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[11] **3,568,106**

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[73] Assignee **Hazeltine Corporation**

[54] **MAGNETOSTATIC DELAY LINE**
13 Claims, 5 Drawing Figs.

[52] **U.S. Cl.** **333/31,** 333/24.1
[51] **Int. Cl.** **H03h 7/30**
[50] **Field of Search** ..... 333/24.1, 29, 30, 30 (M), 31, 31 (A)

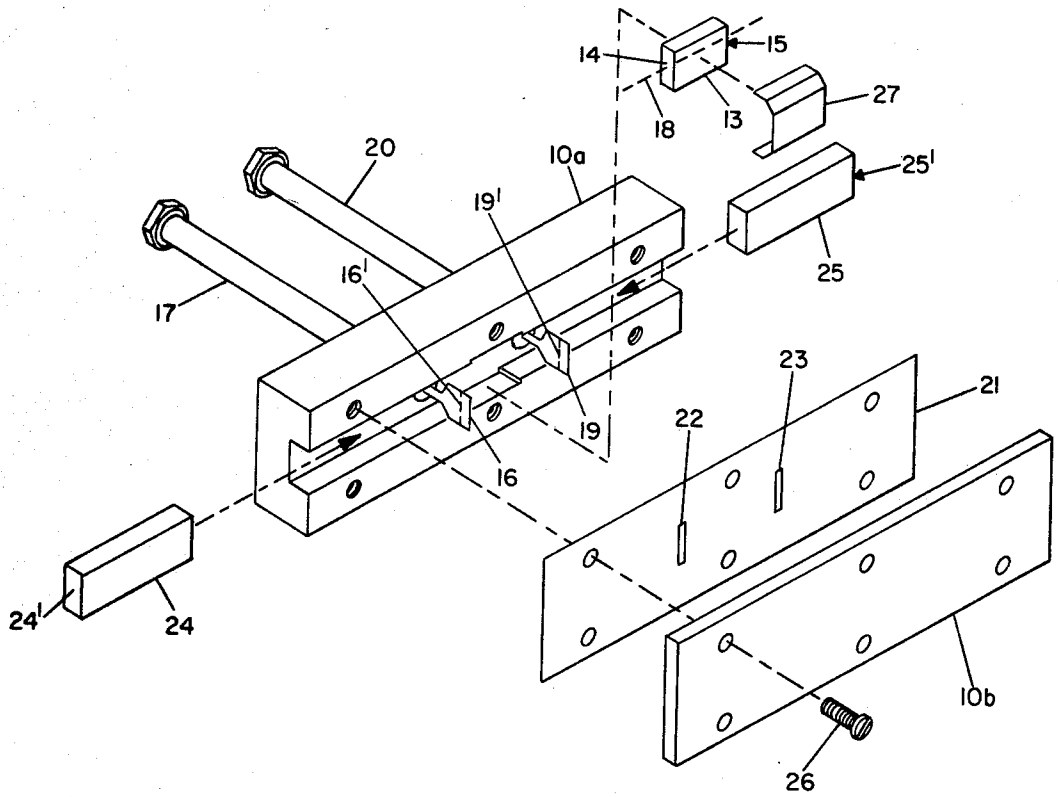
[56] **References Cited**

UNITED STATES PATENTS

3,274,521	9/1966	Nourse	333/24.1
3,309,628	3/1967	Olson	333/31
3,421,116	1/1969	Frank et al.	333/24.1
3,425,003	1/1969	Mohr	333/31(A)
3,475,642	10/1969	Karp et al.	333/31(A)

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ABSTRACT: A wide band magnetostatic delay line having a sample of single crystal yttrium iron garnet (YIG) positioned in an axial bias field. The YIG sample is enclosed in a cutoff waveguide and separated from the walls of the guide by several guide wavelengths, measured in the YIG sample. The input and output probes are backed up by polycrystal YIG pieces which cause the bias field to be substantially uniform in the single crystal YIG. The uniform bias field causes a magnetostatic wave to propagate with a substantially constant wavelength. The polycrystal YIG backup pieces also serve to provide substantially uniform permeability to the electromagnetic fields associated with the input and output probes in order to provide efficient coupling over a wide bandwidth. Longer delays are made possible by cascading several single crystal YIG pieces along their longitudinal axis.



