Oct. 4, 1966 G. J. NEUMANN 3,277,402

INTERNAL MAGNET COAXIAL LINE GYROMAGNETIC DEVICE HAVING MEANS FOR ROTATING ONE CONDUCTOR RELATIVE TO THE OTHER

Filed May 25, 1964

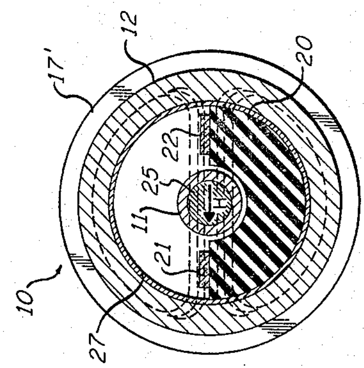

FIG. 2.

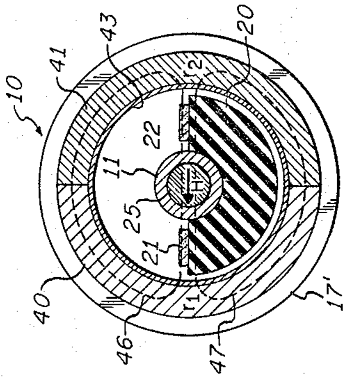

FIG. 5.

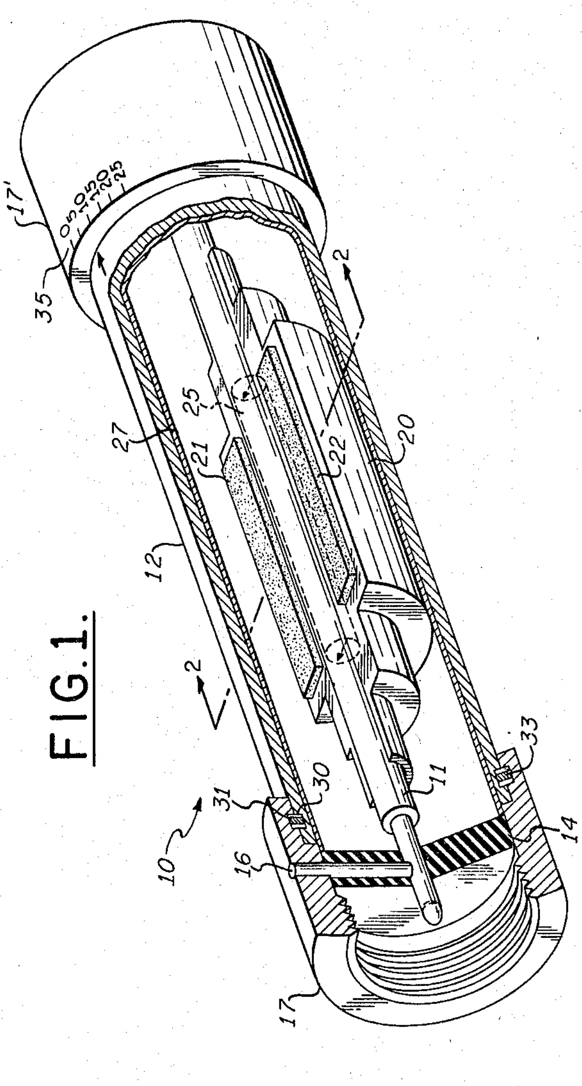

FIG. 1.

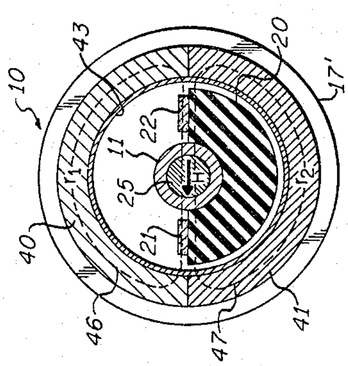

FIG. 4.

