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COAXIAL PHASE SHIFTER

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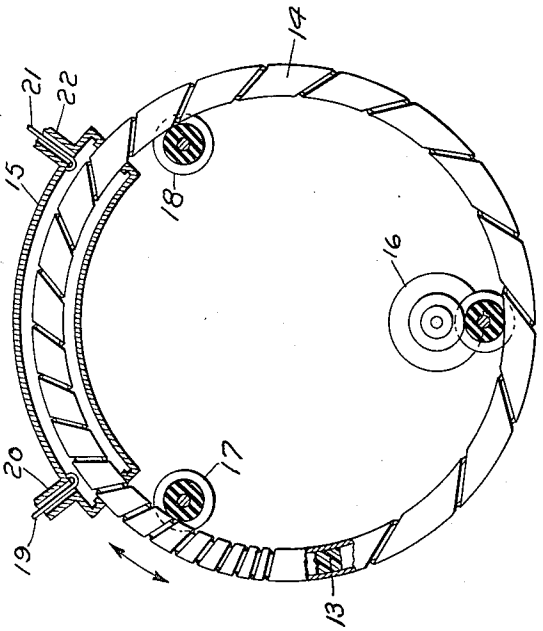


Fig. 2

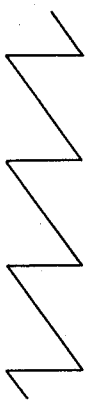


Fig. 2A

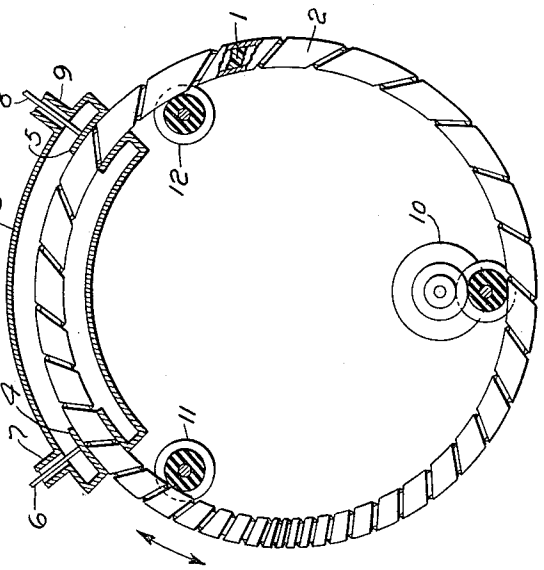


Fig. 1

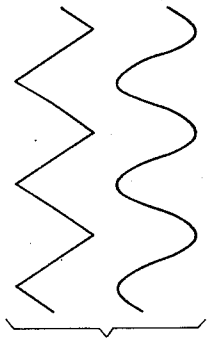


Fig. 1A

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COAXIAL PHASE SHIFTER

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8 Claims. (Cl. 333—31)

This invention relates to electrical phase-shifting devices, and more particularly to a nonresonant coaxial phase shifter.

Various devices for shifting the phase of an electromagnetic signal have been used heretofore. Thus, in a waveguide structure, a long tapered dielectric slab may be moved from one side of the guide, transverse to the direction of propagation, toward the center of the guide, thereby changing the phase velocity in that part of the guide. Also, a line stretcher may be used in which the electrical length of a transmission line is changed by varying the physical length of the line. This may be accomplished by telescoping one section of the line into the other, in a trombone-like manner. Similarly, variable resonant structures are known for varying the tuning response of a high-frequency electric circuit, as shown, for example, in U. S. 2,641,708.

However, in all such devices as known heretofore, various disadvantages are present. Thus, having a structure that is resonant tends to limit the broadbandedness of the electromagnetic wave energy that may be propagated through such a device. Furthermore, such devices are generally discontinuous in nature; that is, they are not capable of giving a continuous, uniform variation of phase in a cyclical manner without resorting to the use of elaborate cam mechanisms or other complicated mechanical artifices. Even where such devices are reciprocating in operation, discontinuities occur at the beginning and end of the cycle. Also, with such devices, it is difficult to obtain any but a simple type of phase shift.

It is an object of the present invention to provide a nonresonant coaxial structure for varying the phase of a propagated electromagnetic signal.

It is a further object to provide such a structure that is readily adaptable for providing cyclic phase shifts of a wide variety of forms and shapes.

It is an important feature of this invention that a coaxial nonresonant structure is provided in which the phase of a propagated electromagnetic signal is varied in a cyclic continuous manner by rotating a closed-loop dielectric member having a helically wound conductor disposed thereabout within a hollow conductor coaxially disposed about this closed-loop member.

It is a further feature that by varying the winding pitch of this conductor about the dielectric member, various types of phase shift outputs may be obtained.

