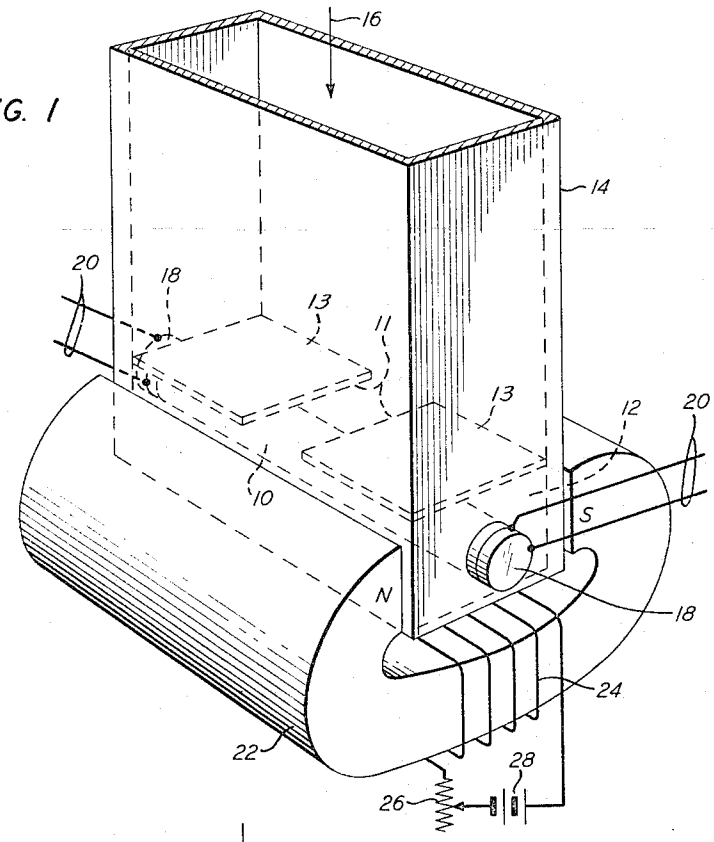
Dec. 13, 1966 W. P. MASON 3,292,114

ULTRASONIC DELAY LINE FOR MICROWAVE AND HIGHER FREQUENCIES

Filed Aug. 16, 1963

FIG. 1



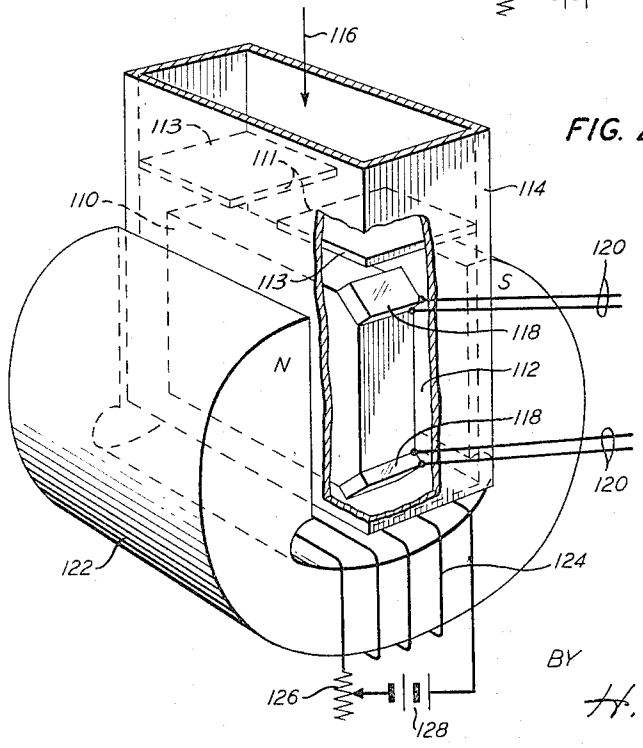


FIG. 2

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ULTRASONIC DELAY LINE FOR MICROWAVE AND HIGHER FREQUENCIES

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1 Claim. (Cl. 333—30)

This invention relates to ultrasonic delay lines. More particularly, it relates to delay lines for use with ultrasonic wave energy at frequencies in the megacycle and higher frequency ranges.