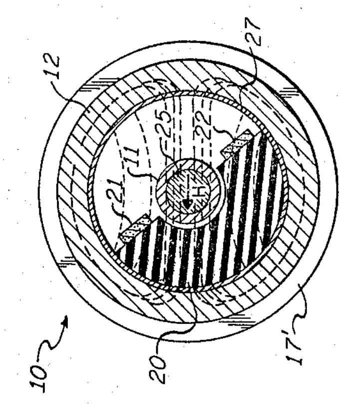

FIG. 3.

INVENTOR.
GEORGE J. NEUMANN
BY
John H. Gallagher
ATTORNEY

United States Patent Office

3,277,402

Patented Oct. 4, 1966

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INTERNAL MAGNET COAXIAL LINE GYROMAGNETIC DEVICE HAVING MEANS FOR ROTATING ONE CONDUCTOR RELATIVE TO THE OTHER

George J. Neumann, Dunedin, Fla., assignor to Sperry Rand Corporation, Great Neck, N.Y., a corporation of Delaware

Filed May 25, 1964, Ser. No. 369,734

11 Claims. (Cl. 333—24.1)

This invention relates to an internal magnet coaxial line device that employs a magnetized gyromagnetic material to impart desired propagating characteristics to said device, and more particularly relates to means for varying the magnetization of the gyromagnetic material.

The type of device to which the present invention relates is disclosed and claimed in U.S. Patent 3,072,867, issued January 8, 1963 in the name of William C. Heithaus, and assigned to applicant's assignee. Briefly stated, the internal magnet coaxial line device described in said patent is comprised of a section of coaxial transmission line having inner and outer conductors. As is known, the coaxial transmission line propagates electromagnetic waves in the dominant TEM mode that is characterized by the absence of any circularly polarized components. To induce circularly polarized components within the transmission line, a portion of the space between the conductors is filled with a low loss dielectric material that has a dielectric constant different from that of the remainder of the dielectric medium separating the conductors. This added dielectric material induces a circularly polarized component in the magnetic field of waves propating between the conductors, and by placing a magnetized member of gyromagnetic material, such as a ferrite or garnet material, in the region of the circularly polarized component, nonreciprocal propagation characteristics may be obtained. The gyromagnetic material is magnetized by a transversely magnetized permanent magnet that is enclosed within the inner conductor of the coaxial line. The outer conductor of the coaxial line is comprised of a low reluctance magnetic material in order to provide a low reluctance return path for the magnetizing field supplied by the internally positioned permanent magnet. Because of its small size and weight this device has enjoyed considerable commercial success for use as an isolator, attenuator, or phase shifter. The propagating characteristics of this device, however, are fixed once the device has been assembled, inasmuch as the internally mounted permanent magnet supplies a fixed value of magnetizing field for the gyromagnetic members. In some instances, such as in laboratory work, it may be desirable to provide different values of isolation, attenuation, or phase shift in a coaxial transmission line circuit.

It therefore is an object of this invention to provide an internal magnet coaxial line device whose propagating characteristics may be changed without the addition of appreciable physical structure that would increase the size and weight to the device.

Another object of this invention is to provide an internal magnet coaxial line gyromagnetic device having means for varying the magnetization of the gyromagnetic mataerial employed within said device.

A further object of this invention is to provide a small, compact coaxial line device whose propagating characteristics may be varied.

A further object of this invention is to provide variable magnetization means in a coaxial line device employing a gyromagnetic material that is magnetized by an internally mounted permanent magnet.

Another object of this invention is to provide means for varying the reluctance of the magnetizing field return

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path in an internal magnet coaxial line device employing magnetizable gyromagnetic material.

In accordance with one illustrated embodiment of the invention, the basic structure of the internal magnet coaxial line device is comprised of a coaxial transmission line section having spaced inner and outer conductors. An annular shaped member of low loss dielectric material of substantially 180° angular extent is disposed between the conductors and is secured to the outer conductor, but is free to rotate relative to the inner conductor. Members of gyromagnetic material are positioned on the dielectric material on opposite sides of the center conductor. A transversely magnetized permanent magnet is disposed within the center conductor in the region of the gyromagnetic members and furnishes the transversely-directed magnetizing field for said members. At respective regions on the outer conductor beyond the two ends of the dielectric material, rotary joints are provided for permitting the outer conductor, the dielectric material, and the gyromagnetic material to rotate as a unit relative to the direction of the magnetizing field provided by the internally mounted permanent magnet. This arrangement permits the gyromagnetic material to be adjustably positioned within the magnetizing field from a region of strongest magnetization to regions of weaker magnetization. Because the propagating characteristics of the device are a function of the state of magnetization of the gyromagnetic material, the propagating characteristics of the device may be varied by rotating the outer conductor, the dielectric material and the gyromagnetic members relative to the fixed magnetizing field.

