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MICROWAVE ENERGY TIME DELAY DEVICES

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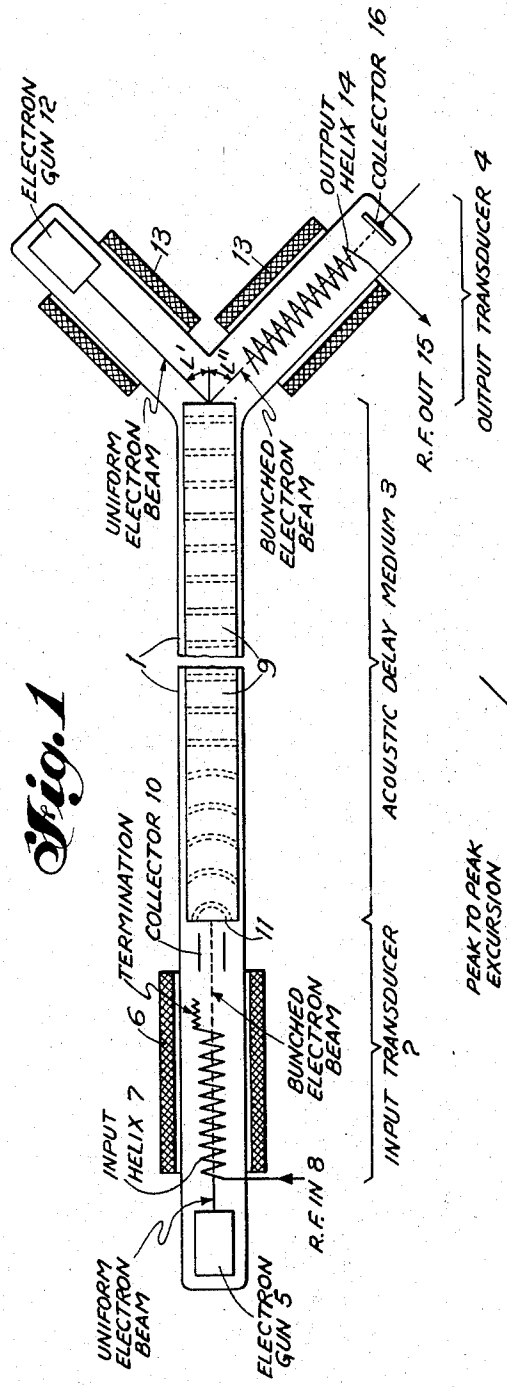


Fig. 1

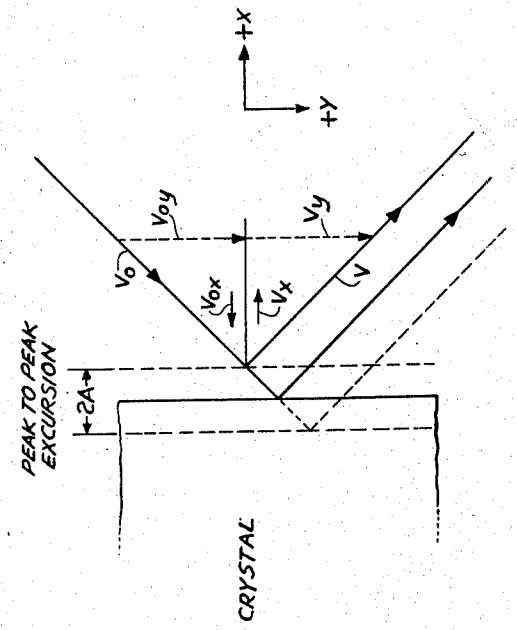


Fig. 2

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MICROWAVE ENERGY TIME DELAY DEVICES

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11 Claims. (Cl. 333—30)

This invention relates to time delay devices and more particularly to devices to time delay microwave radio frequency energy.

An object of this invention is the provision of a time delay device to delay in time microwave radio frequency energy occurring in a relatively wide bandwidth.

