

Oct. 4, 1966

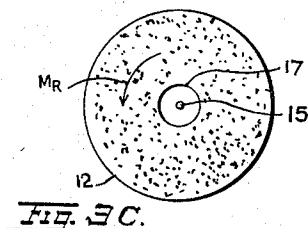
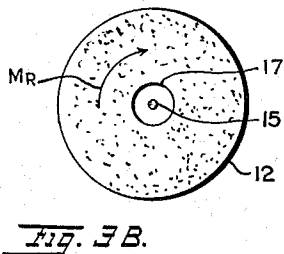
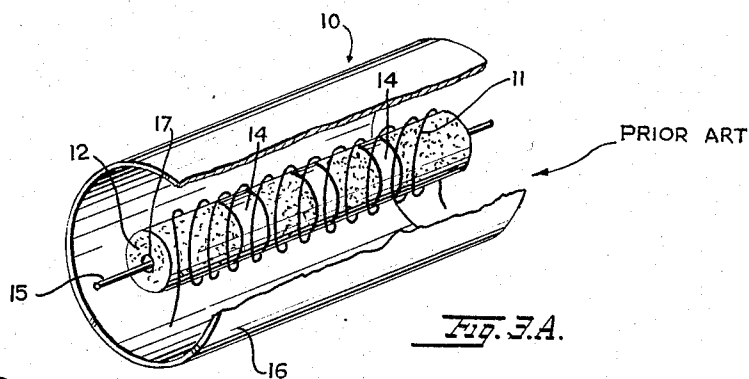
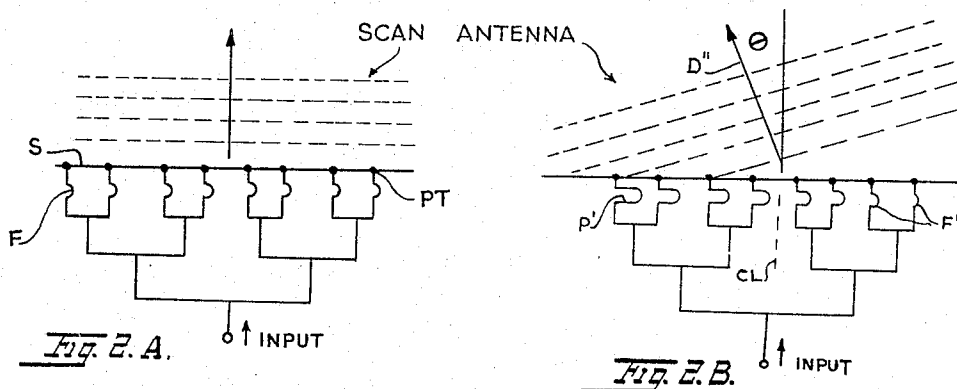
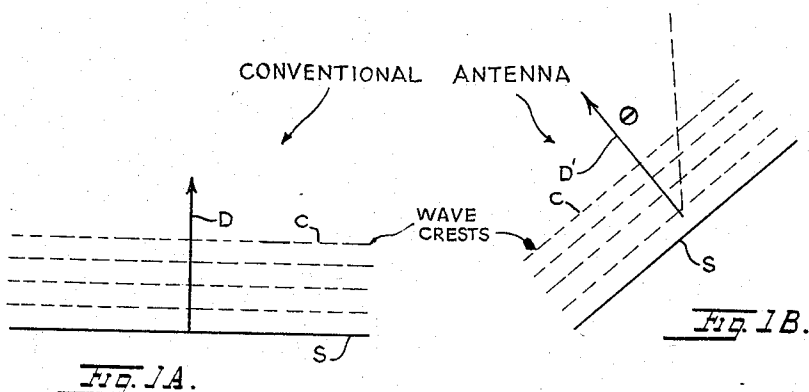
E. STERN