The present invention will be described by referring to the accompanying drawings wherein:

FIG. 1 is a perspective view, partially cut away, illustrating one embodiment of the present invention;

FIGS. 2 and 3 are sectional views taken at section **2—2** of FIG. 1 illustrating the relative positions of the internal members of the device relative to the magnetizing field, for different rotational angles of the adjustably-positioned portion of the device; and

FIGS. 4 and 5 are cross-sectional view illustrating an alternative embodiment of the present invention.

Referring now in more detail to FIGS. 1 and 2 of the drawing, an adjustable internal magnet coaxial line device **10** is comprised of a section of coaxial transmission line having coaxially disposed inner conductor **11** and outer conductor **12**. Inner conductor **11** is supported coaxially within otuer conductor **12** by means of a low loss dielectric bead **14**. A dielectric pin **16** extends diametrically through dielectric bead **14** and through the end of inner conductor **11**, and is secured within the end portion **17** of outer conductor **12** so as to maintain the respective components in fixed position relative to each other. An annular shape member of low loss dielectric material **20** having an angular extent of approximately 180° is disposed between inner conductor **11** and outer conductor **12**. Dielectric member **20** has a dielectric constant differing from that of the air filled region of the coaxial transmission line and thereby provides means for distorting the magnetic field pattern of the electromagnetic waves propagating through the device and induces in said magnetic field circularly polarized components, as is now well understood in the art. Dielectric member **20** is stepped in diameter at each of its ends to provide impedance transformer means for impedance matching purposes. Dielectric member **20** is fixedly secured to outer conductor **12** but is free to rotate relative to inner conductor **11**. Two members of gyromagnetic material 21 and 22 are secured to the top planar surfaces of dielectric member **20** on opposite sides of inner conductor **11**. Members **21** and **22** may be of any of the ferrite, garnet or related materials that are well known for use in non-reciprocal transmission line devices. Disposed within inner conductor 11 in the region of gyromagnetic members 21 and 22 is a permanent magnet 25 that provides a transversely directed steady magnetic field for magnetizing gyromagnetic members 21 and 22. To provide a low reluctance magnetic field return path to internal magnet 25, outer conductor 12 is comprised of a low reluctance magnetic material such as soft iron. The inner surface of outer conductor 12 has a thin coating 27 of a high conductivity material such as copper to provide a highly conductive surface for the propagation of electromagnetic waves through the device.

The central region of outer conductor 12 is adapted to freely rotate relative to the respective end members 17 and 17', each of which constitutes continuations of the outer conductor of the coaxial transmission line. The rotating joint that permits the rotation of the outer conductor 12 relative to the end members 17 and 17' is constructed in the following manner. The right end of end member 17 is undercut to permit outer conductor 12 to extend a short distance therein. The portion of outer conductor 12 that extends within end member 17 is provided with an annular slot 30, and this slot 30 is disposed to register with a similar slot 31 within end member 17. A retaining snap ring 33 is disposed within slot 31 and extends into slot 30 in outer conductor 12, thereby permitting angular rotation of outer conductor 12 relative to end member 17. End member 17' is constructed in like manner to provide a rotary joint at the other end of the outer conductor.

Because dielectric member 20 is secured to outer conductor 12, it and gyromagnetic members 21 and 22 will rotate relative to inner conductor 11 as the outer conductor 12 is rotated. Indexing means 35 may be provided at one of the rotary joints to provide an indication of the relative position of dielectric member 20 and gyromagnetic members 21 and 22 within the device. End members 17 and 17' are constructed in such a manner as to provide conventional coaxial line connector means at their outer ends.