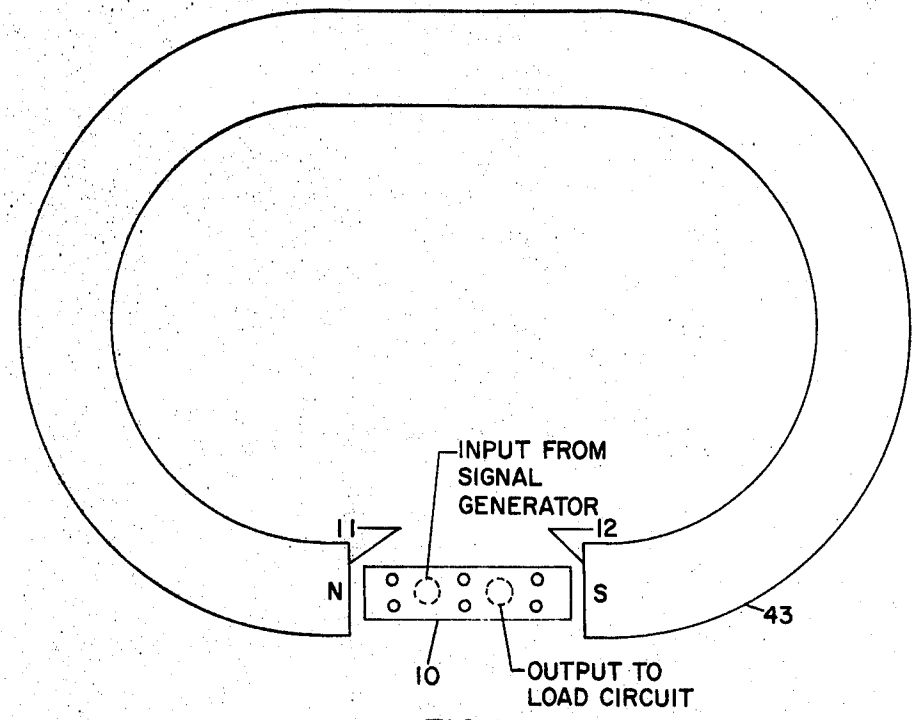

INPUT FROM
SIGNAL
GENERATOR
11
12
N
S
43
10
OUTPUT TO
LOAD CIRCUIT

FIG. 1a

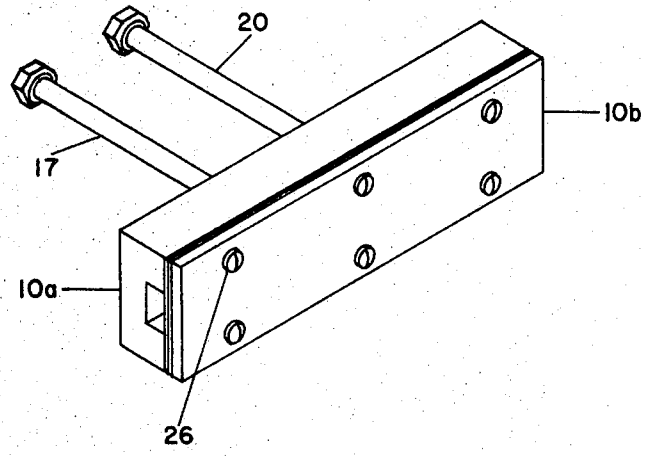

20
10b
17
10a
26

FIG. 1b

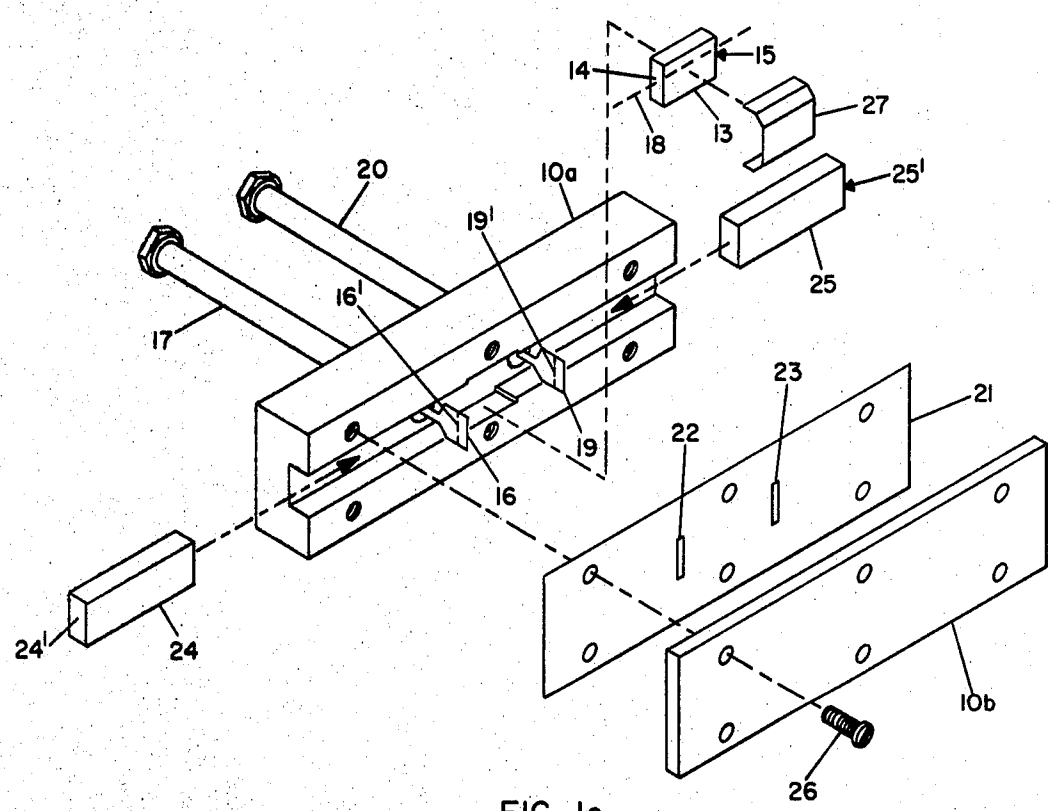


FIG. 1c

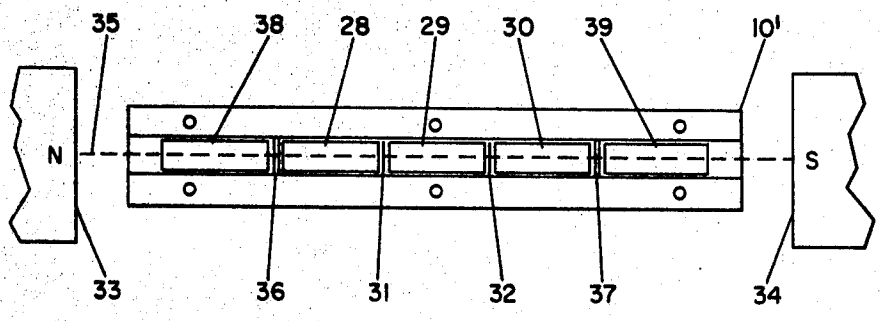


FIG. 2a

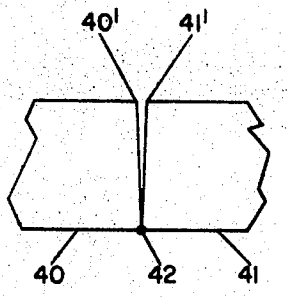


FIG. 2b

MAGNETOSTATIC DELAY LINE

BACKGROUND OF THE INVENTION

The present invention relates generally to magnetostatic mode propagation in magnetic insulator materials and particularly to delay lines utilizing the magnetostatic mode propagation in magnetic insulator material such as yttrium iron garnet (YIG).

Wave propagation in magnetic insulator material has been the subject of substantial investigation in recent years. Of particular interest has been the propagation in yttrium iron garnet (YIG) of medium-*k* waves, exchange spin waves and elastic waves. The present invention relates to a delay line utilizing the propagation of medium-*k* waves in YIG or other magnetic insulator material.

The term medium-*k* wave has been used in literature and is completely described in an article by Carmine F. Vasile and Richard La Rosa entitled "Guided Wave Propagation in Gyromagnetic Media as Applied to the Theory of Exchange Spin Wave Excitation," Journal of Applied Physics, Vol. 39, No. 3, Pages 1863—1873, dated Feb. 15, 1968.

The term magnetostatic wave may also be utilized to describe a medium-*k* wave. However, the term magnetostatic wave has been used by some to describe both a medium-*k* wave and an exchange spin wave as a single wave type. The term magnetostatic is used in the present application to describe a pure medium-*k* wave having no exchange spin wave component.

