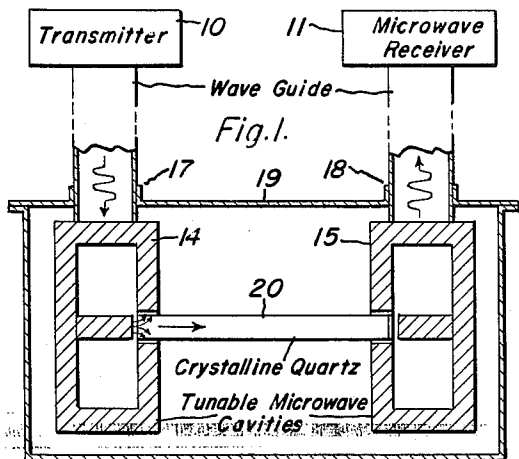
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APPARATUS FOR PRODUCING SONIC VIBRATIONS AT X-BAND

MICROWAVE FREQUENCIES AND HIGHER

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2 Sheets-Sheet 1



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## APPARATUS FOR PRODUCING SONIC VIBRATIONS AT X-BAND MICROWAVE FREQUENCIES AND HIGHER

Edward H. Jacobsen, Rochester, N.Y., assignor to General Electric Company, a corporation of New York  
Original application June 28, 1963, Ser. No. 291,349.  
Divided and this application Nov. 13, 1964, Ser. No. 418,937

3 Claims. (Cl. 343—5)

This is a division of my copending application Serial No. 291,349, filed June 28, 1963, which in turn is a continuation-in-part of my application Serial No. 99, filed January 4, 1960 and now Patent No. 3,105,966. My said copending application Serial No. 291,349 is assigned to the assignee of the present application.

The present invention relates generally to the art of signal transmission and is more particularly concerned with new apparatus for transmitting microwave signals of X-band and higher frequencies.

It has long been recognized by those skilled in the art that the successful generation and propagation of ultrasonic vibrations would hold important scientific and commercial possibilities. Efforts accordingly were made toward the realization of this objective and prior to the present invention, others succeeded in producing sound waves of frequencies up to one-kilomegacycle. On the basis of what was observed and learned in the course of these events, however, it was concluded by the experts that the maximum had been reached and that any effort to go into substantially higher frequency ranges could not succeed because of the inherent physical limitations of materials. In other words, those most highly skilled and knowledgeable in this special field concluded from their experimental results and analyses that they had closely approached, if not actually reached, the theoretical upper limit of sound wave frequency. On this basis, their further work with high frequency sound waves was limited exclusively to frequencies well below the X-band which is preferred as the operating range of radar systems.

In contrast to the stage of development of the prior art at the time when I made my surprising discoveries subsequently to be described, it is now possible by virtue of the present invention predicated upon these discoveries to transmit electromagnetic microwave signals through use of sound waves of ultrahigh-frequencies. Thus, I have successfully produced sound waves of frequencies which are orders of magnitude greater than the maximum produced prior to my present discovery and invention. Further, I have succeeded in causing these unique sound waves to produce electromagnetic microwave signals of corresponding frequencies so that the sound waves may constitute an integral part of the total transmission.

As one of my unexpected discoveries, I have found that under certain critical conditions sound waves of X-band and higher frequencies (i.e., phonons) can be produced and propagated over relatively great distances and over comparatively long periods of time. I have additionally discovered that these phonons can be transduced for readout as electromagnetic microwaves of the same frequency and that such readout can be accomplished after the phonons have been echoed through the propagating medium up to 400 times. The aforesaid critical conditions consist of temperature, input signal frequency, and the nature of the transducing and propagating medium or media. Thus, it is essential to the new results of this invention that the temperature of the phonon producing and propagating component be maintained below about 3.5° K., and for best results this tempera-

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ture should not be above 4.2° K. It is similarly vital to these new results that this phonon medium component be of certain form and that certain portions of it be shaped and related to each other with the unique precision. Further, it is necessary that electromagnetic microwaves of X-band frequency or higher be used as the energy source for the phonon generation.