3,277,401

MULTI-STABLE PHASE SHIFTERS FOR MICROWAVES EMPLOYING
A PLURALITY OF HIGH REMANENT MAGNETIZATION MATERIALS

Filed Feb. 15, 1963

4 Sheets-Sheet 1



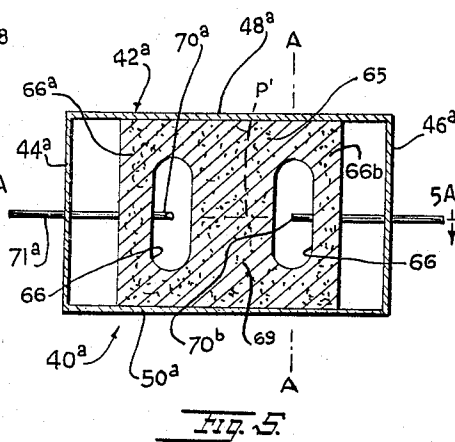
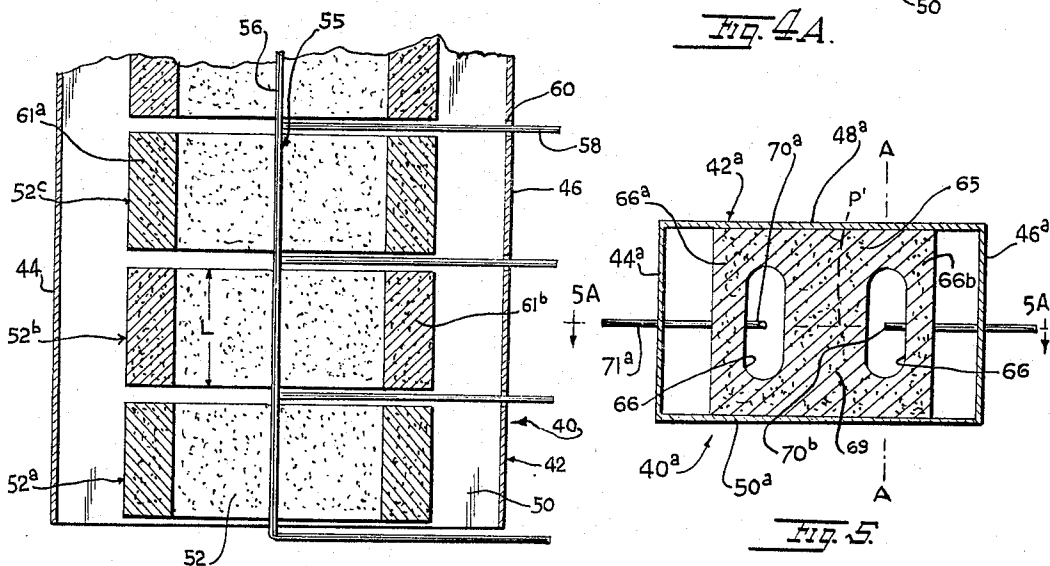
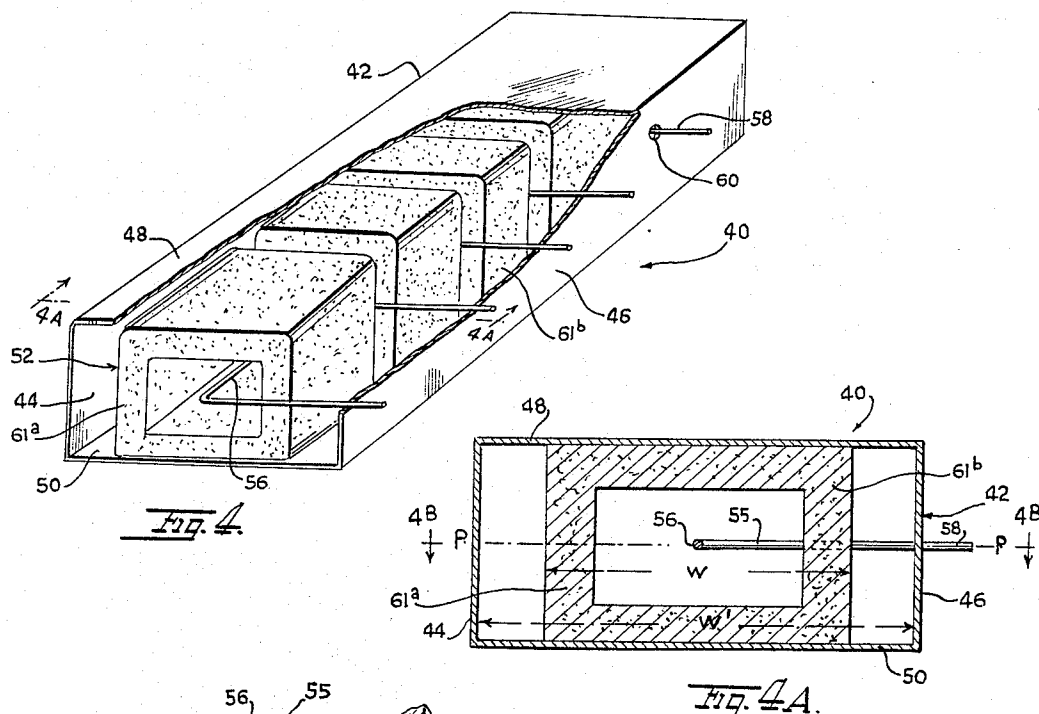
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Oct. 4, 1966 E. STERN 3,277,401
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A PLURALITY OF HIGH REMANENT MAGNETIZATION MATERIALS