The operation of the device of FIG. 1 will be explained by referring to FIGS. 2 and 3. As illustrated in FIG. 2, gyromagnetic members 21 and 22 are positioned along a diameter that is parallel to the direction of the magnetizing field H supplied by internal magnet 25. In this position, gyromagnetic members 21 and 22 will be in the region of strongest field strength of the magnetizing field. With the structural relationship illustrating FIG. 2, the device 10 will provide certain propagating characteristics that are functions of the state of magnetization of gyromagnetic members 21 and 22. These propagating characteristics may be changed in the device of this invention by rotating outer conductor 12, dielectric member 20 and gyromagnetic members 21 and 22 relative to the inner conductor 11 and permanent magnet 25 which are fixedly positioned. This is illustrated in FIG. 3 wherein it may be seen that gyromagnetic members 21 and 22 now lie along a diameter that is angularly displaced from the transverse direction of magnetizing field H. In these positions gyromagnetic members 21 and 22 are in the portion of the magnetizing field H that is of reduced strength relative to the central region of the field. Because gyromagnetic members 21 and 22 now are more weakly magnetized they will impart different propagating characteristics to transmission line device 10. As now may be seen, the operating characteristics of the device 10 may be adjusted by the rotation of outer conductor 12 to provide varying amounts of isolation, attenuation, or phase shift, as may be desired.

An alternative embodiment of the present invention is illustrated in FIGS. 4 and 5 wherein the internal components of the device 10 are substantially identical to those described previously, with the exception that dielectric member 20 is fixedly secured to inner conductor 11, and

outer conductor 12 now is free to rotate relative to fixed dielectric member 20. As before, gyromagnetic members 21 and 22 are secured to the planar surfaces of dielectric member 20. In this embodiment, outer conductor 12 is comprised of two semicircular portions 40 and 41 that are joined along a diametrical plane. Member 40 is comprised of a material such as iron that has a low magnetic reluctance, and member 41 is comprised of a high reluctance material such as copper or brass. The inner surfaces of members 40 and 41 are provided with a thin conductive coating of a material such as copper 43 to assure good electrical conductivity for the propagation of electromagnetic waves within the waveguide section. This embodiment of the invention also is provided with the two rotary joints on the outer conductor 12 in the same manner as illustrated in FIG. 1 so that outer conductor 12 may be rotated angularly with respect to inner conductor 11, permanent magnet 25, dielectric member 20, and gyromagnetic members 21 and 22. With the arrangement illustrated in FIG. 4, the semicircular members 40 and 41 provide parallel magnetic flux return paths 46 and 47 for the transversely directed magnetizing flux provided by permanent magnet 25. The magnetic field return path 46 will be of low reluctance, and magnetic field return path 47 will be of higher reluctance, and the total reluctance R_t provided by both members 46 and 47 may be represented by the expression

$$R_t=\frac{r_1 r_2}{r_1+r_2}$$

wherein r_1 and r_2 are the respective magnetic reluctances of members 40 and 41. As may be seen in FIG. 4, the path 46 lies entirely within the low reluctance material of member 40 and this path will carry a major portion of the magnetizing flux.

FIG. 5 illustrates the arrangement of the device 10 after the outer conductor 12 has been rotated 90° relative to its position illustrated in FIG. 4. As may be seen in FIG. 5, one-half of each of the semicircular members 40 and 41 will lie in each of the magnetic flux return paths 46 and 47, so that now both of said return paths 46 and 47 are of a higher reluctance than path 46 that was provided in FIG. 4. The total reluctance R_t of the magnetic return path arrangement of FIG. 5 may be expressed by the relationship

$$R_t=\frac{\left(\frac{r_1}{2}+\frac{r_2}{2}\right)\left(\frac{r_1}{2}+\frac{r_2}{2}\right)}{\left(\frac{r_1}{2}+\frac{r_2}{2}\right)\left(\frac{r_1}{2}+\frac{r_2}{2}\right)}$$

With given values of reluctance r_1 and r_2 for semicircular members 40 and 41, the second one of the above expressions for R_t will be larger in magnitude than the first expression. Therefore, by varying the angle by which the higher reluctance member 41 extends into the flux return path 46 the magnetization of gyromagnetic members 21 and 22 may be decreased, thereby varying the propagating characteristics of the device 10.