I have found, in addition, that there are only certain solid bodies which will effectively transduce electromagnetic microwaves of X-band frequency and higher to produce ultrasonic waves or phonons of a corresponding frequency. I have now determined, however, that all solids apparently will transmit or propagate or support phonons once they are produced and that phonons may be delivered into any selected solid simply by placing the solid in proper position against a transducing element so that there is a mechanical transmission of the phonons from one body to the other. Transmission from a transducing element to a non-transducing element can, according to my invention, be repeated again and again so that a composite of a variety of non-transducing solid bodies can be assembled with a single transducing element or a plurality of such elements with the result that phonons can be caused to travel the full length of the composite article and can be caused to echo back and forth within the body for eventual readout as an electromagnetic microwave signal through a transducing element at one end or the other of the composite article. It is important, however, according to my further discovery, that there be a certain relationship established between the separate elements or parts of this article and additionally that the components themselves be formed with high precision as to certain portions. Thus, there is a critical interface relationship between the separate components and there is also a critical orientation relationship between all the interfaces within the composite article and between those interfaces and the end surfaces of the article.

I have found that solids of piezoelectric materials will function both as transducers to produce these new phonons from electromagnetic microwave signals and as a transmission medium through which the phonons will propagate, and that a suitable piezoelectric body can therefore be used instead of the composite article generally described above. However, I have also discovered that not all bodies of piezoelectric material have ability to produce these new phonons and, in particular, I have found that a Z-cut of quartz crystal rod (i.e. rod axis parallel to the crystallographic axis of the quartz) cannot be successfully employed for this purpose even though all the other necessary conditions are fully met. Thus, for a solid to serve in producing these new phonons, it must be of a material exhibiting piezoelectric characteristics at its surface within the critical operating temperature range of this invention. Examples of piezoelectric elements which are suitable for use as transducers in accordance with this invention are quartz crystal rods of the X-cut, the Y-cut, the AB-cut, and the BC-cut.

In view of the foregoing, I have conceived and actually reduced to practice a novel and useful species of the composite article generally described above. In this article, the main portion of the body consists of a Z-cut quartz crystal rod. A cap is provided at each end of this rod, the caps being made of X-cut quartz crystal rods and the parts being secured together by means of a suitable adhesive substance which at operating temperature in accordance with this invention is a solid body through which the phonons will readily propagate. In using this article, in accordance with this invention, I have found that new ultrahigh-frequency phonons once produced will propagate across the boundary or interface between the two

crystal elements and will propagate in the Z-cut rod regardless of any disparity in the longitudinal dimensions of the crystal elements. On the basis of this discovery, I have envisioned the possibility of incorporating semiconductor elements in place of Z-cut of quartz crystal rods in the apparatus of this invention and now have confirmed the feasibility of doing this.

I have envisioned uses of the present invention which may be made to great advantage. In particular, I have conceived the possibility of incorporating this invention in a Doppler radar system to substantially increase the accuracy and utility of that system. In this embodiment, the invention performs the function of a delay line and thus serves to store the original signal for later readout and comparison with a component of this signal returning from the object being ranged.

Another application of this invention making use of this delay line feature would have the objective of jamming radar through the means of phantom signals. The system, accordingly, would include a radar receiver, a transmitter and a delay line embodying this invention. A radar signal detected by the receiver would be stored in the novel delay line and subsequently readout and transmitted back to the original signal source at predetermined intervals.

In still another embodiment of this invention, I have conceived the incorporation of the present apparatus in a radar system to maintain the maser amplifier thereof in operating condition throughout the transmission period. In this instance, the ability of the novel apparatus of my present invention to transmit ultrahigh-frequency microwave energy via phonons is utilized to pump the maser cavity from a delay line with a drive signal which will desaturate the maser promptly following initial saturation by the original radar signal.

Those skilled in the art will understand that the present invention is useful also in high speed computers as a delay line because of its high storage capacity and because its stored signal access time is about  $10^{-9}$  seconds.

I have further conceived of using these new phonons to operate a superconducting element, that is, to destroy superconductivity gradually or abruptly and without changing either the temperature of the superconducting element or increasing any magnetic flux to which the superconductor is subjected at the time. In this embodiment of my invention, material such as tantalum, lead or niobium may be applied as a film or coating on one end of a composite article of this invention and suitable electrical or magnetic connections or couplings may be made to other elements, as will be described in detail below. Operation, then, would entail in general the creation of phonons in the composite article whenever the coating was to be changed from its superconducting state to its normal state, or to its transition state between superconducting and normal. The intensity of the phonon signal might be adjusted to provide control over the rate and the extent to which the superconducting state was to be destroyed.

