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VARIABLE DELAY USING DIELECTRIC SCREW ROTATABLE INSIDE
SURROUNDING HELICAL TRANSMISSION LINE
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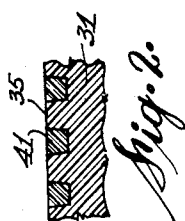
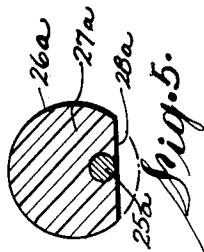
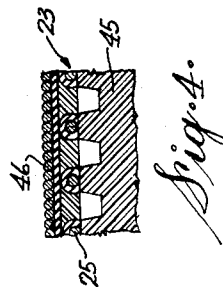
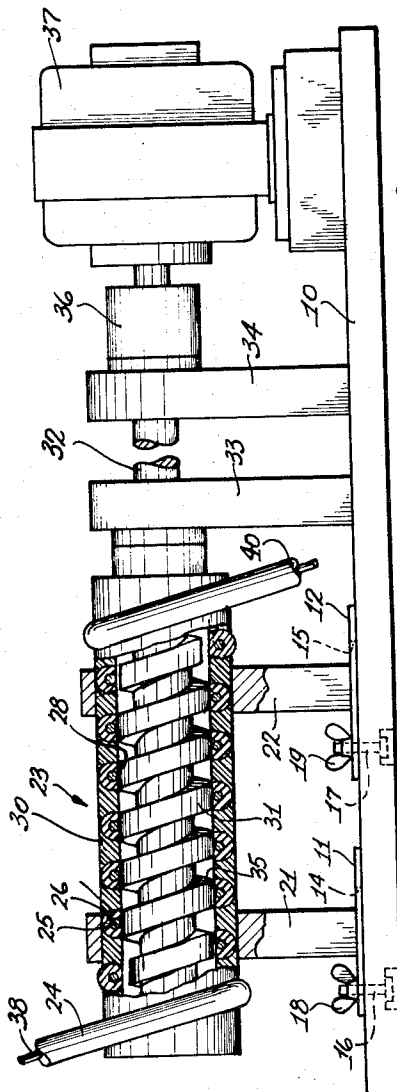


Fig. 1.

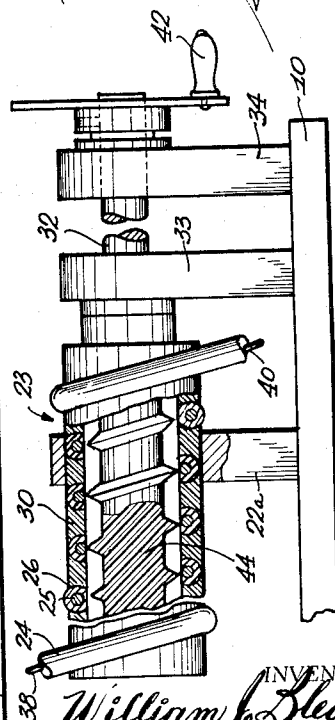


Fig. 3.

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VARIABLE DELAY USING DIELECTRIC SCREW ROTATABLE INSIDE SURROUNDING HELICAL TRANSMISSION LINE

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This invention relates to a helical microwave device, and in particular it relates to a microwave device adaptable for use as a phase shifter, attenuator, and a non-reciprocal device.

When a wave is propagated from one point to another the amount by which the phase difference, amplitude, or other wave characteristic, changes between any two arbitrary points along the propagation path is normally a fixed quantity that is a function of the medium of propagation. Ordinarily the transmission medium, such as that of a waveguide or coaxial line, remains the same and consequently the change in a characteristic of a wave propagated between two points is constant. However, it is often desirable to be able to vary the change in a characteristic of a wave between two points. For example, it may be desirable to vary or shift the phase of a wave in order to shift the angular position of an antenna beam, to change the impedance at a particular point in a transmission line, to phase modulate a wave, or to provide a variable phase wave source in a laboratory; it may be desirable to vary the attenuation in a transmission line to amplitude modulate a wave, or to provide a variable amplitude wave source in a laboratory; and it may be desirable to have a propagation path with one amount of attenuation or phase shift for one direction of propagation and another amount for the opposite direction of propagation.