Although the internal magnet coaxial line type of devices illustrated in the attached drawing are particularly useful as non-reciprocal transmission line devices, the teaching of this invention also would be applicable for use in a reciprocal transmission line device that may be employed as a bilateral attenuator or phase shifter. The structure of such devices would be similar to those previously illustrated except that the dielectric member 20 would be of a different shape and/or different dielectric constant so that it no longer would function as an electromagnetic wave magnetic field distorting means. The remainder of the device to be used as a reciprocal attenuator or phase shifter would be substantially the same as previously described so as to permit the rotation of outer conductor 12, thereby varying the positions of gyromagnetic members 21 and 22 relative to the transversely directed magnetizing field H supplied by internal magnet 25, or to permit the variation of the reluctance of the magnetic field return path provided by outer conductor 12.

From the above description it may be seen that the advantageous features of small size and weight of the internal magnet coaxial line device of the prior art have been retained and that the capability of varying the magnetization of the gyromagnetic material within the device has been added.

While the invention has been described in its preferred embodiments, it is to be understood that the words which have been used are words of description rather than limitation and that changes within the purview of the appended claims may be made without departing from the true scope and spirit of the invention in its broader aspects.

What is claimed is:

1. A coaxial line device having adjustable electromagnetic wave propagating characteristics comprising,
a section of coaxial transmission line having inner and outer conductors,
one of said conductors being comprised of a low reluctance magnetic material over at least a portion of its angular extent,
a magnetizable wave propagating gyromagnetic medium disposed between said conductors in the region of said low reluctance magnetic material,
means within the other one of said conductors for magnetizing said gyromagnetic medium in a transverse direction between said conductors,
said magnetic material being secured in a fixed position relative to the one of said conductors, and
means for rotating one of said conductors relative to the other conductor.

2. A coaxial line device having adjustable electromagnetic wave propagating characteristics comprising,
a section of coaxial transmission line having inner and outer conductors,
one of said conductors being comprised of a low reluctance magnetic material over at least a portion of its angular extent,
a magnetizable wave propagating gyromagnetic medium disposed between said conductors in the region of said low reluctance magnetic material,
means within said inner conductor for magnetizing said gyromagnetic medium in a transverse direction between said conductors,
said magnetic material being secured in a fixed position relative to the one of said conductors, and
means for rotating one of said conductors relative to the other conductor.

3. The combination claimed in claim 2 wherein said gyromagnetic medium is fixed in position relative to said outer conductor, and
said outer conductor is rotatable relative to said inner conductor.

4. The combination claimed in claim 2 wherein said gyromagnetic medium is fixed in position relative to said inner conductor, and
said outer conductor being rotatable relative to said inner conductor,
said outer conductor being comprised of at least two angular portions of different magnetic reluctance.

5. A coaxial line device having adjustable electromagnetic wave propagating characteristics comprising,
a section of coaxial transmission line having inner and outer conductors,
said outer conductor being comprised of a low reluctance magnetic material over at least a portion of its angular extent,
magnetizable gyromagnetic material disposed between said conductors in the region of said low reluctance material,
a permanent magnet within said inner conductor for magnetizing said gyromagnetic material in a direction transverse to the direction of wave propagation through said transmission line,
means for securing said gyromagnetic material in a fixed position relative to one of said conductors, and
means for coaxially rotating one of said conductors relative to the other conductor.

6. A coaxial transmission line device having adjustable electromagnetic wave propagating characteristics comprising,
a section of coaxial transmission line having inner and outer conductors,
magnetizable gyromagnetic material disposed between said conductors,
means disposed within said inner conductor for providing a transversely directed steady magnetic field to magnetize said gyromagnetic material,
said outer conductor being comprised of a low reluctance material over at least a portion of its angular extent in the region of said gyromagnetic material,
whereby said outer conductor serves as a magnetic field return path for the steady magnetic field,
and means for varying the position of said gyromagnetic material relative to the transverse direction of the steady magnetic field.

