

[54] **VARIABLE BROADBAND DELAY LINE**

[75] Inventor: **Martin M. Sokoloski**, Columbia, Md.

[73] Assignee: **The United States of America as represented by the Secretary of the Army, Washington, D.C.**

[22] Filed: **Jan. 25, 1974**

[21] Appl. No.: **436,583**

[52] U.S. Cl. **333/30 R, 310/26, 333/17, 333/30 M, 340/174 VB**

[51] Int. Cl. **H03h 9/00, H03h 9/30, H04b 11/00**

[58] Field of Search **333/30 R, 71, 29, 17; 310/26; 329/199, 200; 340/173.2, 174 VB, 174 TF; 332/2, 51 R**

[56] **References Cited**

UNITED STATES PATENTS

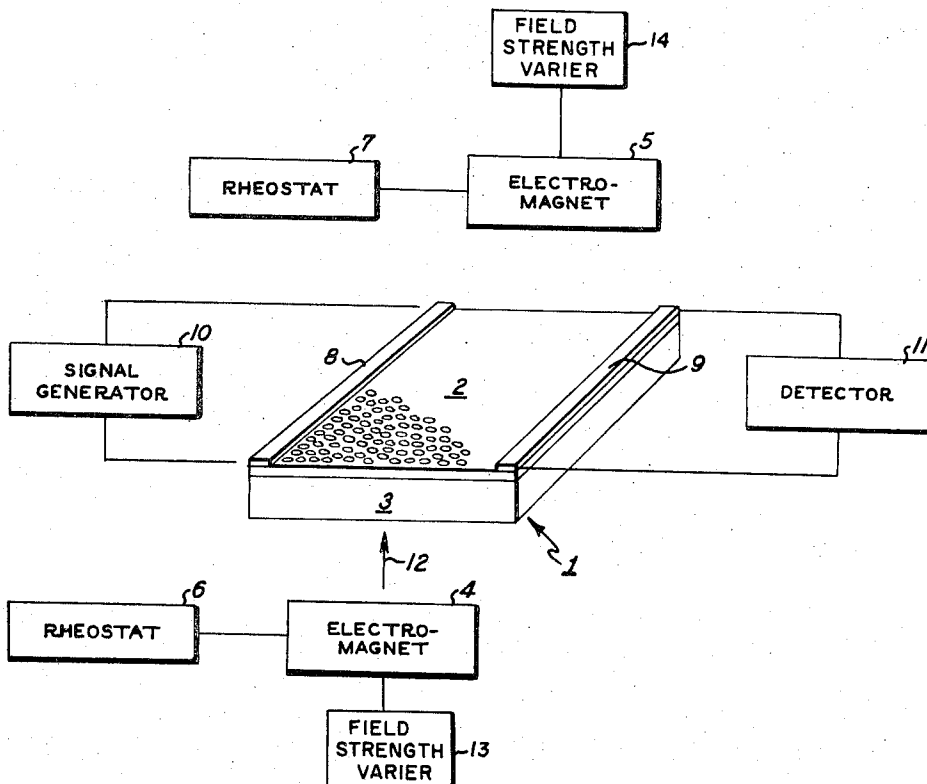
3,691,540	9/1972	Almasi et al.	340/174 TF
3,793,598	2/1974	Hofelt et al.	333/30 M

