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ELECTRICALLY CONTROLLED SURFACE WAVEGUIDE PHASE SHIFTER

Filed Sept. 30, 1966

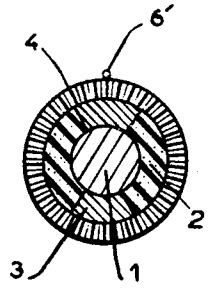


Fig. 1

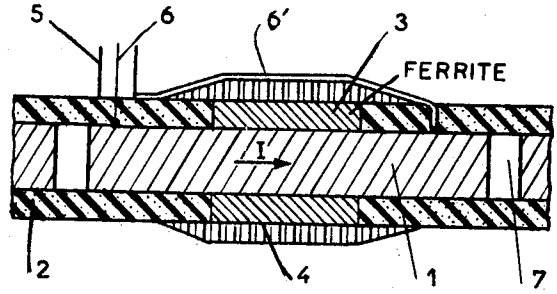


Fig. 2

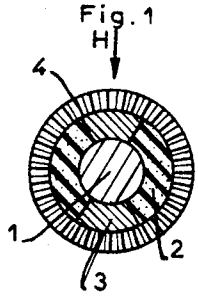


Fig. 3

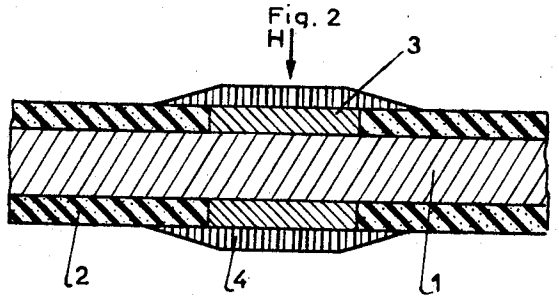


Fig. 4

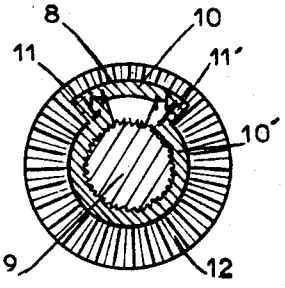


Fig. 5

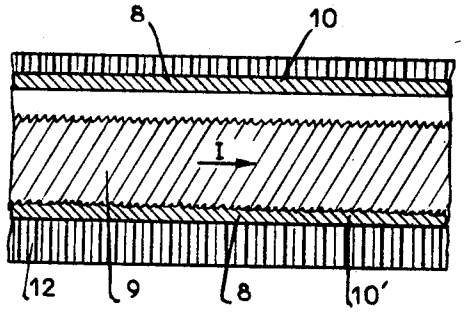


Fig. 6

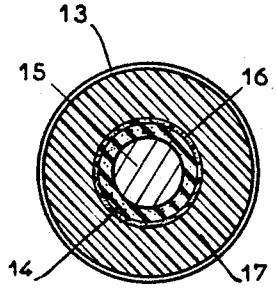


Fig. 7

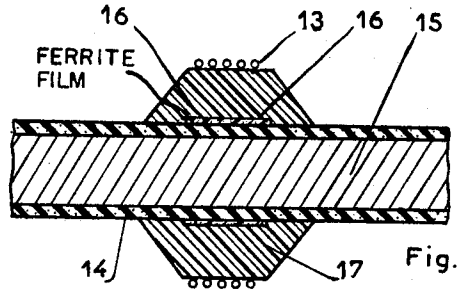


Fig. 8

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ELECTRICALLY CONTROLLED SURFACE WAVEGUIDE PHASE SHIFTER

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ABSTRACT OF THE DISCLOSURE

A surface wave phase shifter is disclosed for use, for example, with electronic beam scanning in phased antenna array systems. It consists of a surface waveguide of the single conductor type, which is partially surrounded by ferro-magnetic material in direct coupling with the wave propagating along the conductor, either as a complete sleeve or as sectoral parts. External means are provided to establish a magnetic field inside said magnetic material, the magnetizing current for which may flow along the waveguide conductor.

The present invention concerns phase shifting devices based on the properties of ferromagnetic materials used in conjunction with surface waveguides. Phase shifters have a very wide range of application. One of the important utilizations of such devices relates to electronic scanning of phased array antennas in which phase shifting of the feed signal is necessary in order to provide for beam scanning. Wide use is made of rectangular waveguide phase shifters incorporating a ferrite rod located along the waveguide axis and magnetized in parallel with the propagation axis by means of an electromagnet. The operation of such a device is fully described by F. Reggia and E. Spencer in the Proceedings of the I.R.E.—November 1957, pages 1510 to 1517 in the article entitled: "A New Technique in Ferrite Phase Shifting for Beam Scanning of Microwave Antennas." By controlling the electromagnet current, the magnetizing field within the ferrite is varied, which accordingly varies the permeability of the ferrite material. Due to permeability variation, the propagation velocity of a microwave within the guide is modified and its phase is varied.