Other objects and features of this invention will be readily apparent by reference to the following description taken in conjunction with the drawings in which:

Fig. 1 is a plan view partly in section of a toroidal member wound in a uniformly variable maximum-minimum manner;

Fig. 1A shows several possible phase shift outputs obtained with the winding of Fig. 1;

Fig. 2 is a plan view partly in section of a toroidal member, according to this invention, wound with a pitch increasing uniformly to a maximum value;

Fig. 2A shows a sawtooth waveform obtainable as an output from Fig. 2.

Referring to Fig. 1, a closed-loop dielectric member **1** preferably in the form of a toroid is shown with a conductor **2**, for example, a ribbon-like material such as silver, wound about the dielectric member. The thickness of this conductor may be varied depending upon the desired electrical characteristics. A hollow conductor **3** is disposed in a dielectrically spaced coaxial relationship about the dielectric member **1** for a fixed length. This hollow conductor has flanged elements **4** and **5** forming re-entrant end portions of the hollow conductor. A coaxial line with a center conductor **6** and an outer conductor **7** may be physically attached to the hollow conductor **3** for coupling a propagated electromagnetic signal thereto. The center conductor **6** joins the flange **4** of the hollow conductor **3** at a point which is approximately a quarter wavelength distant from the ends of the hollow conductor. In a similar manner, a coaxial line consisting of a center conductor **8** and an outer conductor **9** may be coupled to the flanged portion **5** of the hollow conductor **3** for coupling an electromagnetic signal from this coaxial structure. The conductor **2** may be wound about the dielectric member **1** in many different ways depending upon the waveform of the phase shift desired. As illustrated in Fig. 1, the conductor **2** is wound in a manner such that its pitch is uniformly variable about the circular axis of the toroid, increasing uniformly to a maximum value and then decreasing uniformly therefrom to a minimum value. Where the rate of change of pitch varies in a linear manner, the obtained output will be a uniform, linear sawtooth wave as shown in the upper curve of Fig. 1A. Where the rate of change of pitch of the helically wound conductor varies uniformly in a non-linear manner, such as, for example, in a sinusoidal manner, the sine wave output shown in the lower curve of Fig. 1A will be obtained. It should be recognized that from a theoretical point of view, the propagation constant is not a simple mathematical function of the winding pitch and the geometry of the phase-shift structure. However, over a limited, but eminently useful and practical, range of winding pitch and structure geometry, the propagation constant is substantially proportional to the winding pitch and hence may be readily determined using the known theoretical relationships. Various means may be employed for producing a relative movement between the closed-loop dielectric member **1** and the hollow conductor **3**. In general, a ring-drive mechanism **10** with guide rollers **11** and **12** may be used for uniformly rotating the dielectric member within the hollow conductor.

In Fig. 2 the dielectric member **13** is shown with the conductor **14** wound thereabout with a uniformly variable pitch increasing to a maximum value. Upon rotating this member **13** within the hollow conductor **15**, by means of driving mechanism **16** and guide rollers **17** and **18**, a type of sawtooth wave having a gradual rise and a sharp drop, as illustrated in Fig. 2A, will be obtained. In this embodiment of the phase-shift structure, a probe **19** is shown as disposed in an opening **20** for coupling electromagnetic signal energy to the coaxial hollow conductor **15**. In a similar manner, probe **21** disposed in opening **22** serves to couple an electromagnetic signal from the phase shifter.

It is readily apparent that many variations may be made with respect to this invention, and many other embodiments thereof may be proposed, without departing from the essential idea thereof. Thus, while the closed-loop conductor is preferably in the shape of a ring-like toroidal dielectric member, other forms of close-loops may also be used for special purposes, although this may require a more elaborate driving mechanism. For the dielectric member, any known low-loss material commonly employed for high-frequency purposes may be used. Materials such as polyethylene, polystyrene, polytetrafluoroethylene and polymonochlorotrifluoroethylene are

considered suitable. Also, while the conductor wound about the dielectric member may be in the form of a wire, in general a ribbon or foil, made of materials such as copper or silver, is particularly convenient for winding purposes. Many of various known drive mechanisms may be used for rotating the helically wound dielectric member within the hollow conductor. Thus, a constant-speed motor with rim-drive mechanism, as used for phonograph turntables, is suitable for this purpose. It is apparent that the phase shift obtained is a function of the rate of change of pitch of the velocity of the dielectric member and of the relative dimensions of the dielectric member and coaxially disposed outer conductor. Thus, for low-frequency applications, a closer winding of the conductor about the toroid would be used and the physical dimensions of the toroid and hollow conductor would be increased.