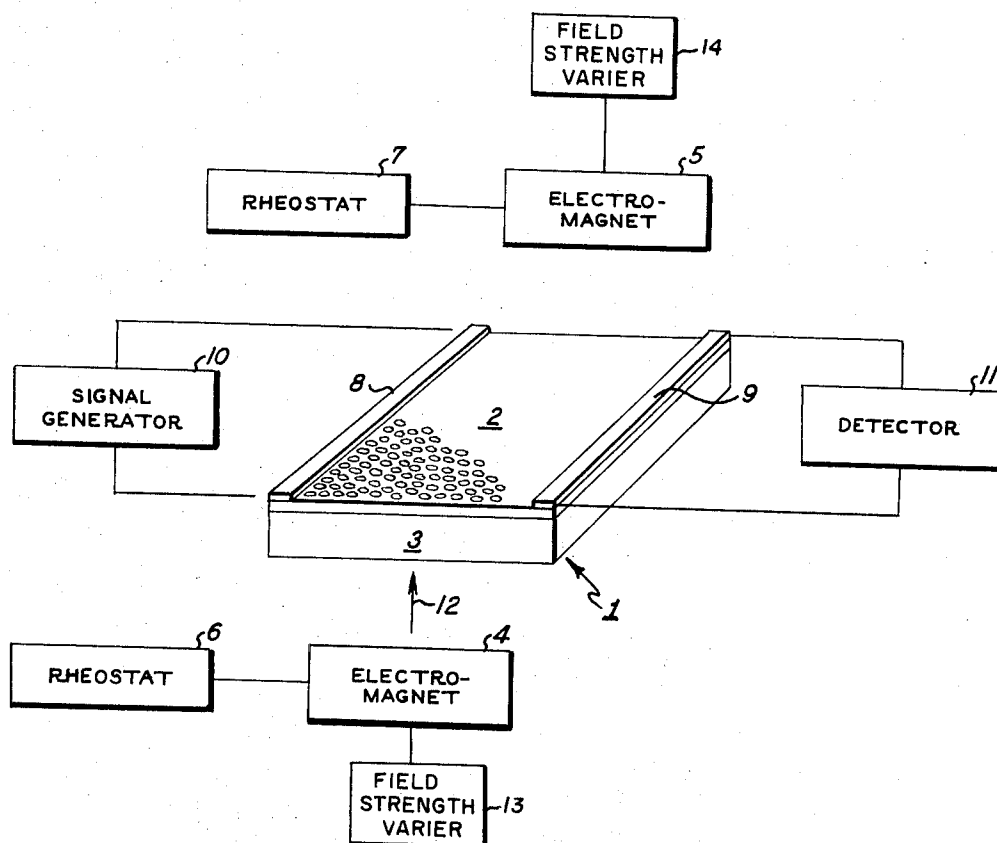
Primary Examiner—James W. Lawrence
Assistant Examiner—Marvin Nussbaum
Attorney, Agent, or Firm—Nathan Edelberg; Robert P. Gibson; Saul Elbaum

[57] **ABSTRACT**

A broadband magnetic bubble delay device having an adjustable delay time. A platelet or film of uniaxial magnetic material which has been appropriately saturated with a two dimensional array of right circular cylindrical domains called magnetic bubbles is immersed in a uniform magnetic field directed transversely to the plane of the film. An evaporated metal launcher electrode is disposed at one end of the film and a detector probe is disposed at the other end. Application of the signal to be delayed to the launcher electrode creates a magnetic field gradient transverse to the plane of the film and causes bubbles near the electrode to vibrate. The vibrations are transmitted to the other end of the film by wave propagation where they are detected by the detector probe and external detector circuitry. The delay is attained by changing the magnitude of the uniform external magnetic field.

9 Claims, 1 Drawing Figure





VARIABLE BROADBAND DELAY LINE

RIGHTS OF THE GOVERNMENT

The invention described herein may be manufactured, used, and licensed by or for the United States Government for governmental purposes without payment to me of any royalty thereon.

BACKGROUND OF THE INVENTION

The present invention relates to a broadband delay device having an adjustable delay time.

Many delay lines of the prior art have taken the form of discrete lengths of conductor cables which are extremely bulky. While acoustic wave delay devices which utilize the propagation of Rayleigh waves on the surface of a material are compact; they are fixed in frequency, and variable delay can be accomplished only by a finite number of detectors arranged on the crystal.

It is therefore an object of the present invention to provide a delay device having an adjustable delay.

It is a further object of the invention to provide a delay device having a broad bandwidth.

It is still a further object of the invention to provide a delay device which is extremely compact and inexpensive to manufacture.

SUMMARY OF THE INVENTION

The above objects are accomplished by providing a film or platelet of uniaxial magnetic material already saturated with a two dimensional hexagonal array of bubbles having a launcher electrode at one end thereof and a detector probe at the other end thereof. A uniform magnetic field is applied transverse to the film which is the direction of the easy axis of the magnetic material and bubbles. The signal to be delayed is applied to the launcher electrode thereby generating a magnetic field gradient corresponding to the signal transversely to the film, in the direction of the easy axis of the magnetic material. The magnetic field gradient corresponding to the signal induces vibrations in the bubbles situated near the launcher electrode and the vibrations are propagated through the bubbles of the film to the other end thereof in the form of a wave. The vibrations of the bubbles at the other end are detected by circuitry which is connected to the detector probe and the delay time of the device is the time of propagation of the wave.

By way of further background, it has been found that magnetic materials are comprised of a number of magnetic domains. In a magnetically uniaxial material which is not in the presence of an external magnetic field these magnetic domains will take the geometric form of strips and in half of the strips the internal magnetic field will point up in the easy direction of magnetization, while in the other half they will point down. When the material is immersed in an external uniform magnetic field parallel to the easy axis and the field strength is increased, the strip domains will transform into the right circular cylindrical domains which are known as bubbles. Decreasing the magnetic field too much will cause the bubbles to revert to strip domains and increasing the field too much will cause the diameters of the bubbles to decrease and will finally cause the bubbles to collapse. For every material, and every thickness of material there is a range of field strength over which the bubbles are stable and magnetic bubble devices are operated in this range. Suitable thicknesses

of various materials and the field strengths to be used therewith to produce a stable bubble configuration are given in an article entitled "Application of Orthoferites to Domain-Wall Devices" by Andrew H. Bobeck et al., IEEE Transactions on Magnetics, 5, 1969, pp. 544-553 and such materials are well known to those skilled in the art.