Several different devices have been made relying on the same basis in which the shaping of the ferrite and the magnetizing fields are appropriate to each particular requirement. Wide use of such devices has been made either in the waveguide range (using rectangular or round waveguides) or with coaxial, bifilar or strip lines at lower frequency ranges.

No phase shifter designed with a surface waveguide made of a single wire conductor is known. Such a single wire surface waveguide has been described by P. Chavance and B. Chiron in Annales des Telecommunications, volume 8, November 1953, page 367, in the article entitled: "Une étude expérimentale de transmission d'ondes centimétriques sur guides d'ondes filiformes." It is made either from a conducting wire coated with a dielectric envelope or from a conducting wire, the surface of which shows periodic corrugations such as can be obtained through threading. As mentioned in the above article, the electromagnetic energy is located around the wire. Concentration of the energy in a small volume is due to a reduction of the propagation velocity with respect to free propagation, such a reduction being obtained by either the envelope or the corrugations.

It is a first object of the invention to provide for much smaller phase shifters than the hollow waveguide phase shifters of the prior art.

It is another object of the invention to provide very low cost phase shifters.

It is another object of the invention to provide wide band phase shifters which can cover the frequency range extending from microwaves to very high frequencies.

It is another object of the invention to provide very simple phase shifters.

It is another object of the invention to provide low weight phase shifters.

The invention will be fully understood by reference to the following description and the accompanying drawings given by way of illustration without any limitative aim in which:

FIGURES 1 and 2 show respectively a cross-sectional and a longitudinal cut view of a first embodiment of the invention.

FIGURES 3 and 4 are the same views of the second embodiment.

FIGURES 5 and 6 represent a third embodiment, and FIGURES 7 and 8 a fourth embodiment of the invention.

In FIGURES 1 and 2 conducting wire **1** which guides the surface wave is made of plain copper thread. The wire is surrounded by a dielectric envelope **2** having two longitudinal sectoral housings in which are located two ferrite parts **3**. A protecting dielectric layer **4** is used to mechanically lock the ferrite in their housings. Layer **4** is tapered at each end in order to provide matching. The magnetizing current I for the ferrite flows in wire **1**. The current input and output are provided at stub **5** by means of two leads **6** and **6'**. The input lead penetrates through dielectric coating **2** to the central conductor **1**. The output lead **6'** is connected at the other end of **1**, passes through the dielectric coating **2** and runs along the outside of protective coating **4**. Lead **6'** is shown in FIGURE 2 as a straight line in order to facilitate illustration of the interconnections. The location and the shape of the leads in actual practice are such as to prevent any short circuiting of the high frequency field in the dielectric coatings **2** and **4**. As is well known, this is obtained by spirally or helically winding the lead around the waveguide. Two dielectric discs **7** with low loss are located at each end of the phase shifter in order to provide insulation of the device with respect to the input and output waveguides as far as the magnetizing current is concerned. As known, the thickness of these discs should be kept within $\frac{1}{100}$ of the wavelength value so as to prevent any mismatch.

The above description relates to a phase shifter to be incorporated in a surface waveguide circuit. When a variable phase waveguide is required, insulating discs **7** are replaced by coupling flanges. If the device is to be connected to coaxial lines, the flanges are replaced by surface wave to coaxial transitions. Output for current I can be obtained through lead **6'** along the external conductor of the coaxial line. Current I establishes a magnetizing field of circular symmetry. The high frequency magnetic field of the propagating wave also has circular symmetry. As can be shown by calculation the magnetizing field has no action on the phase velocity when it is parallel to the high frequency magnetic field. However, in the above described device the ferrite parts introduce discontinuities which interact with the high frequency field distribution. Therefore at each extremity of the device areas are to be found where the magnetic fields are not parallel. As described, the device produces a phase shift which varies with the intensity of magnetizing current I.

In order to obtain higher sensitivity of the phase shift variation with respect to the magnetizing field the ferrite parts should be magnetized by means of an electromagnet which establishes a radial magnetic field H as shown

in FIGURES 3 and 4. In this device, the high frequency and the magnetizing fields are perpendicular with each other increasing the sensitivity.

The two embodiments which have been described concern lump phase shifters. In some applications distributed phase shift is required. Such is the case in the design of feed source for phased array antennas. Such a distributed phase shift waveguide section is shown in FIGURES 5 and 6. The wave guide comprises wire 9 along which flows the magnetizing current I. A closed ferromagnetic structure 8 surrounds completely the waveguide. It is made of two concentric sectoral parts 10 and 10' interconnected by radial arms 11 and 11'. The ferrite structure extends the whole length of the waveguide section. Magnetizing field H is shown in the FIGURE 5. It is radial in arms 11 and 11' and therefore perpendicular to the high frequency magnetic field at this point. The phase shift of such a device is higher than the phase shift obtained on the previous embodiments. A dielectric sleeve 12 protects the ferrite. It is also used in order to concentrate the electromagnetic high frequency energy.