In the past many devices have been developed to achieve variable control of a wave characteristic. These devices may be grouped in two classes. The first class of device uses waveguides to provide the transmission path and may be referred to as waveguide devices. The second class of device uses two conductor cable, that is cable having an inner and an outer conductor, to provide the transmission path. This latter class of device may be referred to for convenience as a cable device, and in its most common form where coaxial cable or coaxial line is used it may be referred to as a coaxial cable device.

Prior art waveguide devices have not proved satisfactory because of their size at lower microwave frequencies, excessive weight or bulk, complex mechanical control, limited bandwidth, high cost, or for other reasons. Cable devices are not inherently subject to some of the aforementioned disadvantages, and it is in this class of microwave device that the present invention falls.

Prior art microwave devices in the cable class are of many types and are generally coaxial cable devices. One type of prior art coaxial cable device for varying phase shift is a line stretcher having a sliding coaxial trombone section in the coaxial line. A major disadvantage of the trombone type line stretcher, and indeed of many other types of phase shifters, is the reciprocating motion required for the sliding section. A reciprocating motion is undesirable for many applications, such as, for example, in a modulator which requires a continuous series of suc-

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cessive in and out movements, often at high speed. Generally, with reciprocating movement wear becomes an important factor and it is difficult to achieve a uniform and continuous phase shift. With a trombone type line stretcher it is often difficult to maintain a low impedance between the sliding parts.

Another known type of coaxial phase shifter comprises a section of coaxial line of larger dimensions coupled into the transmission path. The larger section may have an outer conductor of rectangular cross section, an air dielectric, and an inner conductor in the shape of a flat strip or ribbon. A jacket of a high dielectric constant material surrounds the center conductor for a variable length. The jacket may be slid in and out by a reciprocating movement to vary the length of the inner conductor covered and thus vary the amount of phase shift. As before, a disadvantage of this type of phase shifter is the reciprocating movement required to change the phase shift. This reciprocating motion is not suitable for many applications.

Other types of prior art phase shifters are ferrite loaded coaxial cables and helical phase shifters having a dielectric plug insertable a variable amount into the helix. The ferrite loaded coaxial cable has a limited bandwidth and is expensive to fabricate. A disadvantage of the helical phase shifter is the reciprocating movement required of the dielectric slug.

Prior art coaxial cable devices for attenuating a wave are also of several types. One type comprises a coaxial line or cable having a longitudinal slot in the outer conductor which extends to the inner or center conductor. A slab of lossy material, that is a material having a high dissipation factor or loss tangent, is inserted a variable amount into the slot to vary the attenuation. This attenuator requires some type of reciprocating motion for changing attenuation. Another disadvantage of this type of prior art coaxial attenuator is that it is difficult to prevent leakage of wave energy from the slot. Also, the attenuator usually requires a slot of considerable length.

Another type of prior art coaxial attenuator comprises coaxial line section of larger dimensions having a rectangular cross section for the outer conductor and an air dielectric. The inner conductor comprises a flat metallic strip centrally positioned within the rectangular outer conductor. A jacket of lossy dielectric material is positioned to slide a variable amount along the center conductor so that it surrounds a variable length of the center conductor. This attenuator achieves considerable attenuation in a short length, but, as before, a reciprocating motion is required to vary the attenuation.

Prior art non-reciprocal microwave devices are generally in the waveguide class with fewer types of non-reciprocal cable devices being available. Non-reciprocal devices of both classes frequently have a ferrite in the propagation path arranged to present different characteristics in opposite directions in the path. A magnetic field of variable strength passing through the ferrite may vary the non-reciprocal properties of the device. These prior art non-reciprocal devices are often complex and of difficult manufacture and are not generally adaptable for a plurality of uses.