It is an important feature of this invention that there is provided a relatively simple means of obtaining almost any of a wide variety of variations in phase. Thus, by control of the rate of change of pitch, almost any type of phase variation may be obtained subject only to mechanical limitations in winding. Thus, the conductor may be wound about the dielectric member so that an algebraically varying phase shift is obtained. Similarly, a trigonometrically or harmonically varying phase shift may be obtained. Thus, where p represents the pitch of the winding and θ represents the angle about the circular axis of the toroid over which the change in electrical length occurs, that is the circumferential distance between the input and output of the electromagnetic signal energy, the following relationship may be employed:

$$\frac{dp}{d\theta}=K_1$$

between the limits of 0 and 2π. This results in a linear phase shift and an output such as illustrated in the upper curve of Fig. 1A for the triangular wave is obtained. Where

$$\frac{dp}{d\theta}=K_2 \sin \theta$$

a cisoidal, that is, a sinusoidal or cosinusoidal type of wave is obtained. For the sawtooth type of wave, using the equation

$$\frac{dp}{d\theta}=K_1$$

and integrating positive value of θ between the limits of 0 and 2π results in a sawtooth type of wave, and integrating positive values of K between 0 and π and negative values of K between π and 2π results in a triangular type of wave. From the foregoing, it is apparent that many waveforms may be readily determined by appropriate mechanical calculation. Although it is preferred to rotate the dielectric member at a constant speed, for certain applications it may be preferable to use a variable speed drive. Similarly, the outer conductor may be rotated if desired and the inner dielectric member maintained stationary. The direction of rotation is a matter of choice depending upon the manner of winding. While two types of electromagnetic couplings to the coaxial phase shifter have been illustrated, other types of coupling may also be used in a manner known to those skilled in this art. For certain applications, also, part of the toroid may be wound uniformly with no variation in pitch while other parts of the toroid may be wound with a uniform or non-uniform shifting of pitch. Also, while the coaxially disposed hollow conductor has been illustrated as extending over approximately 90° of the circular axis of the toroid, this may be varied depending upon the particular applications desired. This coaxial phase shifter may be used whenever coaxial lines are considered desirable or suitable for transmission purposes, for example, up to frequencies of the order of 10,000 megacycles per second. Its use at low frequencies is restricted only by the fact that the phase shifter increases in its physical dimensions, and, therefore, at very low frequencies, the structure may prove too bulky or special types of couplings may be required. It should be understood that while the phase-shift device described herein may be resonant at some frequency, within its useful operating range, this device operates in a nonresonant manner; that is, the phase-shift device described herein may be considered from an operational point of view to be resonant.

While I have described above the principles of my invention in connection with specific apparatus, it is to be clearly understood that this description is made only by way of example and not as a limitation to the scope of my invention as set forth in the objects thereof and in the accompanying claims.

I claim:

1. A coaxial nonresonant structure for varying the phase of a propagated electromagnetic signal comprising a closed-loop dielectric member, a conductor disposed helically with a varying pitch about said dielectric member for at least a section thereof, a hollow conductor disposed in dielectrically spaced coaxial relation about a given length of said closed-loop member, means to produce a relative movement between said closed-loop member and said hollow conductor, and means for coupling electromagnetic signal energy to and from said coaxial structure.

2. A coaxial nonresonant structure, according to claim 1, wherein the closed-loop dielectric member is ring shaped and wherein a ribbon-like conductor is disposed helically with a uniformly variable pitch about said dielectric member.

3. A coaxial nonresonant structure, according to claim 1, wherein the rate of change of pitch of the helically disposed conductor increases uniformly to a maximum value and then decreases uniformly therefrom.

4. A coaxial nonresonant structure, according to claim 3, wherein the rate of change of pitch of the helically disposed conductor increases uniformly to a maximum value and then decreases uniformly therefrom to a minimum value, said rate of change of pitch varying in a sinusoidal manner thereby producing a sinusoidal phase shift.

5. A coaxial nonresonant structure, according to claim 1, wherein the rate of change of pitch of the helically disposed conductor increases uniformly and linearly to a maximum value and then decreases uniformly and linearly therefrom to a minimum value.

6. A coaxial nonresonant structure for varying the phase of a propagated electromagnetic signal comprising a toroidal dielectric member, a ribbon-like conductor disposed helically with a continuously variable pitch about said dielectric member, the rate of change of said pitch increasing uniformly to a maximum value over approximately 180° of the circular axis of the toroid and then decreasing uniformly for the remaining 180° of the toroidal circular axis, a hollow conductor disposed in dielectrically spaced coaxial relation for about 90° of said toroidal member, first coaxial means for coupling a propagated electromagnetic signal to said structure and second coaxial means for coupling said electromagnetic signal therefrom.

7. A coaxial nonresonant structure, according to claim 6, including means for moving said toroidal dielectric member relative to said hollow conductor.

8. A coaxial nonresonant structure, according to claim 7, wherein said hollow conductor has flanged elements disposed re-entrantly at end portions thereof and said coaxial coupling means are coupled to said flanged elements at a point approximately a quarter wavelength distant from the ends of the hollow conductor.

No references cited.