4 Sheets-Sheet 2



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4 Sheets-Sheet 3

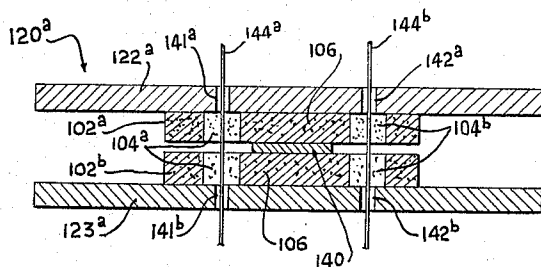


Fig. 9.

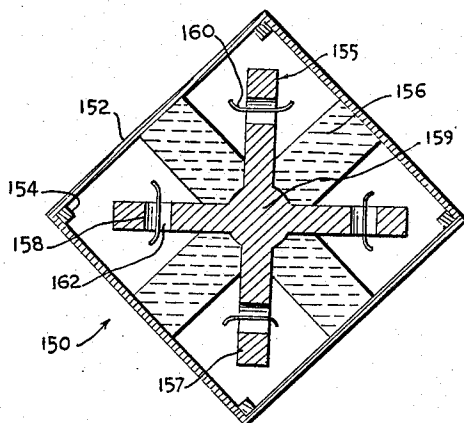


Fig. 10.

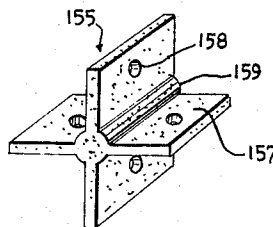


Fig. 10A.

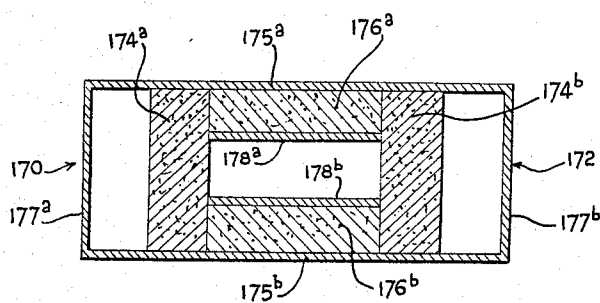


Fig. 11.

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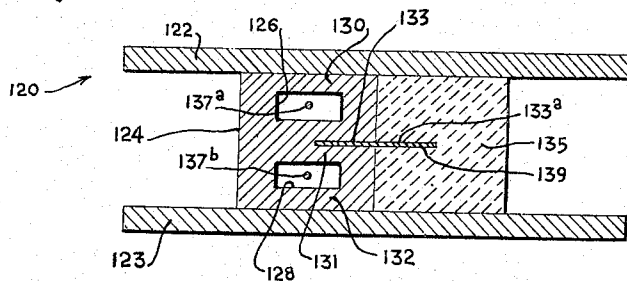
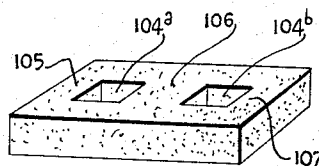
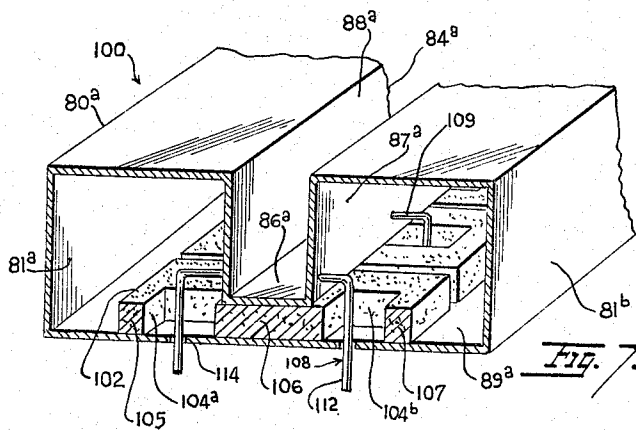
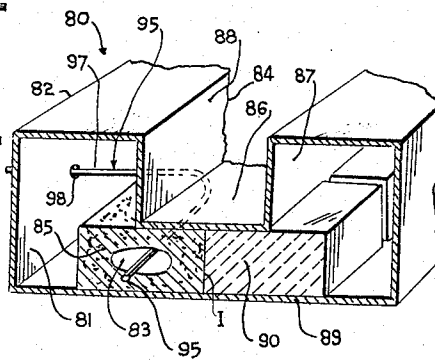
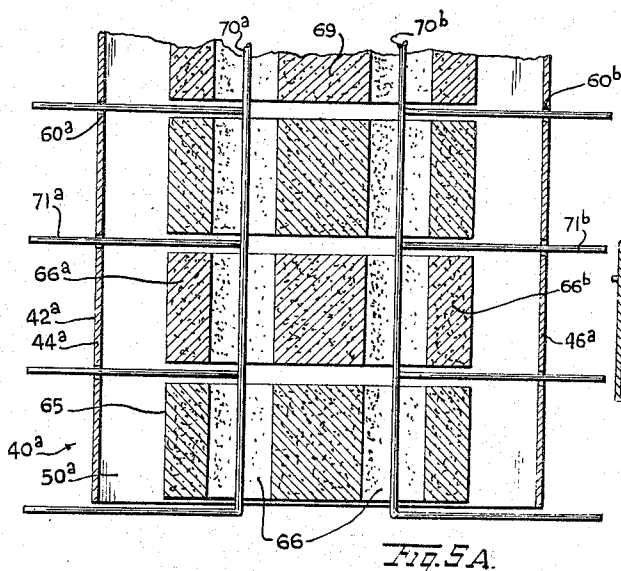
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4 Sheets-Sheet 4