The general theory of magnetostatic wave propagation is explained in "Microwave Ferrites and Ferrimagnetics" by Lax and Button, Lincoln Laboratory Publication, McGraw-Hill. However, utilizing magnetostatic wave propagation in YIG or other magnetic insulator material to construct useful dispersive and nondispersive delay lines has met with limited success. Substantial difficulty has been encountered in propagating a pure medium-*k* wave, having a substantially uniform wavelength along the length of the YIG material. If the wavelength of the propagating magnetostatic wave varies, the delay line becomes so highly dispersive as to adversely affect its usefulness.

A further problem associated with magnetostatic YIG delay lines is the nonlinear frequency vs. time curve (*f–t*). The amount of nondispersive delay obtainable is determined by the ratio of the length of the YIG sample to its width (where the width is the shortest dimension of the cross section). A greater delay, using the same YIG sample, can only be obtained by variations in the bias field which result in a higher dispersive delay. It is therefore desirable to have longer samples of YIG in order to provide a greater nondispersive delay and to generally improve the linearity of the *f–t* curve. However, it is very difficult to grow single crystal samples of YIG that are more than .5 inch long and virtually impossible, at present, to grow a pure single crystal YIG sample which is more than 1 inch long. The amount of delay obtainable has therefore been limited.

Objects of the present invention therefore are to provide new and improved delay lines utilizing magnetostatic wave propagation in magnetic insulator material which overcome the disadvantages of the prior art. Further objects are to provide delay lines which utilize magnetostatic wave propagation having substantially uniform wavelengths throughout the propagating medium.