In accordance with this invention, phonons may be produced at one end of a piezoelectric rod and electromagnetic microwave energy may subsequently be produced at the other end of the rod, the phonon signal being reflected and permitted to travel the length of the rod a number of times before readout. As an alternative, by providing a suitable barrier to the propagation of the phonons at one end of the rod, the phonon signals may be prevented from being coherently reflected so that one end of the rod serves the input transducing function while the other performs the output transducing function. In either instance, the invention apparatus may be operated intermittently so far as the electromagnetic microwave input signal is concerned so that there is time for the signal to be stored and then readout before the next electromagnetic microwave signal input to the system. An advantage of operating in this manner is that a highly sensitive receiver in the system to detect the relatively

weak regenerated microwave signals will be protected from the strong microwave input signals because of the delay between production of input signals and detection of regenerated and received signals.

Referring to the drawings accompanying and forming a part of this specification:

FIGURE 1 is a somewhat diagrammatic view of a system incorporating this invention and including two opposed microwave cavities shown in vertical section;

FIGURE 2 is a view similar to FIGURE 1 of a system embodying this invention in another form wherein the phonon signal is reflected and transmitted to a sensitive receiver protected from the strong microwave signal source;

FIGURE 3 is a side view of a quartz crystal rod illustrating propagation of phonon waves within this body;

FIGURE 4 is a view like FIGURE 3 of a rod-like body disposed in coil form composed of a semiconductor and a comparatively short piezoelectric crystal;

FIGURE 5 is a diagrammatic view of a Doppler radar system including apparatus of this invention and illustrating the principle of its operation as described above;

FIGURE 6 is a schematic view of a radar system including transmitter, antenna, maser amplifier and receiver;

FIGURE 7 is a diagrammatic view of the maser amplifier component of FIGURE 6 showing the apparatus of the present invention in operating relation to the maser amplifier unit;

FIGURE 8 is an elevational view, partly in section, of apparatus embodying the present invention; and

FIGURE 9 is a diagrammatic view of a device of this invention coupled into a superconducting circuit.

In general, the novel apparatus of this invention comprises a tunable electromagnetic microwave cavity and a transducer element coupled through the tunable cavity to a source of X-band or higher frequency signals, and means for reading out sonic signals produced by the transducing element. This invention, however, has an element or article aspect in that the above combination special new and useful results are obtained through the use of novel transducer elements having unique characteristics.

In one embodiment of this invention, the apparatus will incorporate a piezoelectric body in the form of a quartz crystalline rod which is provided at its end remote from the microwave cavity with a coating of material effective to scatter and dissipate ultrasonic waves or phonons traveling through the rod and thus prevent coherent reflection of the signal. In this system, the end portion of the rod within the microwave cavity serves as a transducer for the input electromagnetic microwave signal to the rod and the coated end serves as the transducer for phonon signals of the same frequency. The coating, accordingly, constitutes a terminal in this kind of delay-line component of a microwave signal transmission system.

In another preferred embodiment of this invention the piezoelectric body will be of rod-like form and its ends will be disposed parallel to each other and in planes at right angles to the longitudinal axis of the rod within  $0.01^\circ$ , and the rod will be smooth and round and have no prominences in its side surfaces greater than 5000 Angstroms in elevation. In addition, the body will be of material exhibiting piezoelectric characteristics at temperatures below  $35^\circ \text{K}$ . and the end faces of the bodies will be disposed in planes which are parallel to each other within an angle of about  $0.001^\circ$ . Advantageously, the rod may be a composite of piezoelectric and non-piezoelectric material with a suitable adhesive therebetween which will be effective to conduct, transmit or propagate phonon microwave signals from the piezoelectric material to the non-piezoelectric material and vice versa. Also, as indicated in the drawings, in some instances where a protracted delay is desirable, the rod-like phonon-propagating body may be made in the form of a coil and, here again,

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the body may be a composite of piezoelectric and non-piezoelectric materials, but its ends will be disposed in planes at right angles to the longitudinal center line of the rod in the end portions in the interest of maximum phonon signal strength as will subsequently be more fully described.