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MULTI-STABLE PHASE SHIFTERS FOR MICROWAVES EMPLOYING A PLURALITY OF HIGH REMANENT MAGNETIZATION MATERIALS

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8 Claims. (Cl. 333-24.1)

This invention relates to the art of microwave transmission devices, and more particularly concerns devices for shifting phases of electromagnetic waves at microwave frequencies.

It is a principal object of the invention to provide phase shifting devices for microwaves, which devices operate effectively at frequencies in the range of 4,000 to 60,000 megacycles or higher.

Another object is to provide microwave phase shifters embodying multi-stable modes of operation and utilizing phase shifting elements having remanent magnetization characteristics, said phase shifters being operative at microwave frequencies above 4,000 megacycles.

Still another object is to provide a waveguide including toroidal elements of garnet or ferrite material having remanent magnetization characteristics for microwave phase shifting purposes.

The invention will be best understood from the following detailed description taken together with the drawings, wherein:

FIGURES 1A, 1B, 2A and 2B are antenna diagrams employed in explaining the invention.

FIGURE 3A is a perspective view of a prior art device used in explaining the invention, parts being broken away.

FIGURES 3B and 3C are end views partially diagrammatic in form of the device of FIGURE 3A.

FIGURE 4 is a perspective view of a phase shifter device embodying the invention, parts being broken away to show internal construction.

FIGURE 4A is a cross-sectional view taken on line 4A-4A of FIGURE 4.

FIGURE 4B is a fragmentary cross-sectional view taken on line 4B-4B of FIGURE 4A.

FIGURE 5 is a perspective view partially in section of another phase shifter according to the invention.

FIGURE 5A is a fragmentary cross-sectional view taken on line 5A-5A of FIGURE 5.

FIGURE 6 is a cross-sectional view of another phase shifter device.

FIGURE 7 is a perspective view partially in section of another phase shifter device.

FIGURE 7A is a perspective view of a frequency shift element employed in the device of FIGURE 7.

FIGURE 8 is a cross-sectional view of another phase shifter device.

FIGURE 9 is a cross-sectional view of another phase shifter device.

FIGURE 10 is a cross-sectional view of another phase shifter device.

FIGURE 10A is a perspective view on a reduced scale of a phase shifting element employed in the device of FIGURE 10.

FIGURE 11 is a cross-section of a composite ferrite loop.

Theoretical considerations

Multi-stable phase shifters are unique devices that can be used for many purposes at microwave frequencies. These uses include scan antennas, switching, modulation, diplexing, phase compensation and other applications.

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The unique features of multi-stable phase shifters are:

- (1) The physical configurations.
- (2) The elimination of steady holding currents.
- (3) The low required drive power.
- (4) The extremely short switching time.