The present invention overcomes many disadvantages of the individual prior art microwave devices, and in addition it is readily adaptable to perform more than one function. The invention is for a helical microwave device of the aforementioned cable class that is of simple construc-

tion involving no sliding contacts and no reciprocating motion, is of a convenient size, is not frequency sensitive, and can be used as a phase shifter, attenuator or non-reciprocal device.

It is therefore an object of this invention to provide an improved helical microwave device.

It is another object of this invention to provide a helical microwave device of novel structure for variably modifying characteristics of a wave propagated there-through.

It is another object of this invention to provide a helical cable microwave device of simple construction for varying the phase shift of a wave propagated there-through in response to simple rotary movement of a control member.

It is yet another object of this invention to provide a helical cable microwave device of simple construction for varying the attenuation of a wave propagated there-through in response to simple rotary motion of a control member.

It is also an object of this invention to provide a helical cable microwave device of simple construction having variable non-reciprocal properties of propagation.

Briefly stated the present invention in one form is for a microwave device comprising a cable having an inner and an outer conductor, said cable being in the form of a cylindrical helix having a central axis, said outer conductor extending partly around the inner conductor and being spaced therefrom, said outer conductor terminating in a pair of edges facing interiorly of said helix, said edges and the surface of said inner conductor facing interiorly of said helix being substantially in a line, and a worm core having a longitudinal axis and a pitch substantially the same as the pitch of said helix rotatably mounted within said helix with said longitudinal and said central axes being coincident.

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

FIGURE 1 is a side view, partly in section, of a coaxial microwave device in accordance with one embodiment of the invention,

FIGURE 2 is a fragmentary, sectional side view of an alternative form of the worm of FIGURE 1,

FIGURE 3 is a side view, partly in section, of a coaxial microwave device in accordance with another embodiment of the invention,

FIGURE 4 is a fragmentary, sectional side of view of a part of a coaxial microwave device in accordance with another embodiment of the invention, and

FIGURE 5 is an enlarged sectional view of a preferred form of the cable used in the microwave device of the invention.

Referring to FIGURE 1, there is shown a microwave device suitable for use as a phase shifter. A base 10 supports plates 11 and 12, each of which has a longitudinal slot 14 and 15 respectively. Screws 16 and 17 are fixed in base 10 and extend upwardly through slots 14 and 15 respectively. Thus plates 11 and 12 are supported for slidable longitudinal movement limited by the ends of slots 14 and 15. Wing nuts 18 and 19 engage screws 16 and 17 to clamp plates 11 and 12 in a fixed position.

Upwardly extending support brackets 21 and 22 are fixed to plates 11 and 12 at their lower end and support a helical assembly 23 at their upper end. The helical assembly 23 is shown comprising a coaxial cable 24, which may be a rigid coaxial cable requiring less external support, in the form of a cylindrical helix of substantially constant pitch and having a central axis. The cable 24 has an inner and an outer conductor 25 and 26 respectively, separated by a dielectric 27. Cable 24 is shown as a coaxial cable, that is a cable with concentric inner and outer conductors. From a constructional view-

point the use of a coaxial cable may be preferred, however, the use of an eccentric cable, as will be described hereinafter, will provide improved operation. The outer conductor 26 and the dielectric 27 of cable 24 have a chordal recess extending along the cable 24 from end to end of the helix. The recess forms wall 28 which constitutes an interior surface of the helix and which is preferably tangential to the center or inner conductor 25. A filler material 30 may be used between adjacent turns of the coaxial cable 24 so that the material 30 has an inner surface coextensive with the surface of wall 28 to form a continuous inner cylindrical surface of the coaxial assembly. The material 30 is preferably a metal having reasonably good conductivity that is easy to work with. There are many suitable materials of which one, for example, is brass. The helical assembly 23 may be considered as a circular waveguide and it is desirable that the diameter of the assembly 23 be such that the waveguide is beyond cutoff for the frequency range being used. This will prevent propagation of other modes and reduce radiation from the device.