7. A coaxial transmission line device having adjustable electromagnetic wave propagating characteristics comprising,
a section of coaxial transmission line having inner and outer conductors,
magnetizable gyromagnetic material disposed between said conductors,
means disposed within said inner conductor for providing a transversely directed steady magnetic field to magnetize said gyromagnetic material,
said outer conductor being comprised of a low reluctance material over at least a portion of its angular extent in the region of said gyromagnetic material,
whereby said outer conductor serves as a magnetic field return path for the steady magnetic field,
and means for varying the reluctance of said magnetic field return path.

8. A coaxial transmission line device having adjustable electromagnetic wave propagating characteristics comprising,
a section of coaxial transmission line having inner and outer conductors,
said outer conductor being comprised of a low reluctance magnetic material,
magnetizable gyromagnetic material disposed between said conductors,
magnetizing means disposed within said inner conductor for providing a transversely directed steady magnetic field to magnetize said gyromagnetic material,
first and second rotary joints disposed within said outer conductor at respective regions adjacent the ends of said gyromagnetic material,
whereby the portion of said outer conductor intermediate said rotary joints is rotatable with respect to said inner conductor,
said gyromagnetic material being fixed to said rotatable portion of said outer conductor, thereby to rotate relative to said magnetizing means when the outer conductor is rotated.

9. A coaxial line device having adjustable electromagnetic wave propagating characteristics comprising,
a section of coaxial transmission line having inner and outer conductors,
said outer conductor being comprised of first and second angular portions having different magnetic reluctances,
a magnetizable gyromagnetic member disposed be-

tween said conductors and fixed in position relative to said inner conductor,

magnetizing means disposed within said inner conductor for providing a transversely directed magnetic field to magnetize said gyromagnetic member,

first and second rotary joints disposed in said outer conductor at respective regions beyond the ends of said gyromagnetic member,

whereby the portion of said outer conductor intermediate said rotary joints is adapted to rotate relative to the direction of said magnetic field.

10. A coaxial transmission line device having adjustable electromagnetic wave propagating characteristics comprising,

a section of coaxial transmission line having inner and outer conductors,

said outer conductor being comprised of a low reluctance magnetic material,

a member of low loss dielectric material disposed between said conductors,

said dielectric member having an annular extent to incompletely fill the region between said conductors,

magnetizable gyromagnetic material disposed adjacent said dielectric member in the region between said conductors,

a permanent magnet disposed within said inner conductor and being magnetized in a direction to provide a transversely directed steady magnetic field for magnetizing said gyromagnetic material,

first and second rotary joints disposed within said outer conductor at respective regions adjacent the ends of said gyromagnetic material,

whereby the portion of said outer conductor intermediate said rotary joints is rotatable with respect to said inner conductor,

said dielectric member and said gyromagnetic material being fixed relative to said rotatable portion of said outer conductor thereby to rotate relative to said permanent magnet when said outer conductor is rotated.

11. A coaxial line device having adjustable electromagnetic wave propagating characteristics comprising,

a section of coaxial transmission line having inner and outer conductors,

said outer conductor being comprised of first and second angular portions having different magnetic reluctances,

a member of dielectric material having the shape of a sector of an annulus disposed between said conductors in fixed relationship relative to said inner conductor,

a magnetizable gyromagnetic member disposed between said conductors adjacent said dielectric member and fixed in position relative to said inner conductor,

a transversely magnetized permanent magnet disposed within said inner conductor for providing a transversely directed magnetizing field for said gyromagnetic member,

first and second rotary joints disposed in said outer conductor at respective regions beyond the ends of said gyromagnetic member,

whereby the portion of said outer conductor intermediate said rotary joints is adapted to rotate relative to the direction of said magnetizing field.

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HERMAN KARL SAALBACH, *Primary Examiner.*

P. L. GENSLER, *Assistant Examiner.*