The phase shifters are of particular interest for scan antenna applications. Scan antennas are fixed structures that simulate physical rotation and motion of the antennas.

A conventional antenna radiates a uniform wave that is in phase from all radiation points on its surface. A conventional antenna can be rotated about its central axis as shown in FIGURES 1A, 1B.

When the antenna is horizontal, a microwave is radiated in direction D. The crests C of the wave lie parallel to the antenna surface S. If the antenna is rotated as indicated in FIGURE 1B to angle θ (theta), the crests C remain parallel to the antenna surface S and are radiated in the direction of arrow D'.

A scan antenna simulates this rotation by introducing appropriate delays across the antenna surface. A physical analogue of this is shown in FIGURES 2A and 2B. In FIGURE 2A the input power is distributed to the radiation points PT by the feeders F of equal length. Consequently, the energy arrives at the antenna surfaces simultaneously (or in phase). In FIGURE 2B, the feeders F' on the right hand side of the center line CL have been foreshortened progressively; and feeders P' on the left hand side have been lengthened progressively towards the edges of the antenna. The energy arrives first on the right hand side and last on the extreme left hand side. The resultant radiation propagates in the direction θ (theta) as indicated by the arrow D''. Multi-stable phase shifters are electronic equivalents of the feeder lines F', P'. They produce electronically the foreshortening or lengthening of the transmission line. Since the electromagnetic wave is continuous, and since the amplitudes at the same point on succeeding waves are identical, the feeder lengths can be foreshortened or lengthened by one wavelength (or 2π radians) without altering the antenna radiation pattern.

One known type of microwave phase shifter consists of a rectangular waveguide, a ferrite rod extending along the central axis of the waveguide, and a magnetizing coil wound about the waveguide. This phase shifter, in common with other known conventional phase shifters, requires a supply of steady current to maintain a given electrical length. The inductance of the magnetizing coil is large; consequently, the switching time is relatively long, on the order of one-thousandth of a second.

Another known type of microwave phase shifter is shown in FIGURE 3A. This is a helical transmission line phase shifter. The elements of the phase shifter include a helical transmission line 11 surrounding a series of ferrite cylinders 12. Annular dielectric spacers 14 separate the cylinders 12. A magnetizing wire 15 passes through axial holes 17 in the cylinders and spacers. A metallic sheath 16 is coaxial and concentric with the cylinders 12 and wire 15.

In phase shifter 10, each phase shift section includes one of cylinders 12. Each phase shift section is bi-stable. Its electrical length depends upon the clockwise or counter-clockwise sense of remanent magnetization M_R as indicated in FIGURES 3B and 3C, respectively.

Phase shifter 10 of FIGURES 3A, 3C requires a short impulse of current through the magnetizing wire 15 to change its phase. After the current impulse has passed, the phase (or electrical length) remains fixed until a

negative current impulse is applied. The inductance of a single wire is very small. Switching times of one-millionth second can readily be achieved. Each phase shifter section can possess only two discrete values of electrical length. Consequently, a series of sections are used to approximate all values of electrical length. The numerical arrangement is as follows:

$$0, \frac{\pi}{2}, \frac{\pi}{4}, \frac{\pi}{8}, \frac{\pi}{16}, \text{ etc.}$$

Scan antenna phase shifters must provide all phase shift values from 0 to 2π radians. The multi-stable phase shifter provides

$$\pi, \frac{\pi}{2}, \frac{\pi}{4}, \frac{\pi}{8}, \frac{\pi}{16}, \frac{\pi}{32}$$

etc., changes of phase. By the proper addition of discrete values, the desired phase shifts can be approximated.

The phase shifter 10 of FIGURES 3A, 3C can be made to work satisfactorily in the microwave frequency range of 800 megacycles to about 4,000 megacycles. The present invention is directed at phase shifters which operate effectively in the microwave region above 4,000 megacycles and particularly in the range of 4,000 to 60,000 megacycles. The present invention increases by a large factor the operating range of phase shifters employing and embodying multi-stable concepts of operation.

Magnetic materials in either metallic or insulator forms possess, to a larger or lesser degree, the tendency to remain magnetized, particularly if the material is in the form of a continuous loop. Such shapes as toroids and hollow cylinders are examples of such shapes. In other words, a magnetic field magnetizes the material. After the field is removed, a portion of the magnetization remains. Magnetic materials can be magnetized only to a limiting value called the saturation magnetization. If the magnetizing field is increased, no additional magnetization beyond this value is produced in the material.