Another object of this invention is the provision of a time device to time delay microwave radio frequency energy occurring in a bandwidth of approximately one octave within the frequency range of 1,000 megacycles to 12,000 megacycles.

Still another object of this invention is the provision of a time delay device presenting a constant time delay to radio frequency energy over a relatively wide bandwidth in the microwave frequency range.

A further object of this invention is the provision of a device to time delay microwave frequency energy where the constant delay of the device is dependent upon the length of an acoustic medium formed from a single crystal of a selected material.

It is to be understood that the term "acoustic medium" as employed in the specification and claims means an elastic material that will propagate electrical energy in the form of a physical wave by an alteration in pressure, stress, particle displacement or particle velocity.

It is to be further understood that the term "single crystal" as employed in the specification and claims means a medium that has discontinuities between numerous particles forming the medium that are small in comparison with a wavelength at the operating frequency such that these discontinuities will not introduce excessive propagation losses in the medium.

In accordance with certain features of this invention there is provided a time delay device that includes within an evacuated envelope an acoustic medium of predetermined length, an input transducer and an output transducer. The input transducer which may take the form of a traveling wave tube converts input electrical energy to a density modulated beam of charged particles which is directed to impinge upon one end of said medium to establish a physical wave for travel along said medium cyclically related to the input electrical energy. The output transducer which may also take the form of a traveling wave tube is in coupled relation with the other end of said medium to convert said physical wave to output electrical energy cyclically related to the input electrical energy but time delayed with respect thereto by an amount proportional to the length of the acoustic medium.

The above-mentioned and other features and objects of this invention will become more apparent by reference to the following description taken in conjunction with the accompanying drawings, in which:

Fig. 1 is a schematic representation of a time delay device in accordance with the principles of this invention; and,

Fig. 2 is an enlarged view of the output end of the acoustic medium illustrating the conversion of the physical wave to a density modulated reflected beam of charged particles.

Referring to Fig. 1, the time delay device of this invention is illustrated as comprising three principal components, all of which are contained within a single evacuated envelope 1. The three components are input transducer 2, delay medium 3, composed of acoustic material, and output transducer 4.

Input transducer 2 includes an electron gun 5 with appropriate focusing electrodes and a beam collimating means, such as solenoid 6, external to envelope 1 for the formation of a beam of charged particles, such as an electron beam, and for maintaining the electron beam cylindrical. The electron beam is passed through a propagating structure in the form of a helix 7 or other velocity coupling device. The electron gun 5, solenoid 6, helix 7 and associated coupling circuits are fabricated in accordance with the theory governing traveling wave tube practice and are used here for the purpose of producing a "bunched" or density modulated electron beam wherein the electronic bunching is directly related to the frequency and amplitude of the radio frequency signal applied to the helix at terminal 8. It is to be understood that other means for producing bunched electron beams may be employed, for example, a klystron.

The delay medium 3 consists of an acoustic medium such as a single crystal 9 of appropriate length to produce the desired delay time. The density or velocity modulated electron beam produced by input transducer 2 is directed at one end of crystal 9 where the kinetic energy of the beam is partially transferred to crystal 9. A positively charged collector electrode 10 is provided close to the crystal surface 11 in order to complete the beam circuit. It is possible to deposit a thin metallic film on the crystal surface 11 for this purpose. As the bunching in the beam constitutes a cyclic variation in kinetic energy, the transfer of energy to crystal 9 will likewise be cyclic, thereby producing a cyclic physical disturbance at the point of transfer. Heat, of course, will be one product of the energy transfer. However, we are interested in the resulting physical displacement, or wave motion, which will propagate outward from the point of impact along the length of delay medium 3. If a slender rod-like crystal 9 is employed, with the velocity modulated electron beam directed at one end, the resulting wave will propagate along the length of the crystal, giving rise to a longitudinal or compressional mode acoustic vibration. The velocity of propagation of longitudinal vibration in solids is:

$$V=\sqrt{\frac{\lambda+2\mu}{P}}$$

where λ and μ are the Lamé elastic constants, λ equal to compressional stiffness modulus and μ equal to shear modulus, for the solid, and P is the density of the material.