In accordance with the present invention, there is provided a magnetostatic delay line comprising a sample of single crystal magnetic insulator material having first and second faces; an input device including a first current-carrying member contiguous with the first face for coupling electromagnetic energy to the magnetic insulator material as a result of high frequency current flow in the first current-carrying member; means for subjecting the magnetic insulator material to an axial magnetic bias field that is substantially uniform in the absence of the magnetic insulator material for causing the electromagnetic energy to propagate in the magnetic insulator material as a magnetostatic wave; and output device including a second current-carrying member contiguous with the second face for coupling electromagnetic energy from the magnetic insulator material to produce a signal in the second current-carrying member representative of the high frequency signal in the first current-carrying member delayed by a predetermined amount; a nonmagnetic shielding member surrounding the single crystal magnetic insulator material in the region of the current-carrying members for preventing undelayed leakage of electromagnetic energy from the first current-carrying member to the second current-carrying member; and first and second samples of magnetic insulator material in close proximity to the first and second faces respectively for increasing the uniformity of the magnetic bias field so that the wavelength of the propagating magnetostatic wave remains substantially constant in the single crystal magnetic insulator material without reducing the amount of electromagnetic energy that is coupled between said input and output devices and said single crystal magnetic insulator material.

For a better understanding of the present invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawings and its scope will be pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1*a* illustrates one embodiment of a magnetostatic delay line constructed in accordance with the present invention;

FIG. 1*b* is an enlarged perspective view of a portion of the FIG. 1*a* embodiment;

FIG. 1*c* is a further enlarged, exploded view of FIG. 1*b*;

FIG. 2*a* illustrates another embodiment of a magnetostatic delay line constructed in accordance with the present invention; and

FIG. 2*b* is a FIG. useful in the understanding of the FIG. 2*a* embodiment.

DESCRIPTION OF THE INVENTION

FIG. 1 is an illustration of a wide band magnetostatic delay line constructed in accordance with the present invention. FIG. 1*a* is a side view which illustrates the orientation of the magnetic insulator material which is enclosed in the shielding member 10 in the bias field supplied by a permanent magnet whose pole pieces are numbered 11 and 12. FIG. 1*b* is a partial expanded perspective view of FIG. 1*a*. FIG. 1*c* is an exploded view of FIG. 1*b*.

As illustrated, the delay line includes a sample of single crystal magnetic insulator material 13 having first and second faces 14 and 15 (face 15 is hidden in FIG. 1*c*). At present, yttrium iron garnet (YIG) is the magnetic insulator material which is found to have the best propagation characteristics and sample 13 therefore may be a sample of single crystal YIG. In FIG. 1*c* YIG sample 13 is in the form of a rectangular bar. However, the cross section of sample 13 may take any shape or form but usually is constructed in the form of a slab, a bar or cylindrical rod. The modal field patterns that exist in each of these different configurations are described in the article by Carmine F. Vasile and Richard La Rosa entitled "The Character of Modes in Small Axial Magnetized Ferrite Filled Waveguides," Journal of Applied Physics, Vol. 39, No. 5, Apr. 1968.

The delay line also includes an input device including a first current-carrying member illustrated as the flat foil coupling probe 16 for coupling electromagnetic energy to YIG sample 13 as a result of high frequency current flow in probe 16. The coupling probe 16 is connected to the center conductor of coaxial lead 17. The signal to be delayed is coupled to coaxial lead 17 from a signal generator. The resultant current flow in probe 16 establishes an electromagnetic field in the vicinity of face 14 of YIG sample 13. Probe 16 is contiguous with face 14 and is preferably in physical contact therewith.

The delay line further includes permanent magnet **43** for subjecting the magnetic insulator material **13** to an axial magnetic bias field that is substantially uniform in the absence of the magnetic insulator material **13** for causing said electromagnetic energy to propagate in magnetic insulator material **13** as a magnetostatic wave. As illustrated magnet **43** includes pole pieces **11** and **12** which are arranged so that the longitudinal axis **18** of YIG sample **13** is parallel with the field established by pole pieces **11** and **12**.

The delay line also includes an output device including a second current-carrying member illustrated as flat foil coupling probe **19** contiguous with the second face **15** of YIG sample **13** for coupling electromagnetic energy from YIG sample **13** to produce a signal in the second current-carrying member **19** representative of the high frequency signal in said first current-carrying member **16**, delayed by a predetermined amount. As is probe **16**, flat foil coupling probe **19** is contiguous with YIG sample **13** and is preferably in physical contact with face **15**. When the propagated magnetostatic wave arrives at face **15** it produces an electromagnetic field in the vicinity of face **15** which is intercepted by coupling probe **19** causing current to flow in probe **19** which is representative of the current flow in probe **16**, delayed by a predetermined amount.