It is also well known that periodic magnetic domain structures consisting of two dimensional array of cylindrical domains occur and are stable in thin platelets of uniaxial magnetic material. Such two dimensional arrays are known to those skilled in the arts and are mentioned in the article, "Bubble Lattices" by F. A. DeJonge and W. F. Druyvesteyn, A.I.P. Conference Proceedings, No. 5, *Magnetism and Magnetic Materials*, C. D. Graham, Jr. and J. J. Rhyne, Editors, 1971, pp. 130-134; and references therein.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to the Figure, delay device 1 is comprised of a platelet or film 2 of uniaxial magnetic material disposed on substrate 3 which is utilized for mechanical rigidity and which is substantially thicker than film 2. Substrate 3 may, for instance, be a synthetic material and as is known to those skilled in the art it is possible to grow the film 2 directly on substrate 3. In the Figure, the hard axis of film 2 is in the plane of the film, and the easy axis is perpendicular thereto.

Electromagnets 4 and 5 are external to the device 1 and are arranged to produce a uniform magnetic field over the extent of film 2. If desired only a single electromagnet may be used. The field strength of the electromagnets and thus the delay time of device 1 is controlled by adjusting rheostats 6 and 7. If desired, when two electromagnets are used the current in both may be controlled with a single rheostat.

In the operation of the device, appropriate current is applied to electromagnets 4 and 5 to produce a magnetic field onto a film 2 with a hexagonal two dimensional array of bubbles. As indicated above, the uniform magnetic field is directed along the easy axis of the uniaxial magnetic material and its direction is indicated by arrow 12 in the figure. With a uniform magnetic field applied by electromagnets 4 and 5 and before current is sent through launcher electrode 8, the bubbles of the generated bubble array are essentially stationary.

Launcher electrode 8 is an evaporated metal strip on the surface of film 2 which preferably extends across the entire width of the film at one end thereof. The signal to be delayed which, of course, may be any electrical signal but which is shown for purposes of illustration as being the output of signal generator 10, is applied to launcher electrode 8 thereby creating a magnetic field gradient in the direction 12. This magnetic field gradient causes the bubbles situated nearest the launcher electrode to vibrate. The bubbles undergo two simultaneous movements or vibrations as a result of the magnetic field—first, the radii of the bubbles increase and decrease about the equilibrium radius, and secondly, the nearest neighbor separation or the separation between the centers of the bubbles increases and decreases about the nearest neighbor separation at equilibrium. The term "vibrate" as used in the specification and claims encompasses both of these distinct movements. It should be noted that the signal applied

to electrode 8 should be attenuated or amplified so as to be in the proper range for causing the bubbles to vibrate. The particular ranges as known to those skilled in the art will vary from magnetic material to material but generally a signal which is too small will not produce a field large enough to cause vibrations and a signal which is too large will cause the bubble array to break down. Also, electrode 8 should be thick enough to properly conduct the required current.

A vibrating bubble can be modeled by a damped harmonic oscillator, and a two-dimensional film of N-bubbles can be modeled by N interdependent harmonic oscillators acting through the usual magnetostatic force. The harmonic oscillators are interdependent as opposed to being independent because if one bubble is displaced by vibration at a particular time the equilibrium positions of its neighbors are affected. The effect of the vibration of one bubble causing its neighbor to move and the vibration of the neighbor in turn affecting its neighbor and so on may be expressed as a wave propagating through the film. Thus a specific movement of a bubble at the left-most end of film 2 in the Figure caused by the magnetic field of electrode 8 will be transmitted to a bubble at the right-most end of the film after a predetermined time which is the transit or propagation time of the film. The amplitude of the vibrations is controlled by the amplitude of the electrical signal so that vibrations of a particular amplitude at the left end are later detected at the right end by probe 9. The frequency response of the device is extremely broad and the cut-off frequency is the minimum frequency to which the bubbles cannot respond which will vary from magnetic film to magnetic film.

The above-described system is closely analogous to the way in which waves propagate through crystal lattice of a solid wherein the vibrations of atoms (caused by heat) are transmitted from atom to atom of the lattice. For a more complete discussion of the propagation of crystal lattice waves reference may be had to pp. 111-161 of *Introduction to Solid State Physics* by Charles Kittel, 3rd edition, John Wiley and Sons, Inc., New York, 1966.