The helical assembly 23 may be conveniently made by forming a rigid coaxial cable into a desired cylindrical helix having a brass filler material between adjacent turns and then machining away the inner surface of the helix until the inner conductor 25 of the cable is just exposed. The most efficient operation is obtained with the inner conductor just exposed and this construction is therefore preferred.

A shaft 32 is rotatably supported in bearings in bearing support brackets 33 and 34, the axis of shaft 32 being aligned with the central axis of coaxial assembly 23. A worm core 31 is fixed to the end of shaft 32 as an extension thereof. The worm core 31 has a longitudinal axis that is coincident with the central axis of the helix, that is the worm core 31 is supported centrally within the helix formed by the coaxial cable 24. The worm core 31 has a pitch that is substantially the same as the pitch of the helix and a flat topped tooth profile. The outer diameter of the worm core 31 is such that it fits snugly within the helix. That is, the flat top 35 of the tooth profile is closely adjacent the inner surface of the helical assembly 23.

In a preferred form of the invention, the flat top of a tooth, measured in a longitudinal direction, is substantially the same size as the size of wall 28 measured in a longitudinal direction between the pair of edges of a turn of the outer conductor 26, and the spacing between adjacent edges of the flat tops of adjacent teeth is also substantially the same size as the wall 28 in a longitudinal direction. In other words in a preferred form, the pitch of the helix and core, and the tooth size of the worm; are chosen so that in one rotary position of the core the flat tooth top is able to cover the chordal recess, and in another rotary position the chordal recess is not covered and the flat top is positioned opposite the surface of filler material 30 between the turns of the helix.

The worm core 31 is made of a dielectric material having a high dielectric constant and a low dissipation factor or loss tangent. Any dielectric material will, of course, have some effect, and will provide a phase shift in the microwave coaxial device of FIGURE 1. However, the use of materials having higher dielectric constants provide more phase shift and result in a shorter length of coaxial cable in the device for the same phase shift. Consequently it is desirable to use materials having a dielectric constant above that of the dielectric constant of the material in the coaxial cable itself which may be of the order of 2.2 and it is preferred to use a dielectric material in the worm core having a dielectric constant above 15. Similarly, in a phase shifter, it is usually desirable to keep the losses low and consequently it is desirable to use a dielectric material for worm core 31 having a loss tangent below about 0.001 and pref-

erably of the order of or below 0.0007. It will, however be apparent that the material may have loss tangent above these values if low loss is not important.

It will be seen that if the ends 38 and 40 of the coaxial cable 24 where they become part of the helical assembly 23 make an abrupt change from the straight external part to the helix, there will be two points of discontinuity or mismatch in the device. It is therefore desirable to use a tapered transition or gradual transition. In other words, as the cable 24 in the helical assembly 23 nears either end of the helix, it is spiralled outwards slowly for perhaps one turn before the end of the helix. This tapered transition can be seen in FIGURE 1. As a further aid, the teeth at both ends of worm core 31 may be gradually reduced in outer diameter or tapered over perhaps the distance of the tooth pitch of the core. It will be seen that when core 31 is not inserted to substantially its full extent within assembly 23, then the taper on the teeth at the end of worm 31 nearer shaft 32 will be outside assembly 23 and be ineffective. The taper at the farther end of core 31 will, however have a tapering effect at all amounts of insertion.

In the phase shifter of FIGURE 1, a coupling 36 couples shaft 32 to a ratiomotor or selsyn 37 or other remote control driving device. It will, of course, be apparent that the shaft 32 may be rotated manually if desired.