In the FIG. **1** embodiment improved ground return for probes **16** and **19** is provided by the thin copper sheet **21** which is secured between waveguide body **10***a* and cover plate **10***b*. In assembling the delay line, probes **16** and **19** are inserted in slots **21** and **23**, respectively, and bent away from single crystal sample **13** along dotted lines **16'** and **19'** so that a portion of each probe **16** and **19** is in contact with copper sheet **21**. A good contact for the ground return is thereby provided from probes **16** and **19** through copper sheet **21** and waveguide body **10** to the outer conductor of coaxial leads **17** and **20**.

The delay line also includes nonmagnetic shielding member **10** including the waveguide body **10***a* and cover plate **10***b*, which is secured to waveguide body **10***a* by screws **26**. When cover plate **10***b* is in place, the shielding member surrounds the single crystal YIG sample **13** in the region of the current carrying members **16** and **19**. The waveguide **10** comprises a cutoff waveguide whose internal dimensions prevent the propagation of electromagnetic energy, excited by current flow in probe **16**, in a hollow waveguide, thereby preventing undelayed leakage of said electromagnetic energy from the first current-carrying member **16** to the second current-carrying member **19**.

Although YIG sample **13** may fit snugly within waveguide **10**, it has been discovered that less loss is incurred if YIG sample **13** is spaced from the walls by several guide wavelengths; i.e., wavelengths of the propagating energy in YIG. Therefore, the interior of waveguide **10** is enlarged slightly in the region of YIG sample **13** and YIG sample **13** is separated from the waveguide walls by a thin sheet of dielectric **27**, such as Teflon, having a thickness of several guide wavelengths. In this case, the YIG bar acts as a magnetic waveguide; however propagation is substantially the same as in a metal wall waveguide.

The principal function of waveguide **10** is to prevent coupling of undelayed energy between probes **16** and **19**. By placing a cutoff waveguide between the two probes the only energy that can be coupled between them is the energy propagating in the YIG medium. Several different forms of shielding members will achieve the same result. For example, it has been discovered that removal of the center portions of cover plate **10***b* and grounding plate **21** does not result in any substantial increase in undelayed energy between probes **16** and **19**. Furthermore, the internal cross section of waveguide **10** need not conform to the cross section of the YIG sample. Useful delay lines have been constructed utilizing square YIG bars in circular waveguides and cylindrical YIG rods in rectangular waveguides. The important criteria is that the waveguide form a cutoff waveguide as previously explained.

The delay line also includes first and second samples of magnetic insulator material illustrated as polycrystal samples of YIG **24** and **25** which are in close proximity to faces **14** and **15**, respectively, of the single crystal sample of YIG **13**. Backup pieces **24** and **25** increase the uniformity of the magnetic bias field within the single crystal sample of YIG **13** so that the wavelength of the propagating magnetostatic wave remains substantially constant while propagating through the YIG sample **13**. The increased uniformity is provided by backup pieces **24** and **25** without substantially reducing the amount of energy that is coupled between the input and output devices and the single crystal magnetic insulator material **13**. Backup pieces **24** and **25** preferably have substantially the same cross section as the single crystal sample of YIG **13**, in both shape and size.

OPERATION

The general theory relating to the propagation of magnetostatic waves in magnetic insulator material, such as yttrium iron garnet (YIG), has been explained in the literature. For example, see the article by R. W. Damon and H. Van de Vaart "Propagation of Magnetostatic Spin Waves at Microwave Frequencies" Journal of Applied Physics, Vol. 37, No. 6, May 1966. A further understanding of magnetostatic propagation in YIG samples having different cross sections can be obtained from the above-mentioned article by Carmine F. Vasile and Richard La Rosa, "The Character of Modes in Small Axial Magnetized Ferrite Filled Waveguides."

Briefly described, the signal to be delayed is coupled from the signal generator to probe **16** by coaxial lead **17**. Current flowing in probe **16** establishes an electromagnetic field in the region of the single crystal YIG sample **13**, causing a magnetostatic wave to b launched at face **14** of YIG sample **13**. The axial field provided by pole pieces **11** and **12** of magnet **43** causes the magnetostatic wave to propagate through the YIG medium in the direction of face **15**. At face **15** an electromagnetic field is established which results in current flowing in probe **19** which corresponds to the current flow in probe **16**, delayed by a predetermined amount, namely, the time required for the magnetostatic wave to propagate through the YIG medium. Probe **19** is coupled to the center conductor of coaxial cable **20** which is coupled to a load circuit for further signal processing.

The single crystal YIG **13** is enclosed within waveguide **10** in order to isolate the input probe **16** from output probe **19**. As stated, waveguide **10** is a cutoff waveguide in that the internal dimensions of the waveguide are such that it will not propagate the electromagnetic energy, corresponding to current flow in probe **16**, as a hollow waveguide. Energy can propagate within the waveguide only at the shorter wavelengths determined by the YIG medium. Therefore, the electromagnetic field associated with probe **16** will not propagate within waveguide **10** except in the YIG medium and the only energy coupled to probe **19** is the energy which has propagated through the YIG medium, the delayed energy.