Still another desirable application of the present invention is its incorporation in a radar system including the maser amplifier in operative relation to a receiver. In this instance, as illustrated in FIGURES 6 and 7, the maser cavity is pumped with a microwave signal to maintain the maser constantly in operational condition through the means of a phonon-propagating and transducing quartz crystalline body or the like. In this system, phonons are produced in the piezoelectric body by means including a microwave cavity.

I have further envisioned, on the basis of my surprising discoveries, the use of a body of electrostrictive (i.e., ferroelectric) material in place of the piezoelectric body of the novel combination described above. The advantage would be that frequency doubling would result. Lead mataniobate would be satisfactory as the ferroelectric for this purpose because it does not go through a phase change when its temperature is reduced to that of liquid hydrogen. Unlike the semiconductors used in this invention, the ferroelectric bodies need not be composites, but will function as integral bodies to produce the new desired results. It is important, as in the case of the piezoelectric bodies, that the end faces of the ferroelectric bodies be "square-cut" in order to minimize the tendency toward attenuation of the high frequency signal, and preferably these end faces are provided with a high degree of precision as described above to maximize the strength and persistence of the sonic signal. Apparatus including an electrostrictive body combination with signal source means, tunable cavity means and a second tunable cavity means is disclosed and claimed in my aforesaid applications Serial No. 99 and Serial No. 291,349.

More in detail referring specifically to the drawings, the apparatus of FIGURE 1 comprises a source or transmitter 10 capable of producing electromagnetic microwave signals of X-band frequency or higher, a microwave electromagnetic signal receiver 11 and transformed means for converting electromagnetic microwave signals into phonon signals of the same frequency and for regenerating the electromagnetic microwave signal therefrom. The transformer means in this system includes tunable electromagnetic microwave signal cavities 14 and 15 suitably of conventional design and construction as known to those skilled in the art. Cavity 14 is connected to transmitter 10 by an electromagnetic signal waveguide 17 while cavity 15 communicates with receiver 11 through an electromagnetic signal waveguide 18 likewise of a suitable design. The microwave cavities 14 and 15 are disposed with their side openings in register and in accordance with the invention. A rod-like body 20 of crystalline quartz is disposed with one of its ends within the side opening of microwave cavity 14 and the other of its ends in its corresponding opening of microwave cavity 15. Rod 20, accordingly, is located in such a manner that electromagnetic microwave signals may be tuned and focused in cavity 14 and directed against the end of rod 20 therein to produce phonon microwave signals within the rod. Likewise, the other end of rod 20 is situated so that through transducing action of rod 20 in this region, electromagnetic microwave signals are produced from the phonon microwave signals and directed to and through waveguide 18 to receiver 11. Rod 20 at its end within cavity 15 is provided with a coating of indium of thickness sufficient that the phonons are scattered and dissipated and are not reflected back toward microwave cavity 14 in any coherent manner. This indium coating will suitably be at least 0.0001 inch in thickness, but it will not be so heavy as to materially adversely affect the transducing action of rod 20 and the regeneration of electro-

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magnetic microwave signals within cavity 15. This ability of indium and its equivalents to serve as terminating media is due to their lossy nature which is quite marked at liquid helium temperatures.

In the system illustrated in FIGURE 2, an X-band microwave frequency, electromagnetic signal transmitter 24 is arranged to direct electromagnetic microwave signals toward microwave cavity 25, again suitably of conventional or standard design, waveguides 26 and 27 serving with TR switch or valve 28 to connect transmitter 24 and microwave cavity 25. A receiver 30 also communicates with microwave cavity 25 through TR switch 28 and waveguide 27. The assembly is completed with a quartz crystalline rod 31 of piezoelectric characteristic which is related to microwave cavity 25 in the manner described above with reference to FIGURE 1 and microwave cavity 14 and rod 20. In this instance, however, the rod is not provided at its remote end with a coating of indium or equivalent material because of the desirability of having the ultrasonic vibrations or phonons reflected from the remote end back to the microwave cavity for regeneration of the delayed electro-magnetic microwave signal in cavity 25.

In the operation of the FIGURE 2 system, receiver 30, which is highly sensitive and therefore requires protection against direct high-amplitude signals directly from transmitter source 24, TR switch 28 serves to close the receiver against communication with the waveguide 27 during periods when microwave signals are traveling from transmitter 24 to cavity 25. Between these two emission periods, TR switch 28 connects the receiver and waveguide 29 to cavity 25 so that delayed microwave signals regenerated by transducing action of rod 31 can be utilized by receiver 30.