The present invention employs materials that are good insulators and whose remanent magnetization is a substantial portion of the saturation magnetization. Garnets are magnetic ceramics which have remanent magnetization characteristics useful in the present invention. Magnetic type ferrites also have remanent magnetization qualities useful in the present invention.

These ferrites and garnets useful in the present invention are said to have an effective permeability which is dependent, in part, upon the degree of magnetization of the material, upon the frequency of the microwave propagating through the body, and upon the geometric interrelationships of the magnetization direction and the direction and sense of polarization of the microwave magnetic field. If the direction of the microwave magnetic field is in a plane perpendicular to the magnetization, and if the polarization of the field is linear, then the effective permeability is equal to

$$\mu_{eff}^L = 1 - \left(\frac{4\pi\gamma M_r}{\omega} \right)^2 \quad (1)$$

If the physical orientations remain the same, but if the polarization is positive circular or negative circular, then the effective permeability is equal to the two values shown below:

$$\text{positive circular polarization: } \mu_{eff}^+ = 1 - \frac{4\pi\gamma M_r}{\omega} \quad (2)$$

$$\text{negative circular polarization: } \mu_{eff}^- = 1 + \frac{4\pi\gamma M_r}{\omega} \quad (3)$$

$4\pi M_r$ is the remanent magnetization of the material.

γ is the gyromagnetic ratio equal to roughly $2\pi \times 2.82 \times 10^6$ radians per oersted, and ω is the microwave frequency

in radians per second. The electrical length of a section of material L inches long is equal to

$$\frac{2\pi}{\lambda_0} \sqrt{\mu_{eff} K} L \text{ radians} \quad (4)$$

where

μ_{eff} = effective permeability of ferrite

K = dielectric constant of ferrite

λ_0 = wavelength in vacuum

The effective permeability for the linear polarized case is related to remanent magnetization (see Equation #1). If remanent magnetization is made to be zero in one instance, and is made to be close to the saturation magnetization in the other instance, a large change of effective permeability is achieved. For the circularly polarized cases (see Equation #2), the sense of polarization is reversed if the direction of remanent magnetization is reversed. Therefore, a large change of effective permeability can be achieved by these means.

The change of the effective permeability is proportional to the magnitude of the remanent magnetization. One might suppose that materials with the greatest remanent magnetization are the most desirable. However, the material becomes opaque to microwave energy if the saturation magnetization exceeds ω/γ . Therefore, at each frequency there exists an optimum material. With this restriction in mind, it follows that the theoretically possible change of effective permeability for the linearly polarized case is from zero to one; and for the circularly polarized case, from zero to two. In available materials the remanent magnetization usually is no greater than 70% of the saturation magnetization; this is considered to be an example of high remanent magnetization for the purposes of this disclosure and claims. Consequently, the effective permeability in a linearly polarized configuration has the two values of 1 and 0.5; and in the circularly polarized case, the value of 1.7 and 0.3. In a practical sense, the minimum physical length L of a π radian phase shifter is equal to

$$\frac{\lambda_0}{2\sqrt{K}} \left[\frac{1}{\sqrt{\mu_1} - \sqrt{\mu_2}} \right]$$

Suppose, for example, a ferrite with a saturation magnetization of 3,100 gauss, a remanent magnetization of 2200 gauss, a dielectric constant of 9 is used at 10 kmc. The minimum length of a linearly polarized π section is .77 inch, and a circularly polarized section is 1.32 inches.

There will now be described a number of phase shifters embodying the invention, which employ the multi-stable concepts discussed above.

FIGURES 4, 4A and 4B illustrate one embodiment of the invention. The device 40 is a multi-stable phase shifter which includes a waveguide 42 in the form of a hollow rectangular metal pipe with opposing narrow walls 44, 46 and opposing wider walls 48, 50 perpendicular to walls 44, 46. Short rectangular pipes 52 are disposed in waveguide 42. These pipes are made of a suitable ferrite or garnet. The pipes 52 are rectangular in cross-section and their external height V is equal to the internal height of the waveguide. The external width W of the pipes is less than the internal width W' of the waveguide. The pipes are centered in the waveguide and spaced from the inner sides of walls 44, 46.

The pipes may have any required lengths L axially of the waveguide. The pipes are spaced very short distances apart and are disposed in axial alignment. The pipes are coaxial with the waveguide. Wire loops 55 extend through the pipes 52. These loops are defined by a wire 56 which extends axially of the pipes and by lateral branch wires 58 which extend from wire 56 between the opposing ends of the pipes 52 and out of holes 60 formed in narrow wall 46 of the waveguide. The loops are disposed in a common plane P which is the median plane

of the pipes and waveguide parallel to and between walls 48, 50.