In the operation of the FIGURE 1 phase shifter a signal is fed in at end 38 of coaxial cable 24 and cut at end 40. The worm 31 may be rotated to alter the amount of phase shift between the input and output of the device. When the center of the flat top of a tooth is directly opposite the inner conductor 25 of the cable in the helix the phase retardation is a maximum. As the core is rotated through 180° the flat tops of the teeth move away from the high electric field region near the exposed inner conductor and the phase retardation becomes a minimum when the teeth are between the turns of the inner conductor. The maximum amount of phase retardation can be controlled by positioning the coaxial assembly 23 longitudinally so that more or less of worm core 31 is inserted in the coaxial assembly. The shape of the phase-shift curve as a function of core rotation may be altered by changing the shape of the teeth on the core.

It is a desirable feature of the invention that the curve of phase shift vs rotation of core 31 has substantially the same shape for various amounts of insertion of core 31 within helical assembly 23. This may be better expressed by the relationship given below where ϕ is the phase shift achieved by a rotational position θ of worm core 31. Then ϕ may be expressed generally as a function of θ

$$\phi = f\theta$$

For various amounts of insertion of the worm core 31 in the helical assembly 23

$$\phi_1 = C_1 \cdot f\theta$$

$$\phi_2 = C_2 \cdot f\theta$$

$$\phi_3 = C_3 \cdot f\theta$$

where C_1 , C_2 , and C_3 are constants associated with different amounts of insertion. This type of relationship results in a device that may be readily calibrated and quickly set for a desired situation.

Additionally the simple rotary motion and straightforward construction make the device readily adaptable to a number of uses.

It will be recalled that the cable 24 need not be a coaxial cable but may be an eccentric two conductor cable where the inner conductor axis is displaced from the axis of the outer conductor. FIGURE 5 is a sectional drawing of an eccentric cable as it would appear in the helical assembly 23 with a chordal recess through the outer conductor 26a and the dielectric 27a forming a

wall 28a. Thus, the wall 28a is defined by the terminating edges of the outer conductor 26a and the exposed surface of dielectric 27a. The wall 28a is preferably tangential to a surface of the inner conductor 25a as shown. As before, the wall 28a faces inwardly of the helix forming a portion of the inner surface of helical assembly 23. When an eccentric cable is used in helical assembly 23, it is desirable to obtain any advantage that the cable be oriented so that the chordal recess forming wall 28a extends through that part of the cable towards which the inner conductor 25a is displaced is indicated in FIGURE 5. That is, the chordal recess should be at right angles to the direction of displacement and should pass adjacent the surface of the inner conductor farthest from the center of the outer conductor. Thus, in a microwave device using eccentric cable, that part of the cable normally having a higher electric field concentration is exposed to the influence exerted by the worm core 31. Consequently a greater effect is achieved by the core and a smaller device can be used to achieve the same phase shift as compared to a coaxial device.

FIGURE 2 shows an alternative form for the worm core 31 in which the spaces between the teeth of the core are filled with a dielectric material 41 having the same loss tangent as the material of core 31 and having the same dielectric constant as air. This construction provides a uniform loss tangent in the core and minimizes amplitude variation that might occur with rotation of the core.

Referring now to FIGURE 3, there is shown a coaxial microwave device suitable for use as an attenuator. The device is similar in many respects to the device of FIGURE 1. As in FIGURE 1, a helical assembly 23 is supported above base 10 by support brackets (only one support bracket 22a is shown in FIGURE 3). The support brackets are fixed to base 10 so that the coaxial assembly 23 is not movable longitudinally. However, it will be apparent that the FIGURE 3 device could be readily adapted for longitudinal movement of helical assembly 23.

The helical assembly 23 of FIGURE 3 is the same as that of FIGURE 1 comprising a coaxial cable 24 having an inner conductor 25, an outer conductor 26 and a dielectric 27, in the form of a helix of predetermined pitch.

In FIGURE 3, the shaft 32, rotatably supported in bearing support brackets 33 and 34, has a handle 42 at one end for manual rotation. It will, of course, be apparent that shaft 32 could be adapted for remote rotation by a selsyn motor or similar drive. A worm core 44 is fixed to the other end of shaft 32 for rotation therewith. The worm core 44 has a longitudinal axis coincident with the axis of the helix, that is the worm core 44 is rotatably supported centrally of the helix formed by cable 24. The worm core 44 has a pitch substantially the same as the pitch of the helix and a V crest tooth profile. The outer diameter of worm core 44, that is the diameter from crest to crest, is such that the crest of the teeth are closely adjacent the interior surface of the coaxial assembly.