The nature of the magnetic bias field in the single crystal YIG sample **13** affects the type of wave propagation in YIG sample **13**. If the field increases along the axis **18** of YIG sample **13**, as the wave propagates into the YIG medium, the wavelength of the magnetostatic wave will be reduced as the wave propagates into the YIG **13** away from face **14**. If certain conditions are met, the magnetostatic wave will convert to an exchange spin wave, which will, in turn, convert to an elastic wave which is reflected back towards face **14**. The YIG waveguide will be cut off and there will be no signal detected at probe **19**. The magnetic bias field provided by the pole pieces **11** and **12** should therefore be substantially uniform.

In the absence of magnetic material, such as YIG sample **13**, between pole pieces **11** and **12**, the magnetic field between the faces of pole pieces **11** and **12** is substantially uniform. However, since YIG is a magnetic material, placing sample **13** in the magnetic field causes poles to be induced at the ends of

YIG sample 13. The induced poles have magnetic fields associated with them which distort the uniform nature of the magnetic fields provided by pole pieces 11 and 12.

In the present invention, polycrystal YIG backup pieces 24 and 25 increase the uniformity of the bias field within the single crystal YIG sample 13 by preventing induced poles from being established in the single crystal sample 13. Backup pieces 24 and 25 are placed in close proximity to the single crystal sample 13. As previously stated probes 16 and 19 are preferably in contact with faces 14 and 15 of YIG sample 13, respectively. Backup pieces 24 and 25 are in close proximity and preferably in contact with coupling probes 16 and 19, respectively. Therefore the space between the single crystal sample of YIG 13 and polycrystal YIG backup pieces 24 and 25 is in the order of 1 or 2 mils. Insofar as the magnetic bias field is concerned, the single crystal YIG 13 and polycrystal samples of YIG 24 and 25 appear to be a continuous structure and poles will only be induced at the end of this combined structure, namely at face 24' of backup piece 24 and face 25' of backup piece 25. Since there are no poles induced in YIG sample 13 the bias field within the single crystal sample 13 will be substantially uniform. Therefore, magnetostatic waves propagating through the single crystal YIG medium 13 will have a substantially constant wavelength. Propagation through the entire single crystal sample 13 will be in the magnetostatic mode with no conversion to the exchange spin wave or elastic mode.

A uniform field within the single crystal sample 13 can be provided by other apparatus. For example, a channel can be notched in a sphere of polycrystal YIG and a single crystal sample located within the channel. The magnetic bias field within the single crystal sample is substantially uniform and the magnetostatic wave propagating within the single crystal sample has a substantially uniform wavelength throughout the YIG medium. However, providing a uniform bias field in the YIG sample 13 can introduce other problems. If the field is nonuniform end faces 14 and 15 of YIG sample 13 are tuned far from resonance. There is a reasonable impedance match between the face of the YIG and free space so there is good coupling between probe 16 and the single crystal sample of YIG 13. However, when the magnetic bias field in the YIG medium is made substantially uniform, end faces 14 and 15 are tuned close to resonance and each face has a high permeability. In the absence of a backup piece, the high permeability presented by face 14 causes the magnetic field component of the electromagnetic field associated with probe 16 to bunch up on the side probe 16 opposite that of the YIG sample 13. Most of the current flowing in the probe 16 also congregates on the side of probe 16 opposite the YIG sample 13 and there would poor coupling between probe 16 and YIG sample 13. The same poor coupling would exist between face 15 and probe 19.

In the FIG. 1 embodiment backup pieces 24 and 25, besides providing uniform magnetic bias field in the single crystal YIG sample 13, overcome the coupling problem that would otherwise be associated with providing a uniform internal bias field. Backup pieces 24 and 25 provide increased permeability to the electromagnetic field associated with probes 16 ad 19 so that the permeability is substantially the same on both sides of probes 16 and 19. The current distribution in probes 16 and 19 is therefore forced to be substantially symmetrical and there is efficient coupling from probes 16 and 19 into and out of the YIG sample 13.

Although there is a 3*db* loss as a result of coupling energy into the polycrystal backup pieces 24 and 25, the coupling provided with backup pieces 24 and 25 is vastly superior to that that would exist in the absence of the backup pieces. The reflection loss due to mismatch in the absence of backup pieces 24 and 25 is substantially greater than 3*db*.

In FIG. 1 backup pieces 24 and 25 consist of samples of polycrystal YIG. Single crystal YIG could also be utilized but polycrystal samples are preferred because of their lower cost. Furthermore, polycrystal YIG is more lossy and does not cause spurious waves to be reflected from discontinuities in the backup pieces. Although improved coupling will result from using backup pieces of any cross section, backup pieces 24 and 25 preferably have substantially the same cross section as the single crystal sample 13 as is illustrated in FIG. 1*c*.