The narrow upright walls 61a, 61b of each pipe 52 interact with circularly polarized waves inside the waveguide. The wire loops 55 cause the remanent magnetization of the garnet or ferrite material of each pipe to orient itself either clockwise or counter-clockwise with respect to the axis of wire 56. The wave propagating through this multi-stable phase shifter propagates through a composite medium whose electrical length changes as a result of changes in the effective permeability. The phase delay through each pipe 52 is changed whenever the magnetization direction is reversed because a positive current impulse traveling through a wire loop causes a clockwise orientation of the magnetization or a negative current impulse causes a counter-clockwise orientation of the magnetization.

Each pipe 52 produces a differential phase shift. The first section 52a produces a shift of π (pi) radians, the second section 52b produces a shift of $\pi/2$ radians, the third section 52c produces a shift of $\pi/4$ radians, etc. A single pipe 52 may be regarded as a phase shift element. The multi-stable phase shifter 40 thus contains a multiplicity of phase shift elements.

FIGURES 5 and 5A show another multi-stable phase shifter 40a which has a series of ferrite or garnet phase shifter elements 65 disposed axially along the waveguide 42a. Each of these elements is made of a suitable ferrite or garnet material. Each element has a pair of parallel passages 66 which are generally rectangular or oval in cross-section. The major transverse dimension or axis A—A of each passage 66 is perpendicular to the wider walls 48a, 50a of the waveguide. The narrow walls 66a, 66b of the elements 65 are spaced from the narrow opposing walls 44a, 46a of the waveguide.

Wires 70a, 70b extend axially through the passages in the median plane P' of the waveguide and elements 65. Each of the passages is separated by a central wall or partition 69 integral with opposing wider top and bottom walls of the elements 65. Partition 69 is disposed in a region of linear polarization of a wave in the waveguide.

Each of elements 65 is tri-stable since the magnetization in each half of the element can independently be made clockwise or counter-clockwise. If the magnetization in the left wall 66a is directed upwardly and magnetization in the right wall 66b is directed downwardly, then the central wall or partition 69 is unmagnetized. This produces one value or magnitude of phase delay. If the left wall magnetization is downwards and the right wall magnetization is upwards, central wall 69 is again unmagnetized, and another value or magnitude of phase delay is produced. If the outer walls 66a, 66b are both magnetized in the same direction either upwards or downwards, then the central wall 69 is magnetized and a third value or magnitude of phase delay is obtained in each element 65. Consequently, the elements 65 are tri-stable.

Laterally extending branch wires 71a, 71b are connected to the wires 70a, 70b and pass between opposing ends of elements 65. The branch wires extend outwardly of the narrow walls 44a, 46a respectively of the waveguide through holes 60a, 60b in these walls. The branch wires define two loops with wires 70a, 70b in the median horizontal plane P' in each of elements 65.

In FIGURE 6 is shown a circularly polarized multi-stable phase shifter 80 in which waveguide 82 has a central metallic ridge 84. A series of rectangular phase shifter pipe-like elements 85 are disposed in the guide with upper sides of the elements 85 partially abutting the underside of ridge wall 86 and partially extending laterally of vertical ridge wall 88. Rectangular dielectric slabs 90 are also disposed in the waveguide with upper sides of the slabs partially abutting the underside of ridge wall 86, and partially extending laterally of ridge wall 87. The dielectric slabs and ferrite or garnet phase shifter elements respectively abut each on the central vertical longitudinal plane of the waveguide.

The interface I is the plane of abutment of each element 85 with its associated slab 90. Elements 85 and slabs 90 abut bottom wall 89 of the waveguide.

The pipe-like elements 85 have aligned central passages 83 through which pass wire loops 95. Each loop has a portion of wire 96 coaxial with the passage and laterally extending branches 97 passing through holes 98 in side wall 81 of the waveguide.

The presence of the dielectric slabs 90 produces circular polarization at the interface I. The ferrite or garnet at the interface can be magnetized up or down causing the effective permeability to assume positive and negative circular polarization values, respectively.

FIGURE 7 shows a linearly polarized multi-stable microwave phase shifter 100 employing a ridged waveguide 80a which is similar to waveguide 80. The waveguide 80a has a longitudinal metallic central ridge 84a defined by vertical parallel side walls 87a, 88a and a horizontal bottom wall 86a. The waveguide has narrow opposing vertical side walls 81a, 81b and a flat bottom wall 89a.