The worm core 44 is made of a dielectric material having a relatively high loss tangent. The material may, for example, have a loss tangent in excess of unity, and preferably in the range between 1 and 10. It will be apparent that materials having lower loss tangent values would work but a greater length helix is required when lower loss materials are used. Many suitable lossy materials have dielectric constants in the neighbourhood of 10-15 and this is quite suitable. However, dielectric materials with other values of dielectric constants are also suitable. If it is desirable that the device of FIGURE 3 should vary the attenuation with as little change in phase shift as possible, it is important that the space between the core teeth (as in FIGURE 2) be filled with a material having the same dielectric constant as the core material and a low loss tangent. With this construction the material ad-

jacent the inner conductor of the helix will have the same dielectric constant regardless of the rotary position of the core, thereby reducing phase shift change with the rotary core position.

A sharp tooth or V crest tooth profile is used for the core of the FIGURE 3 attenuator to keep the insertion loss of the device low, that is to keep the loss or attenuation associated with the device in its minimum attenuation position as low as possible. Other tooth profiles may be used if low insertion loss is not important. The insertion loss may also be reduced by stretching the helix and the core (increasing the pitch).

As in the case of FIGURE 1, tapered transitions may be used in the FIGURE 3 attenuator to achieve a better match at the ends of the device. Also, eccentric two conductor cable may be used instead of concentric or coaxial cable to increase the effect of the core.

In the operation of the FIGURE 3 attenuator, a signal is fed into the device at end 38 of coaxial cable 24 and out at end 40. The worm 44 may be rotated by means of handle 42 to alter the amount of attenuation of the signal propagated through the device from input to output. When the centre or crest of a tooth is opposite the inner conductor 25 of the cable in the helix the attenuation is a maximum, when the tooth crest is midway between two center conductors the attenuation is minimum. If the device is designed for longitudinal movement of the helical assembly (as in FIGURE 1) the amount of insertion of core 44 within the helix can be adjusted to vary the attenuation limits.

Referring now to FIGURE 4 there is shown a portion of a coaxial microwave device suitable for use as a non-reciprocal device. In the non-reciprocal device the helical assembly is substantially the same as that previously described for FIGURES 1 and 3. However this device has a worm core 45 of dielectric ferrite material. The core has flat topped teeth which are positioned substantially opposite the inner conductors 25. A coil of wire 46 has been added around the exterior of helical assembly 23. The coil 46 may be connected to a variable source of power (not shown) to cause an electrical current to flow through coil 43 and create a variable magnetic field extending through the ferrite core 45. Variation in the strength of the magnetic field will vary the saturation of the ferrite. The ferrite can thus be biased to gyromagnetic resonance where the propagation properties of the device are not the same in the opposite directions of wave propagation. The non-reciprocal properties are controlled by change in current through the coil as is known. The non-reciprocal properties of this device may be controlled or adjusted by varying the biasing current, varying the amount of insertion of core in the helical assembly, or by minor rotational changes of the core. These several means of control give the device more versatility than prior art devices.

It will be seen that the helical microwave device of this invention may be used as a variable phase shifter, variable attenuator or non-reciprocal device, and that there is no reciprocating motion of parts required to vary the properties of the device.

I claim:

1. A microwave device comprising a cable having an inner and an outer conductor separated by a first dielectric material, said cable being in the form of a cylindrical helix of a predetermined pitch and having a central axis, said outer conductor and said first dielectric material having a chordal recess extending along said cable from end to end of said helix, the wall of said recess passing adjacent said inner conductor and constituting an interior surface of said helix, and a worm core of a second dielectric material having a pitch of substantially said predetermined pitch and a longitudinal axis, said core being mounted within said helix for rotation about said longitudinal axis with said longitudinal and central axes being coincident between a first position in which the teeth of the

core are substantially opposite the inner conductor of said cable and a second position in which the teeth of the core are substantially between adjacent turns of said inner conductor, the outer periphery of said core fitting snugly within said interior surface.