The exact choice of material for use as the delay medium will depend upon the results required. Many materials possess suitable properties to accomplish the desired delay. However, it is clear that the material employed must be one obtainable as single crystals several inches in length. This arises from the general expression for the attentuation of acoustic vibrations in solids: $L=Af+Bf^4$ where the coefficients A and B are both related to particle size and f is the frequency of the acoustic vibrations. The first term is attributable to elastic hysteresis, hence, is a linear function of frequency while the second term describes Rayleigh scattering. It is evident that super-high frequency vibrations in a medium containing small particles will be subject to large losses. By contrast, the discontinuities present in a single crystal are merely molecular discontinuities and both coefficients will

be exceedingly small. Accordingly, the attentuation of wave propagation in the medium would be negligible.

Numerous synthetic single crystals of useful length are available commercially, including quartz, silver chloride, and lithium fluoride.

Output transducer 4 is employed to convert the delay acoustic energy to usable electric energy and comprises a second electron gun 12 including the necessary focusing electrodes and beam collimating means, such as solenoids 13, to maintain and produce a cylindrical beam of charged particles, such as an electron beam. The output transducer 4 also includes a short helix 14 and associated coupling circuits (not illustrated). The output transducer will again be fabricated in accordance with the prior theory governing traveling wave tube practice. The uniform unmodulated electron beam generated from an electron gun 12 is directed against the terminal or other end of the crystal 9 at an appropriate angle to the normal, as indicated by L'. It is known that an electron beam is subject to reflection at the surface of a crystal when certain necessary conditions have been met. Some of these conditions include among other the angle of incidence of the electron beam and the energy of the incident electrons. The reflection of incident electron beams from a surface of a crystal will not be gone into detail herein since it is common knowledge to those skilled in the art and may be found in numerous references, one of these references being for example the text book by J. D. Stranathan, entitled "The Particles of Modern Physics," page 541 to page 545, the Blakiston Company, 1942. The output coupling helix 14 is positioned in such a manner that the reflected electron beam passes through it. Coincident with the process of reflection, the electron beam incident on the terminal end of crystal 9 will be bunched or velocity modulated synchronously with the arrival of each acoustic wave projected from the input end 11 of crystal 9. The bunching of the output beam is due to the cyclic variation in beam path length with crystal face motion as is illustrated in Fig. 2. Fig. 2 is an enlarged view of the output face of the delay medium and a thin "ray" contained in the incident and reflected electron beam. It may be shown that the velocity modulation of the electron beam has a cyclic variation dependent upon the crystal face motion. Assume $L'=L''$ and the movement of the output or terminal end of crystal 3 varies according to sin wt where $wt=2\pi ft$ is proportional to the frequency of the physical wave with a peak-to-peak excursion of 2A employing trigonometric relations

$$\sin L'=\frac{V_{oy}}{V_o}$$

and

$$\cos L''=\frac{V_{ox}}{V_o}$$

From these relations and above assumptions

$$V_y=V_{oy}=V_o \sin L'$$

$$V_x=-V_{ox}+2\frac{d}{dt}(A \sin wt)$$

$$=-V_o \cos L'+2A\mu \cos wt$$

This latter expression expresses mathematically that the density modulation is due to the cyclic variation in beam path length with crystal face motion.

The bunched output beam will induce a signal in the output helix 14 which is coupled from terminal 15. The signal at terminal 15 is a substantial replica of the signal applied at terminal 8 but delayed with respect thereto by a value proportional to the length of medium 3. A collector electrode 16 is provided to complete the beam circuit.