As is well known to those skilled in the art, fused silica ultrasonic delay lines offer many substantial practical advantages for use in systems employing ultrasonic energy of a frequency within the range of from 10,000 cycles per second to several kilomegacycles per second. However, since the attenuation loss in such prior art lines increases substantially as the square of the frequency of the ultrasonic energy, operation in the kilomegacycle range, and even the megacycle range, may involve prohibitively high energy loss in the line.

To overcome this objection, this invention proposes that the ultrasonic energy be amplified as it traverses the line. It has been discovered that this can be achieved if a limited amount of specific impurities is introduced into the fused silica of the delay line, the terminal or transducer surfaces of the line are made smooth and aligned accurately to be perpendicular to the path of the ultrasonic energy, the line is subjected to a unidirectional magnetizing field of appropriate strength directed perpendicularly to the direction of propagation of the ultrasonic waves and the line is further subjected to or irradiated by an electromagnetic field of an appropriate amplitude and of a frequency several times that of the ultrasonic energy, the electromagnetic waves impinging upon the line in a direction substantially perpendicular to both the direction of propagation of the ultrasonic wave energy and the direction of the unidirectional magnetizing field.

When the various above-mentioned steps have been suitably effected, this arrangement will result in an amplification of the ultrasonic energy which is believed to result from a sort of "maser" action which effects a transfer of energy from the electromagnetic waves to the ultrasonic waves.

It is believed that the transfer results from the creation by the unidirectional magnetic field of three electron spin energy levels among the electrons of the added impurity atoms, which for convenience may be designated E_3 for a higher level, E_1 for a lower level and E_2 for an intermediate level.

The irradiating electromagnetic wave energy, which should have a frequency of from two to six times that of the acoustic energy, is believed to supply energy to raise electrons of the added impurity atoms from the lower level to the higher level. The ultrasonic wave is believed to tend to equalize the energy division between the higher and intermediate levels, the net effect being that the energy of the ultrasonic wave is increased at the expense of the energy of the electromagnetic wave as electrons give up energy in passing from the higher to the intermediate energy level. The theoretical aspects as applied to a single crystal of quartz are more fully explained in an article entitled "Kilomegacycle Ultrasonics" by K. Dransfeld, published in the Scientific American Magazine, June 1963, at page 66 and the related descriptive material. The degree of amplification thus obtained varies directly with the number of added impurity atoms, the difference between the ultrasonic and electromagnetic wave frequencies and the strengths of the electromagnetic and unidirectional magnetic fields. While the system may

become unstable if too great a degree of amplification is attempted, amplification entirely sufficient to overcome the prohibitive attenuation losses of prior art delay lines to ultrasonic wave energy in the upper portions of the range of frequencies mentioned hereinabove can readily be realized.

Delay lines are, of course, of very substantial utility as information storage devices, as essential elements of moving target indicating systems, in pulse-code signaling systems and for other purposes too numerous to mention, well known to those skilled in the art.

A principal object of the invention is, accordingly, to eliminate the excessive attenuation of ultrasonic wave energy in fused silica delay lines at megacycle and higher frequencies.

A further object is to afford amplification of ultrasonic wave energy in fused silica delay lines at megacycle and higher frequencies.

The above and further objects, features and advantages of the invention will become apparent from a perusal of the following detailed description of illustrative embodiments of the invention in conjunction with the accompanying drawing in which:

FIG. 1 illustrates in diagrammatic form a first arrangement for practicing the invention; and

FIG. 2 illustrates in diagrammatic form a second arrangement for practicing the invention.

In more detail in FIG. 1, delay line **10** is a cylindrical rod of fused silica having therein, as a substantially uniformly distributed impurity, from 100 to 10,000 parts per million (metal ions per million silicon atoms) of a metal ion selected from the class consisting of manganese, iron, nickel and chromium. Such a rod can be produced by the conventional flame fusion of silica admixed with either an oxide of the metal or a compound of the metal, such as a nitrate, which decomposes to form the oxide under the flame fusion conditions. Under these conditions, the metal ions will be produced in their higher valence states. When ions in lower valence states are desired, the divalent or doubly ionized metal ions being particularly suitable, the fused silica rods can be heated in dry hydrogen. Alternatively, the rod can be produced by plasma fusion of the mixture of silica and metal compound in a controlled atmosphere to produce the desired valence state of the metal ions. In fused silica it is possible to obtain concentrations of metal ions which are high relative to the concentrations which it has been possible to introduce into quartz.