2. A microwave device as defined in claim 1 in which said second dielectric material is a ferrite and further including a variable magnetic field forming means around said helix for forming an axial magnetic field therein.

3. A microwave device as defined in claim 1 in which the cable at the ends of the helix is spiralled outwards to form a tapered transition.

4. A microwave device as defined in claim 1 in which the teeth at the ends of the worm core have a reduced outer diameter to form a tapered transition.

5. A microwave phase shifter comprising a cable having an inner and an outer conductor separated by a first dielectric material, said cable being in the form of a cylindrical helix of a predetermined pitch and having a central axis, said outer conductor and said dielectric material having a chordal recess extending along said cable from end to end of said helix, the wall of said recess passing adjacent said inner conductor and constituting an interior surface of said helix, and a worm core of a second dielectric material having a dielectric constant greater than said first dielectric material, a longitudinal axis, a pitch of substantially said predetermined pitch and a flat-topped tooth profile, said core being mounted within said helix for rotation about said longitudinal axis with said longitudinal and central axes being coincident between a first position in which the flat top of the tooth profile of the core is opposite the inner conductor of said cable to provide a maximum phase shift and a second position in which the flat top is between adjacent turns of said inner conductor to provide a minimum phase shift, the flat top of said worm core tooth profile fitting snugly within said interior surface.

6. A microwave phase shifter as defined in claim 5 and further including adjustable means for mounting said helix for longitudinal movement with respect to said core for varying the amount of said core inserted within said helix to adjust the maximum amount of phase shift available.

7. A microwave phase shifter as defined in claim 5 and further including a dielectric filler material between the teeth of said worm core to the level of said flat top of said teeth, said dielectric filler material having substantially the same dielectric constant as air and the same loss tangent as said second dielectric material.

8. A microwave attenuator comprising a cable having an inner and an outer conductor separated by a first dielectric material, said cable being in the form of a cylindrical helix of a predetermined pitch and having a central axis, said outer conductor and said first dielectric material having a chordal recess extending along said cable from end to end of said helix, the wall of said recess passing adjacent said inner conductor and constituting an interior surface of said helix, and a worm core of a second dielectric material having a loss tangent above about unity, said core having a longitudinal axis, a pitch of substantially said predetermined pitch and a V crest tooth profile, said core being mounted within said helix for rotation about said longitudinal axis with said longitudinal and central axes being coincident between a first position in which crest of the tooth profile of the core are opposite the inner conductor of said cable to provide maximum attenuation and a second position in which the crests are between adjacent turns of said inner conductor to provide minimum attenuation, the crest of said worm core teeth being closely adjacent to said inner surface.

9. A microwave attenuator as defined in claim 8 and further including a dielectric filler material between the teeth of said worm core to the level of the crest of said teeth, said dielectric filler material having substantially the same dielectric constant as second dielectric material and a loss tangent below about 0.001.

10. A microwave non-reciprocal device comprising a coaxial cable having an inner and an outer conductor separated by a dielectric material, said cable being in the form of a cylindrical helix of a predetermined pitch and having a central axis, said outer conductor and said dielectric material having a chordal recess extending along said cable from end to end of said helix, the wall of said recess passing adjacent said inner conductor and constituting an interior surface of said helix, a worm core of a ferrite material having a longitudinal axis, a pitch of said predetermined pitch and a flat topped tooth profile, said core being mounted within said helix with said longitudinal and central axes coincident for limited rotation about

said longitudinal axis to adjust the position of said flat top teeth in the region of said inner conductor, the flat top of said worm core teeth being adjacent said inner conductor and, a coil surrounding said helix to create a variable magnetic field within said helix passing through said core.

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