The embodiment shown in FIGURES 7 and 8 is a lower cost design of a lump phase shifter. The magnetizing field is established by coil 13. The surface waveguide is composed of the cylindrical copper conductor 15 surrounded by a dielectric envelope 14. Envelope 14 is coated with a ferrite film 16 over a part of its length. The film is covered with a dielectric sleeve which serves as a mandrel for coil 13. In order to be electrically matched, this sleeve should have a dielectric constant as near as possible to the dielectric constant of air. It is tapered at each end in order to prevent reflections. The thickness of this sleeve is chosen so that coil 13 is located outside the high frequency energy concentration zone. Such a device has been operated at C-band (5.5 gHz.) with the following specific parameter: conductor 15 is 3 mm. diameter copper tubing, the dielectric coating outside diameter is 4.5 mm. The ferrite coating is .7 to .8 mm. thick. A surface waveguide can be defined by the 90% power flow radius of the field which is the radius of a cylinder concentric to the waveguide in which is located 90% of the electromagnetic energy. The radius for such a waveguide is between 30 and 50 mm. The inside radius of coil 13 is 30 mm. The magnetic field along the axis of the coil is $H=nI$ amp/m. The length of the coil is 0.01 m. and it is made of 10 turns of wire. The equivalent turn/meter value is $n=1000$. For a current value of $I=4.8$ A., the field $H=4800$ amp/meter$=60$ oersteds. The phase shift with respect to the same waveguide with a zero field is 6° per cm. It increases linearly with the field up to a saturation value (about 7° per cm. at 80 oersteds). Due to saturation of the ferrite, the phase-shift will increase no more if the field becomes higher. To increase the phase-shift it is necessary either to increase the waveguide length or to replace the ferrite film by a ferrite ring or a dielectric ring loaded with ferrite and surrounding the dielectric coating. In the case of a dielectric ring the dielectric coating can be suppressed. However, such a design shows rather high losses due to the fact that the ferrite is located within the electromagnetic field. This prohibits the use of such design in many applications. A feed for a phased array antenna is made of several such devices located along a surface waveguide between two successive radiating elements.

We claim:

1. A surface waveguide distributed phase shifter comprising a conducting wire, a ferromagnetic sleeve surrounding said conducting wire within the electromagnetic field of said surface waveguide, means for establishing controllable magnetic field in said ferromagnetic sleeve, input and output means for said surface waveguide, supply means for said magnetic field establishing means decoupled from said electromagnetic field.

2. A surface waveguide lumped phase shifter comprising a conducting wire, a ferromagnetic part surrounding said conducting wire within the electromagnetic field of said surface waveguide, means for establishing controllable magnetic field in said ferromagnetic part, means for supplying electromagnetic energy to said surface waveguide, output means for said waveguide and supply means for said magnetic field establishing means decoupled from said electromagnetic field.

3. A surface waveguide lumped phase shifter comprising a conducting wire length surrounded by a dielectric envelope, input coupling means for applying electromagnetic energy to said wire, output coupling means for said wire, two longitudinal recesses worked out in said dielectric envelope, two ferromagnetic material pyramidal rods with a curvilinear trapezoidal cross section located in said recesses, a dielectric sleeve surrounding said rods, means for supplying an adjustable current to said conducting wire decoupled with respect to the electromagnetic propagating along said conducting wire, end means for insulating said adjustable current supply from input and output coupling means.

4. A surface waveguide lumped phase shifter comprising a conducting wire length surrounded by a dielectric envelope, input coupling means for applying electromagnetic energy to said wire, output coupling means for said wire, two longitudinal recesses worked out in said dielectric envelope, two ferromagnetic material pyramidal rods with a curvilinear trapezoidal cross section located in said recesses, a dielectric sleeve surrounding said rods, electromagnetic means for establishing a radial magnetic field through said conducting wire.

5. A surface waveguide distributed phase shifter comprising a threaded conducting wire, a longitudinal ferromagnetic sleeve with an approximately 8-shaped cross-section surrounding said conductor on the greatest part of its circumference and all its length, a dielectric sleeve on said ferromagnetic sleeve, means to supply said threaded conducting wire with an adjustable current.

6. A surface waveguide lumped phase shifter comprising a conducting wire, a dielectric envelope surrounding said wire, a ferromagnetic sleeve, coating part of the length of said dielectric envelope, a dielectric sleeve protecting said ferromagnetic sleeve made of a material the permittivity of which is almost equal to that of air, an electromagnetic winding coiled around said dielectric sleeve.

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