In FIGURE 3, a composite rod constituting a delay-line component in accordance with this invention is illustrated as comprising a rod 35 of suitable semiconductor material, such as a portion of a silicon crystal and two end caps of piezoelectric quartz 36 and 37. Caps 36 and 37 are of the same cross-sectional size and shape as rod 35 and are secured to the rod by an adhesive material which does not materially impair phonon-propagation throughout the length of the composite body. I found ordinary stop-cock grease to be an effective adhesive because of its ability to perform both the adhesive and phonon-propagating functions at normal operating temperatures (below 80° K.) of the cryogenic devices of this invention.

The element illustrated in FIGURE 4 is functionally the same as rods 20 and 31 and composite rod 35. It differs from those others, however, in its physical form, being of somewhat reduced cross-section and being a coil rather than a cylindrical article. As illustrated, it is not a composite body although it is contemplated that this may be made after the manner of the article of FIGURE 3. As in the case of all the others, however, it has end faces which are disposed in planes extending perpendicularly to the longitudinal end portions in each case. The primary advantage in this coil form of delay-line component is the protracted delay period which it affords due to the longer time required for phonon signals to traverse the body. I have found, surprisingly, that the tendency toward attenuation of the phonon signal in this novel component is not significantly different from the acceptable attenuation effects in the corresponding non-helical cylindrical components. Apparently, the important thing in minimizing these effects is the angularity of the end faces. So long as the ends of these elements are "square-cut," microwave electromagnetic signals of X-band frequency and higher can be effectively and efficiently transduced with the production of ultrasonic vibrations or phonons of the same frequency. A phonon-reflecting end face should for the same reason be "square-cut" but the importance of this angular relationship is diminished where, as in FIGURE 1, reflection is not de-

sired and the phonon signals are transduced after passage once through the full length of the piezoelectric body. In that case, the orientation of the microwave cavity with respect to the indium coated end face will determine the efficiency of the transducing action and the strength of the regenerated microwave signal.

The Doppler radar transmitter illustrated in FIGURE 5 is arranged to deliver a component of each of its electromagnetic signals to microwave cavity 43 through waveguide 44 for storage in the form of ultrasonic vibrations in piezoelectric, rod-like body 45. Thus, this transmitter bears the same relationship to the delay-line components of this invention just enumerated that transmitter 10 of FIGURE 1 bears to the corresponding elements of that system. Accordingly, it will be understood that a Doppler radar signal reflected back from the target to the transmitter and received there can be compared with the counterpart of that signal readout of rod 45. This general combination of elements is claimed in my aforesaid copending application, Serial No. 99.

In the system of FIGURE 6, transmitter 50 of X-band frequency electromagnetic microwaves is employed in a radar system which includes a receiver 51 and a maser amplifier 52 in operative relation to receiver 51. For the purpose of protecting amplifier 52 against high-amplitude signals from transmitter 50, a delay-line assembly of this invention is incorporated in the system as illustrated in FIGURE 7. Here again, a microwave cavity 55 is provided with a microwave guide 56 to bring electromagnetic signals of predetermined desired frequency from a suitable source of microwave energy (not shown) and a piezoelectric rod 58 is disposed with one end portion in cavity 55 for the production of ultrasonic vibrations of phonons, as described above. The other end portion of rod 58 is disposed in the cavity of maser amplifier 52 and with its end face in firm engagement with maser ruby element 59 so that the maser may be pumped with a signal of suitable strength and desired frequency by the transduced phonon energy of rod 58 to maintain it in operating condition throughout periods when high-energy signals are being received by the maser.

In a specific example of the use or operation of the FIGURE 7 system, the maser is pumped continuously through waveguide 60 with an electromagnetic signal of 25-kilomegacycles. At the same time, the maser is pumped with a microwave phonon signal of 15-kilomegacycles through the sub-combination of this invention comprising waveguide 56, microwave cavity 55 and piezoelectric rod 58. An electromagnetic signal of 10-kilomegacycles representing a reflected radar signal requiring maser amplification is delivered into the maser cavity via waveguide 61. Through the action of this unique combination of elements and functions, the reflected signal is amplified by the action of the maser and then delivered to receiver 51 through waveguide 62. There, thus, is no impairment of the maser operation due to high-amplitude microwave signals reaching the maser before or during the period when reflected signals requiring amplification are being received by the maser.