The end surfaces of the delay line should be smooth and should be accurately aligned in parallel relation to each other so that ultrasonic wave energy generated by a transducer mounted on one end surface will impinge perpendicularly upon the other end surface.

At each end of delay line **10**, an electroultrasonic transducer **18** having electrical leads **20** may be attached, as, for example, by a thin film of a strongly adhering adhesive material such as an epoxy resin, or otherwise as suggested specifically in the art for the several different varieties of transducers mentioned hereinunder.

The transducers **18** may be piezoelectric crystals operated at a high harmonic, or, alternatively, they may be of the depletion layer type as disclosed and claimed in the copending application of D. L. White, Serial No. 64,808, filed October 25, 1963, now Patent 3,185,935 issued May 25, 1965 and assigned to applicant's assignee, for frequencies in the kilomegacycle range. For somewhat lower megacycle frequency range systems transducers **18** may be of the epitaxial layer or related types as disclosed and claimed in the copending application of D. L. White, Serial No. 208,185, filed July 3, 1962, and assigned to applicant's assignee.

As a further alternative, transducers **18** may be of

the type disclosed in United States Patent No. 3,037,174, granted May 29, 1962 to H. Bommel and K. Dransfeld.

All of the above noted transducers are now well known and extensively used by those skilled in the art.

If desired, an amplifier (not shown) of the type disclosed and claimed in the copending application of D. L. White, Serial No. 105,700, filed April 26, 1961, now Patent 3,173,100 issued March 9, 1965 and assigned to applicant's assignee, and also now well known to those skilled in the art, may obviously be inserted between either or both of the transducers **18** and the end of the delay line adjacent to each transducer, respectively, to compensate for the energy loss in the transducers.

Delay line **10** except for its protruding ends is enclosed in a cavity **12** the dimensions of which are proportioned to render the cavity **12** resonant at the frequency of the electromagnetic wave energy **16** introduced via wave guide **14** and the slit-type coupling orifice **11** between plates **13** into cavity **12** from any of several suitable sources (not shown) well known to and widely used by those skilled in the art. Alternatively, orifice **11** may be of the circular, oval or of a number of differing rectilinear slit types as is well known to those skilled in the art.

Closely adjacent the front and rear surfaces, respectively, of resonant cavity **12** are the poles of an electromagnet **22** energized by direct current source **28** connected in series with rheostat **26** and coil **24**, the latter being wound on the central portion of magnet **22**, as shown.

The purpose of the magnet is, obviously, to establish a unidirectional steady magnetizing field which is perpendicular to both the direction of propagation of ultrasonic energy along the fused silica delay line **10** and to the electromagnetic wave energy **16**. The strength of the field may of course be adjusted by adjusting the rheostat **26**. Alternatively, a permanent magnet of appropriate field strength can be employed.

Assuming, as indicated hereinabove, that the left transducer **18** is the input transducer, this transducer converts electrical energy of magacycle or kilomegacycle frequency applied to it via leads **20** into ultrasonic wave energy of the same frequency and launches the ultrasonic wave energy into the left end of delay line **10**. The ultrasonic wave energy is then propagated along the delay line **10** from left to right in a direction perpendicular to both the electromagnetic wave energy **16** and the unidirectional magnetic field of magnet **22**.

At suitable strengths of the electromagnetic wave energy **16** and the unidirectional magnetic field, it will be found that the ultrasonic wave energy can be amplified sufficiently, by the mechanism described below, to compensate for the normally excessive attenuation of the silica delay line to ultrasonic waves of such high frequency.

As stated above, the frequency of the electromagnetic wave energy **16** should be from two to six times that of the ultrasonic wave energy.

The optimum frequency of the ultrasonic wave depends upon the impurity which has been added to the fused silica line **10**. By way of examples, for all of the above-mentioned impurities the frequency of the ultrasonic wave energy should be approximately nine kilomegacycles with the optimum frequency for each specific impurity varying by a small percentage from that for each of the other impurities.