The bubble wave or the vibrations of the bubbles are detected at the right hand end of film 2 by detector probe 9 operating in conjunction with detector 11. Any one of several known probe/detector combinations may be used, such as a Hall effect detecting system or a magnetoresistance detecting system. In the Hall effect system detection probe 9 would be a semiconductor slab carrying a direct current and when the magnetic field of a bubble acts perpendicularly to the slab and at right angles to the current a voltage appears across the slab which is detected by detector 11. In the magnetoresistance type of system, detector probe 9 would be made of a material whose resistance changes with magnetic field such as Permalloy whose resistance would be changed by the presence of a bubble. The change in resistance would be measured by a bridge network in detector 11.

The delay time of the device is a function of the group velocity of excitations of the magnetic medium. The group velocity is in turn a function of the repulsive interaction strengths between the magnetic bubbles which is a function of the external uniform magnetic field. Hence, changing the magnitudes of the fields emitted by magnets 4 and 5 has the effect of changing

the delay time of the device and it is in this way that the delay time is adjusted.

The signal detected by detector 11 will thus have the same shape as that generated by signal generator 10 but it will be delayed by the transit or propagation time of film 2. The delay device is broadband because it will delay all frequencies up to the cut-off frequency of the film beyond which the bubbles cannot respond and the delay time is adjustable as described above by controlling the field strength of the uniform magnetic field.

The form or shape of the wave propagating in the bubble array between launcher 8; and detector 9 can be changed at will by changing the external uniform magnetic field caused by electromagnets 5 and 4 either as a function of time or direction from 8 to 9 and field strength varying means 13 and 14, the exact design of which is known to those skilled in the art are shown in the Figure. This will cause the propagation velocity to be a function of distance along 8 to 9 as well as time dependence of the external electromagnetic field.

I wish it to be understood that I do not desire to be limited to the exact details of construction shown and described, for obvious modifications can be made by a person skilled in the art.

What I claim:

1. A magnetic bubble wave shaping apparatus for shaping an input signal in accordance with a desired wave shaping characteristic comprising a film of uniaxial magnetic material saturated with a two dimensional hexagonal array of magnetic bubbles, said film extending in a plane perpendicular to the easy axis of said magnetic material and having at least two opposite ends which are spaced apart by a distance much greater than the nearest neighbor separation of the bubbles in said material, means for producing a magnetic field which is oriented transversely to said plane of said film, means for varying the strength of said field as a function of the distance between said two ends in accordance with said desired wave shaping characteristic, a launcher electrode deposited on said film at one of said two ends and a detector probe deposited on said film at the other of said two ends, whereby the shape of an electrical signal applied to said launcher electrode is modified in accordance with said wave shaping characteristic.

2. The apparatus of claim 1 wherein said launcher electrode is substantially straight and extends entirely across said film at said one end.

3. The apparatus of claim 2 wherein said film is rectangular in shape.

4. The apparatus of claim 3 wherein said launcher electrode is a thin metallic electrode which is evaporated on said film.

5. The apparatus of claim 4 wherein said film is on a substrate having a thickness which is substantially greater than the thickness of said film.

6. The apparatus of claim 5 wherein said detector probe is part of a magnetoresistive detector means for detecting movement of said bubbles.

7. The apparatus of claim 5 wherein said detector probe is a semiconductor slab which is connected to a means for measuring the Hall-effect induced voltage across said slab.

8. A magnetic bubble wave shaping apparatus for shaping an input signal in accordance with a desired wave shaping characteristic comprising a film of uniaxial magnetic material saturated with a two dimensional

hexagonal array of magnetic bubbles, said film extending in a plane perpendicular to the easy axis of said magnetic material and having at least two opposite ends which are spaced apart by a distance much greater than the nearest neighbor separation of the bubbles in said material, means for producing a magnetic field which is oriented transversely to said plane of said film, means for varying the strength of said field as a function of time in accordance with said desired wave shaping characteristic, a launcher electrode deposited on said film at one of said two ends and a detector probe deposited on said film at the other of said two ends, whereby the shape of an electrical signal applied to said launcher electrode is modified in accordance with said wave shaping characteristic.

9. A method of wave shaping a first electrical signal in accordance with a desired characteristic comprising the steps of,

providing a film of uniaxial magnetic material,

saturating said material with a two dimensional hexagonal array of magnetic bubbles,

immersing said film in a magnetic field which is oriented perpendicular to the plane of said film,

inducing vibrations in the bubbles at one end of said film by applying a magnetic field produced by said electrical signal at said one end of said film, the vibrations of said bubbles thereby propagating in the form of a wave to the other end of said film,

varying the strength of said magnetic field as a function of the distance between said two ends in accordance with said desired wave shaping characteristic, and

transducing the vibrations of the bubbles at said other end thereof back into an electrical signal whereby the shape of said first electrical signal is modified in accordance with said wave shaping characteristic.

* * * * *