It is contemplated that the devices of this invention will operate as indicated above at extremely low temperatures. I have found that at room temperature attenuation tendencies are much too strong to permit coherent signal transmission in X-band or higher frequency phonon range even in very small or short piezoelectric rod-like bodies. I have, accordingly, concluded that there is an inherent or material limitation barring practical utility of components of the present invention and particularly piezoelectric portions thereof at temperatures above about 80° K. Thus, although not illustrated in all the accompanying drawings, those skilled in the art will understand that the phonon propagating and transducing components, such as bodies 20, 31, 35, 39, 45, and 58, are subjected to extremely low temperatures in use—preferably in the range of liquid hydrogen temperatures or even liquid he-

lium temperatures. Any suitable cryostat device may be employed for this purpose and, in the experiments which I have conducted, this device has taken the form of an enclosure for the microwave cavities and piezoelectric rod-like bodies. Thus, in FIGURE 1, the lower portions of waveguides 17 and 18 and the entire sub-assembly comprising microwave cavities 14 and 15 and the crystalline quartz rod 20 is housed in a liquid-tight enclosure or shell 19 submerged in and refrigerated by boiling liquid hydrogen so that throughout the operation period the temperature of the assembly within the enclosure does not exceed 25° K.

Those skilled in the art will gain a further and better understanding of the present invention from the following illustrative, but not limiting, example of the novel method and apparatus actually constructed and used:

#### Example

In using this invention and establishing that the new advantages and results set forth above can be obtained, I employed the cryogenic equipment illustrated in FIGURE 8. As illustrated in that drawing, the equipment comprises an outer dewar flask 70 containing a body of liquid nitrogen 71, an inner Dewar flask 73 containing a body of liquid helium 74 and means (not shown) for supporting flasks 70 and 73 in the positions illustrated. In addition, this equipment includes tunable microwave cavities 75 and 76 provided respectively with waveguides 77 and 78 extending upwardly from the microwave cavities disposed near the lower end of flask 73 to a point well above the top of the flask assembly. A magnetron transmitter (not shown) is operatively related to waveguide 77 at its upper end while waveguide 78 is equipped with a superheterodyne receiver (also not shown). A quartz crystalline rod 80 completes the assembly and is disposed with its ends in microwave cavities 75 and 76, this rod being permitted to rest against the walls of the microwave cavities or otherwise suitably supported.

With the nitrogen and helium boiling off continuously and rod 80 consequently being maintained at 4.2° K., and with the rod tuned to the microwave cavities, a pulse one microsecond in width of 10-kilomegacycles microwave electromagnetic energy was delivered from a 20-watt magnetron transmitter into waveguide 77 and microwave cavity 75. By means of the superheterodyne receiver, the resulting delayed signal produced in microwave cavity 76 by the transducing action at the end of rod 80 was detected, demodulated, and displayed on an oscilloscope. A total of 400 separate signals could thus be obtained and observed from one input pulse as a result of the sustained echoing action of the phonons produced in the quartz rod.

Microwave cavities 75 and 76 employed in this experiment each had a Q of approximately 2,000

$$Q = \frac{\text{energy stored}}{\text{energy loss due to resistance}}$$

Thus, the conversion factor was relatively small (about 0.1%), but was clearly sufficient for the present purposes.

Quartz rod 80 was 3 centimeters long and 0.3 centimeter in diameter and of uniform cylindrical shape. The ends of the rod were substantially planar and disposed in planes parallel to each other to within an angle of about 0.001°. Further, the plane of each end face of the rod was within 0.01° of 90° to the axis of the rod. The end surfaces were optically precise, that is, they had no irregularities or prominences greater than 5,000 Angstroms in elevation. The side of the rod was similarly optically precise and smooth to less than 5,000 Angstroms variation. The object in establishing these conditions and characteristics in the rod of X-cut quartz crystal was to minimize attenuation tendencies in the phonon signals produced in the rod in accordance with this invention and promote many reflections within the rod. The necessity for parallelism in the relationship of planar end

faces is attributable to the unusually strong tendency towards attenuation loss of phonon signals in the X-band frequency range and higher. The relationship in this regard is expressed in the formula

$$\alpha \sim \frac{\lambda \text{ sound}}{2nD}$$

where  $\lambda$  is the wave length of the phonon or sound wave in the quartz rod,  $n$  is the number of echoes to be obtained,  $D$  is the diameter of the rod and  $\alpha$  is the angle which the planar end faces of the rod define with each other.