DESCRIPTION OF THE FIG. 2 EMBODIMENT

FIG. 2*a* is another embodiment of a magnetostatic delay line constructed in accordance with the present invention. FIG. 2*a* is an enlarged view of the waveguide looking in the same direction as in FIG. 1*a*. In FIG. 2*a* the cover plate of waveguide 10' has been removed in order to illustrate the orientation of the samples of magnetic insulator material within the waveguide structure.

The FIG. 2*a* waveguide includes a plurality of samples of single crystal magnetic insulator material 28, 29 and 30. As previously stated yttrium iron garnet (YIG) is the preferred magnetic insulator material. The single crystal samples are separated from each other by thin dielectric spacers 31 and 32 and are axially oriented in the magnetic field provided by pole pieces 33 and 34 such that the common longitudinal axis 35 of samples 28, 29 and 30 is parallel to the magnetic field.

The delay line further includes coupling probes 36 and 37 whose structure and function corresponds to probes 16 and 19 in the FIG. 1 embodiment. Probe 36 is coupled to a signal generator and has current flow in the probe which corresponds to the signal to be delayed. The current flow establishes an electromagnetic field which causes energy to be coupled to the single crystal sample of YIG 28 which establishes a magnetostatic wave in sample 28. The magnetostatic wave propagates through samples 28, 29 and 30. At the end of the propagation in YIG sample 30 an electromagnetic field is established in the vicinity of coupling probe 37. This electromagnetic field produces a current flow in probe 37 corresponding to the current flow in probe 36, delayed by a predetermined amount.

The delay line also includes polycrystal YIG backup pieces 38 and 39 which correspond in structure and function to the backup pieces 24 and 25 of the FIG. 1 embodiment. Backup pieces 38 and 39 provide a uniform magnetic bias field in the single crystal samples 28, 29 and 30 provides a substantially uniform permeability to coupling probes 36 and 37 so that efficient coupling is provided between probes 36 and single crystal YIG sample 28 and probe 37 and single crystal sample 30 even though the end faces of these samples are tuned near resonance.

OPERATION

As previously stated, the nondispersive delay that can be obtained is related to the length of the YIG sample. Since it is very expensive to construct a YIG bar more than 0.6 inch long and virtually impossible to grow a single crystal YIG sample having no defects which is more than 1 inch long, the amount of nondispersive delay obtainable, and more generally, the *f–t* curve linearity, has been restricted. In the present invention two or more single crystal YIG samples are cascaded along their longitudinal axis 31 in order to provide a longer delay path than is possible with one single crystal sample. The magnetostatic wave excited in bar 28 as a result of current flow in probe 36 couples between samples 28 and 29 and between samples 29 and 30 because the coupling does not depend on the continuity of the crystal lattice. The coupling between bars is electromagnetic and is not due to electron exchange or elastic lattice vibrations. The discontinuity in the lattice structure therefore does not prevent coupling of the energy between bars 28 and 29 or 29 and 30.

Dielectric spacers 31 and 32 provide improved coupling between single crystal samples 28 and 29 and between samples 29 and 30, respectively. Delay lines which have been constructed in accordance with the present invention but which have not utilized such spacers, have exhibited periodic fluctuations in the amplitude of delayed signals. The fluctuations

are the result of beating between waves arriving by two different paths. The reason two different paths exist is illustrated in FIG. 2*b*, which illustrates two samples of YIG **40** and **41** placed end to end. Even if samples **40** and **41** are accurately machined and highly polished it is virtually impossible to have samples **40** and **41** in physical contact over their respective faces **40'** and **41'**. The usual contact will be as illustrated in FIG. 2*b* wherein samples **40** and **41** are in contact only at one point, contact point **42**. It is believed that this produces two undesirable effects. First, the DC flux tends to crowd towards the contact point **42** and brings the region of each sample **40** and **41** in the vicinity of contact point **42** closer to ferromagnetic resonance. Second, there is magnetostatic propagation through the contact point as well as direct electromagnetic coupling across the air gap. Since the magnetostatic wave is a backward wave, the phase through this path advances as the bias field is increased in order to increase the delay. Since the coupling through the air gap has little phase shift the two couplings go through reinforcement and cancellation. The path through contact point **42** being closer to ferromagnetic resonance changes phase more rapidly than the bulk of the bar so many beating cycles are obtained.

In the FIG. 2*a* embodiment the thin dielectric spacers **31** and **32** inserted between samples **28** and **29** and between samples **29** and **30**, respectively, prevent the samples from being in physical contact at any point. Therefore, all the coupling between the bars is electromagnetic. Since there is negligible distortion of the internal bias field, the entire ferromagnetic waveguide is operating at the same value of internal bias field.