In its simplest form, the device described will produce a train of delayed replicas of the input signal. If it is assumed, by way of example, that the input signal consists of a substantially rectangular pulse, two microseconds in duration, and that the one way or primary delay time through the single crystal 9 is equal to T, then the output signal will contain a number of rectangular pulses of two microseconds' duration each, wherein the first or primary pulse appears at a time T after the introduction of the input signal, the subsequent secondary pulses appearing after intervals equal to 2T. The amplitude of the primary delay pulse will be smaller than the amplitude of the input pulse due to the insertion loss of the device and the amplitude of the subsequent secondary pulses will continuously decrease in accordance with a decay decrement characteristic of the parameters involved.

A single input pulse will be productive of a number of output pulses, reflections, due to the impedance mismatch encountered at each end of crystal 9. The resulting decay decrement determined by the magnitude of mismatch along with the loss in transit.

In a more complex design, the secondary output signals may be substantially attenuated, that is, eliminated for all practical purposes, through the use of suitable matching devices. These may take various forms, but would all serve the same function, namely, that of absorbing or dissipating all incident energy. Most of the area of the output end of crystal 9 would be coated with a suitable absorber leaving only a small area uncoated for reflection of the electron beam. Assuming near perfect absorption by the absorber, only a small amount of energy will then be reflected from the uncoated area which would be further decreased to a negligible amount by the attentuation of medium 3.

While I have described above the principles of my invention in connection with specific apparatus, it is to be clearly understood that this description is made only by way of example and not as a limitation to the scope of my invention as set forth in the objects thereof and in the accompanying claims.

I claim:

1. A device for time delaying input electrical energy comprising within an envelope an acoustic medium of predetermined length, an input transducer to convert said input electrical energy to a density modulated beam of charged particles, means for directing said beam to impinge upon one end of said medium to establish a physical wave for travel therealong cyclically related to the density modulation of said beam, and an output transducer in coupled relation to the other end of said medium to convert said physical wave to output electrical energy cyclically related to said input electrical energy but time delayed with respect thereto by an amount proportional to said predetermined length.

2. A time delay device comprising within an envelope, means for generating a beam of charged particles, an acoustic medium of predetermined length, means for directing said beam to impinge upon one end of said medium to establish a physical wave for travel therealong, means for density modulating said beam at a predetermined frequency, and means in coupled relation to the other end of said medium to convert the physical wave at said other end to electrical energy time delayed with respect to said density modulation by an amount proportional to said predetermined length.

3. A time delay device comprising within an envelope, an acoustic medium, a first traveling wave tube type of configuration projecting a density modulated electron beam upon one end of said medium to establish a physical wave for travel therealong to the other end of said medium for cyclic longitudinal movement thereof, and a second traveling wave tube type configuration coupled to said other end to extract from the longitudinal movement of said other end electrical energy delayed with respect to the establishment of said physical wave.

4. A time delay device comprising within an envelope, an acoustic medium of predetermined length, an electron gun for projecting a beam of electrons to impinge upon one end of said medium to establish a physical wave for travel therealong to the other end of said medium for cyclic variation thereof, means for density modulating said beam in accordance with an electrical signal coupled thereto to set up said cyclic variation, a second electron gun for projecting a beam of electrons on said other end of said medium density modulating the electron beam of said second electron gun, and means in coupled relation to the electron beam of said second electron gun to extract electrical energy from the density modulation thereof.

5. A time delay device comprising within an envelope, an acoustic medium of predetermined length, an electron gun for projecting a beam of electrons to impinge upon one end of said medium to establish a physical wave for travel therealong to the other end of said medium for cyclic variation thereof, a radio frequency slow wave propagating structure in coupled relation to said beam of electrons for density modulating said beam in accordance with an electrical signal coupled thereto to set up said cyclic variation, a second electron gun for projecting a beam of electrons on said other end of said medium at a given angle for reflection therefrom, the cyclic variation of said other end of said medium density modulating the electron beam of said second electron gun, and means in coupled relation to the electron beam of said second electron gun to extract electrical energy from the density modulation thereof.