It may be noted that the fact that the microwave cavities and the quartz rod were all submerged in liquid helium throughout the period of the experiment in no way impaired the operation of the apparatus or obtaining of the desired results. Likewise it may be noted that tuning of the microwave cavities and the rod by positioning the rod longitudinally relative to the cavities constituted no difficulty although the rod was not suspended from the microwave cavities or supported independently of them, but rested against side walls thereof.

In the embodiment of this invention illustrated in FIGURE 9, a rod 85 of material having piezoelectric characteristics at 4.2° K. is provided with a cap or coating 86 of niobium on one end and is disposed with its other end in receiving relation to a tunable electromagnetic microwave cavity (not shown) in the manner shown in FIGURE 5. Cap 86 is connected by leads 88 and 89 to a circuit including an electric current source and an inductance 90 in parallel with cap 86. With the cap and its leads maintained at a temperature below 9.2° K., the superconducting critical temperature of niobium, there is current flow through the leads and cap but no current flow through inductor 90 and this condition prevails until a sonic signal of X-band microwave frequency is produced in rod 85 as a result of transducing action of the end of the rod in receiving relation to an X-band electromagnetic microwave signal source. Current then flows through only inductor 90 because its electrical resistance is less than that of cap 85 in its normal resistive state. Thus, cap 85 constitutes a gate which is operative in response to ultrasonic signals and the apparatus of FIGURE 9 may therefore find significant utility in cryotron circuit assemblies in which it is preferable to quench the superconducting state other than by heating the gate element to above its critical temperature or subjecting it to a magnetic field higher than its superconducting critical magnetic field.

Having thus described this invention in such full, clear, concise and exact terms as to enable any person skilled in the art to which it pertains to make and use the same, and having set fourth the best mode contemplated of carrying out this invention, I state that the subject matter which I regard as being my invention is particularly pointed out and distinctly claimed in what is claimed, it being understood that equivalents or modifications of, or substitutions for, parts of the specifically described embodiments of the invention may be made without departing from the scope of the invention as set forth in what is claimed.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. Apparatus for transmitting and detecting microwave signals of frequency greater than about nine-kilomegacycles comprising a microwave signal source capable of generating high-amplitude microwave signals of at least nine-kilomegacycles frequency, a receiver to detect relatively low-amplitude microwave signals, wave guide means communicating with the said source and the receiver to receive and guide microwave signals, transformer means having a tunable microwave cavity communicating with the wave guide means to receive high-amplitude microwave signals and to deliver relatively low-amplitude microwave signals into the wave guide means for transmission to the receiver, a quartz crystal rod having an end portion removed from the microwave cavity and another end portion disposed in the microwave cavity to receive microwave signals and convert them into phonon signals for travel through the rod and for reconversion of phonon signals into relatively low-amplitude microwave signals, and microwave signal gate means operatively associated with the wave guide means to connect the signal source and the receiver alternately to the transformer microwave cavity whereby the receiver is protected against high-amplitude microwave signals without diminishing its utility as a receiver for relatively low-amplitude microwave signals.

2. Apparatus of the class described comprising a microwave signal source capable of producing signals of at least X-band frequency, a transformer means including a tunable microwave cavity to receive microwave signals from said source and concentrate and direct those signals, a quartz crystalline rod having one end portion disposed in the microwave cavity of the transformer and having its other end portion directed away from the transformer and disposed outside the microwave cavity, said other end portion of the rod being provided with a layer of indium at least 0.0001 inch thick covering the entire transverse surface of said other end portion of the rod, and a microwave receiver operatively associated with the microwave cavity to receive microwaves regenerated by the quartz rod.

3. In a radar system including a source of microwave energy of at least X-band frequency, a microwave receiver to receive reflected microwave signals from the transmitter, and a maser amplifier operatively associated with the receiver, the combination of a rod-like body in which phonons of X-band microwave frequency can propagate and be disposed to pump the maser, and means including a microwave cavity for producing X-band frequency phonons in the said body.

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