In general, the frequency of the ultrasonic wave energy should be substantially that obtained from the relation

$$f_{(\text{ultrasonic})}=E_2-E_1/h \qquad (1)$$

and the frequency of the electromagnetic wave energy **16** should be substantially that obtained from the relation

$$f_{(\text{electromagnetic})}=E_3-E_1/h \qquad (2)$$

where E_1, E_2 and E_3 are the electron energy levels, low, intermediate and high, respectively, as mentioned hereinabove, and h is Planck's constant which may be taken as 6.62×10^{-27}.

In FIG. 2 a second arrangement for practicing the invention is illustrated in diagrammatic form. It differs from that of FIG. 1 principally in that the fused silica delay line **110** is of the polygon type.

The specific form of the delay line illustrated by way of example is that disclosed and claimed in United States Patent No. 2,624,804, granted January 6, 1953 to D. L. Arenberg. Numerous other delay lines of this general type are well known and widely used by those skilled in the art. This type of delay line is characterized by the fact that the ultrasonic wave energy is multiply reflected about the polygon from the input transducer **118** (assume for example that the upper transducer is the input transducer) before reaching the output (lower) transducer **118**.

The surfaces of the polygon **110** on which the transducers are mounted should be smooth and accurately aligned to be perpendicular to the path of the ultrasonic wave energy starting and/or terminating at them, respectively. For the purposes of the present application, the fused silica polygon **110** must have as a uniformly distributed impurity therein from 100 to 10,000 parts per million of a metal ion selected from the group consisting of manganese, iron, nickel and chromium.

The delay line **110** is enclosed in resonant cavity **112** which is resonant at the frequency of the electromagnetic wave energy represented by vertically directed arrow **116** introduced via wave guide **114** and orifice **111** between plates **113** to cavity **112**. Any of numerous sources (not shown) well known and extensively used by those skilled in the art may be employed to provide the electromagnetic wave energy.

An electromagnet **122** has its poles closely adjacent the front and rear surfaces of cavity **112** as shown so that a unidirectional magnetic field, resulting from the passage of current from direct current source **128** in series with rheostat **126** and the coil **124** wound on the central portion of magnet **122**, will be horizontally directed through delay line **110**, perpendicular to the major surfaces of the delay line. The strength of the field can, of course, be adjusted by adjustment of rheostat **126**. As for the arrangement of FIG. 1, a permanent magnet of appropriate field strength may be employed in place of the electromagnet just described.

Transducers **118** of FIG. 2 may be of any of the types indicated as suitable for transducers **18** of FIG. 1. Leads **120** provide electrical connections to their respective associated transducers.

As for the arrangement of FIG. 1, in FIG. 2 the frequency of the electromagnetic wave energy **116** must be from two to six times that of the ultrasonic energy being transmitted through the delay line **110**. Also, as is obvious from FIG. 2, the directions of the unidirectional magnetic field, the electromagnetic field in the cavity and the propagation of ultrasonic energy must be substantially orthogonally related.

Numerous and varied modifications and rearrangements of the above-described specific illustrative embodiments can obviously be readily devised by those skilled in the art without departing from the spirit and scope of the principles of the invention. Accordingly, it is to be understood that the specific embodiments are merely illustrative and not to be construed as specifically limiting the invention.

What is claimed is:

A delay line for use with ultrasonic waves at a prescribed frequency in the megacycle and higher frequency ranges comprising in combination a fused silica delay line having therein as a substantially uniformly distributed impurity from 100 to 10,000 parts per million of a doubly ionized metal selected from the class consisting of manganese, iron, nickel and chromium, the delay line having a pair of smooth terminal surfaces accurately aligned to be perpendicular to the direction of propaga-

tion of ultrasonic waves through the adjacent portions of the line, means for impressing a unidirectional steady magnetizing field perpendicular to the direction of propagation of ultrasonic waves in the delay line, means for irradiating said delay line in the direction normal to both the direction of propagation of ultrasonic waves in the delay line and said unidirectional magnetizing field with electromagnetic waves of a frequency several times greater than the said prescribed frequency, means for injecting ultrasonic waves of said prescribed frequency into one terminal surface of said delay line and means at the other terminal surface of said delay line for converting ultrasonic wave energy to electrical wave energy.

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