6. A time delay device comprising within an envelope, an acoustic medium of predetermined length, an electron gun for projecting a beam of electrons to impinge upon one end of said medium to establish a physical wave for travel therealong to the other end of said medium for cyclic variation thereof, means for density modulating said beam in accordance with an electrical signal coupled thereto to set up said cyclic variation, a second electron gun for projecting a beam of electrons on said other end of said medium at a given angle for reflection therefrom, the cyclic variation of said other end of said medium density modulating the electron beam of said second electron gun, and a radio frequency slow wave propagating structure in coupled relation to the electron beam of said second electron gun to extract electrical energy from the density modulation thereof.

7. A time delay device comprising within an envelope, an acoustic medium of predetermined length, an electron gun for projecting a beam of electrons to impinge upon one end of said medium to establish a physical wave for travel therealong to the other end of said medium for cyclic variation thereof, a radio frequency slow wave propagating structure in coupled relation to said beam of electrons for density modulating said beam in accordance with an electrical signal coupled thereto to set up said cyclic variation, a second electron gun for projecting a beam of electrons on said other end of said medium at a given angle for reflection therefrom, the cyclic variation of said other end of said medium density modulating the electron beam of said second electron gun, and a radio frequency slow wave propagating structure in coupled relation to the electron beam of said second electron gun to extract electrical energy from the density modulation thereof.

8. A time delay device comprising within an envelope, an acoustic medium of predetermined length, an electron gun for projecting a beam of electrons to impinge upon one end of said medium to establish a physical wave for travel therealong to the other end of said medium for cyclic variation thereof, a helical propagating structure in coupled relation to said beam of electrons for density modulating said beam in accordance with an electrical signal coupled thereto to set up said cyclic variation, a second electron gun for projecting a beam of electrons on said other end of said medium at a given angle for reflection therefrom, the cyclic variation of said other end of said medium density modulating the electron beam of said second electron gun, and means in coupled relation to the electron beam of said second electron gun to extract electrical energy from the density modulation thereof.

9. A time delay device comprising within an envelope, an acoustic medium of predetermined length, an electron gun for projecting a beam of electrons to impinge upon one end of said medium to establish a physical wave for travel therealong to the other end of said medium for cyclic variation thereof, means for density modulating said beam in accordance with an electrical signal coupled thereto to set up said cyclic variation, a second electron gun for projecting a beam of electrons on said other end of said medium at a given angle for reflection therefrom, the cyclic variation of said other end of said medium density modulating the electron beam of said second electron gun, and a helical propagating structure in coupled relation to said beam of electrons in coupled relation to the electron beam of said second electron gun to extract electrical energy from the density modulation thereof.

10. A time delay device comprising within an envelope, an acoustic medium of predetermined length, an electron gun for projecting a beam of electrons to impinge upon one end of said medium to establish a physical wave for travel therealong to the other end of said medium for cyclic variation thereof, a helical propagating structure in coupled relation to said beam of electrons for density modulating said beam in accordance with an electrical signal coupled thereto to set up said cyclic variation, a second electron gun for projecting a beam of electrons on said other end of said medium at a given angle for reflection therefrom, the cyclic variation of said other end of said medium density modulating the electron beam of said second electron gun, and a helical propagating structure in coupled relation to said beam of electrons in coupled relation to the electron beam of said second electron gun to extract electrical energy from the density modulation thereof.

11. A time delay device comprising within an envelope, a single crystal having a predetermined length, an electron gun for projecting a beam of electrons to impinge upon one end of said crystal to establish a physical wave for travel therealong to the other end of said crystal for cyclic variation thereof, a helical propagating structure in coupled relation to said beam of electrons for density modulating said beam in accordance with an electrical signal coupled thereto to set up said cyclic variation, a second electron gun for projecting a beam of electrons on said other end of said crystal at a given angle for reflection therefrom, the cyclic variation of said other end of said crystal density modulating the electron beam of said second electron gun, and a helical propagating structure in coupled relation to said beam of electrons in coupled relation to the electron beam of said second electron gun to extract electrical energy from the density modulation thereof.

No references cited.