Experimentation on .040 inch × .04 inch × .4 inch YIG bars indicates that the thickness of the dielectric sheet should be at least .001 inch to insure that there is no physical contact between the bars in order to eliminate the beating effect. The maximum thickness of the dielectric spacer should be less than .010 inch. A larger spacing between the bars distorts the magnetic field rather than making it more uniform.

While there have been described what are at present considered to be the preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention and it is, therefore, aimed to cover all such changes and modifications as fall within the true spirit and scope of the invention.

We claim:

1. A magnetostatic delay line, comprising:

a sample of single crystal magnetic insulator material having first and second faces;

an input device including a first current-carrying member contiguous with said first face for coupling electromagnetic energy to said magnetic insulator material as a result of high frequency current flow in said first current-carrying member;

means for subjecting the magnetic insulator material to an axial magnetic bias field that is substantially uniform in the absence of said magnetic insulator material for causing said electromagnetic energy to propagate in said magnetic insulator material as a magnetostatic wave;

an output device including a second current-carrying member contiguous with said second face for coupling electromagnetic energy from the magnetic insulator material to produce a signal in said second current-carrying member representative of the high frequency signal in said first current-carrying member delayed by a predetermined amount;

a nonmagnetic shielding member surrounding said single crystal magnetic insulator material in the region of said current-carrying members for preventing undelayed leakage of electromagnetic energy from said first current-carrying member to said second current-carrying member; and

first and second samples of magnetic insulator material in close proximity to said first and second faces respectively for increasing the uniformity of said magnetic bias field so that the wavelength of said propagating magnetostatic wave remains substantially constant in said single crystal magnetic insulator material without reducing the amount of electromagnetic energy that is coupled between said input and output devices and said single crystal magnetic insulator material.

2. A magnetostatic delay line as claimed in claim **1** in which the single crystal magnetic insulator material is yttrium iron garnet (YIG).

3. A magnetostatic delay line as claimed in claim **1** which includes a plurality of samples of single crystal magnetic insulator material cascaded along their longitudinal axis and in which said input and output devices are positioned at the opposite ends of said cascaded samples.

4. A magnetostatic delay line as claimed in claim **3** in which the single crystal magnetic insulator material is yttrium iron garnet (YIG).

5. A magnetostatic delay line as claimed in claim **3** in which the single crystal magnetic insulator material is yttrium iron garnet and in which the cascaded samples of yttrium iron garnet are separated from each other by thin dielectric spacers.

6. A magnetostatic delay line as claimed in claim **3** in which the single crystal magnetic insulator material is yttrium iron garnet and in which the cascaded samples of yttrium iron garnet are separated from each other by thin dielectric spacers having a thickness between .001 inch and .010 inch.

7. A magnetostatic delay line as claimed in claim **1** in which the single crystal magnetic insulator material is yttrium iron garnet (YIG) and in which the nonmagnetic shielding member comprises a metal wall cutoff waveguide whose internal dimensions are less than that required to propagate said electromagnetic energy as a hollow waveguide.

8. A magnetostatic delay line as claimed in claim **7** in which the single crystal YIG sample is separated from the interior wall of the metal waveguide by several wavelengths of the magnetostatic energy in the YIG sample.

9. A magnetostatic delay line as claimed in claim **2** in which said first and second samples of magnetic insulator material are samples of polycrystal yttrium iron garnet (YIG).

10. A magnetostatic delay line as claimed in claim **9** in which the first and second samples of polycrystal YIG have substantially the same cross section as the sample of single crystal YIG.

11. A magnetostatic delay line comprising:

a plurality of samples of single crystal magnetic insulator material cascaded along their longitudinal axis having first and second faces at the opposite ends of the cascaded combination;

an input device including a first current-carrying member contiguous with said first face for coupling electromagnetic energy to said magnetic insulator material as a result of high frequency current flow in said first current-carrying member;

means for subjecting the magnetic insulator material to an axial magnetic bias field that is substantially uniform in the absence of said magnetic insulator material for causing said electromagnetic energy to propagate in said magnetic insulator material as a magnetostatic wave;

an output device including a second current-carrying member contiguous with said second face for coupling electromagnetic energy from the magnetic insulator material to produce a signal in said second current-carrying member representative of the high frequency signal in said first current-carrying member delayed by a predetermined amount; and

a nonmagnetic shielding member surrounding said single crystal magnetic insulator material in the region of said current-carrying members for preventing undelayed leakage of electromagnetic energy from said first current-carrying member to said second current-carrying member.

12. A magnetostatic delay line as claimed in claim **11** in which the plurality of single crystal samples of magnetic insu-

lator material are single crystal samples of yttrium iron garnet (YIG).

13. A magnetostatic delay line as claimed in claim 12 in which the plurality of single crystal YIG samples are separated from each other by thin dielectric spacers having a thickness between .001 inch and .010 inch.