A series of ferrite or garnet plates 102 shown to best advantage in FIGURE 7A are disposed along the waveguide on bottom wall 89a. Each plate has two holes 104a, 104b defining three parallel arms 105, 106 and 107 in the plate. L-shaped wires 108 have their horizontal portions 109 secured at side walls 87a, 88a of the ridge and the vertical arms 112 of the loops extend downwardly through the holes 104a, 104b and through holes 114 in the bottom wall 89a of the waveguide. The upper sides of the central arms 106 of the plates are centered at and abut the underside of ridge wall 86a. The plates are slightly spaced apart longitudinally of the waveguide.

The microwave magnetic field in phase shifter 100 is linear. If a current pulse flows in the same direction along the two wire arms 112, the central portion 106 of the ferrite plate will be unmagnetized. If the current pulse flows in opposite direction through the two wire arms 112, the central portion 106 of the plate will be magnetized. The net change of permeability obtained corresponds to the linearly polarized case defined by Equation 1 above.

In FIGURE 8 is shown a phase shifter 120 which generates circularly polarized energy. Two parallel metal plates 122 and 123 are provided. Between these plates is a bi-stable ferrite or garnet plate 124 having two axially parallel passages 126, 128 defining three walls 130, 131, 132. Walls 130 and 132 abut plates 122, 123, respectively. A central slot 133 is formed in the side of the plate partially bisecting central wall 131. A dielectric slab 135 abuts the side of the plate 124. A slot 133a partially bisects the slab. A metal strip 139 is seated in slots 133, 133a. In interface I', circular polarized energy is generated. Wires 137a, 137b extend axially through passages 126, 128. Current impulses always flow through both wires 137a, 137b in the same direction. The change of permeability in the active ferrite or garnet region is defined by Equations 2 and 3 above for the positive and negative circularly polarized cases respectively.

In FIGURE 9 is shown a linearly polarized phase shifter 120a in which two bi-stable ferrite or garnet plates 102a and 102b similar to plate 102 of FIGURE 7 are employed. The upper side of the plate 102a abuts the underside of a metal grounding plate 122a and the underside of plate 102b abuts the upper side of a metal grounding plate 123a. The center portions 106 of the plates 102a, 102b are separated by a metal strip 140. Holes 141a, 141b in the metal plates 122a, 123a are axially aligned with holes 104a in the plates 102a, 102b. Holes 142a, 142b in the metal plates are axially aligned with holes 104b in the plates 102a, 102b. Two parallel wires 144a, 144b extend through the two sets of aligned holes.

If current impulses flow in the same direction in two wires, the central active portions 106 of the plates

102a, 102b are unmagnetized. If the current impulses flow in opposite directions in the two wires, the central portions of the plates 102a, 102b are magnetized.

In FIGURE 10 is shown a polarization rotator 150 in which the principle of the invention is applied. The rotator includes a square waveguide 152 in which corner ridges 154 are provided. A ferrite or garnet cross-plate 155 is supported by metallic members 156 in the waveguide. Holes 158 are centrally located in the four, flat rectangular arms 157 of plate 155. Wires 160 are supported by dielectric elements 162 in holes 158 and extend outwardly of the arms 157. Plate 155 is shown to best advantage in FIGURE 10a.

The rotator 150 transmits microwaves in the TE_{11} mode, and allows polarization rotation. If current impulses flow in a clockwise direction through wires 160 as viewed in FIGURE 10, then the cylindrical central portion 159 of plate 155 from which arms 157 radiate, is magnetized along its axial length into the plane of the paper. If the current impulses flow in a counter-clockwise direction in wires 160, the magnetization is directed lengthwise of the plate 155 out of the plane of the paper. If the current impulses on two of the four wires 160 are clockwise, and on the remaining two wires the current impulses flow counter-clockwise, then the central portion 159 of the plate 155 is unmagnetized. Consequently, the plate 155 is capable of rotating the polarization in three discrete angles, resulting in a tri-stable Faraday rotator. This device while only indirectly useful as a phase shifter, can be used advantageously to perform valuable switching and modulation functions.

In FIGURE 11 is shown a modification of the invention. Phase shifter 170 includes a rectangular waveguide 172 in which are two parallel plates 174a, 174b extending between upper and lower wider sides 175a, 175b of the waveguide and spaced from narrow sides 177a, 177b of the waveguide. The plates 174a, 174b are made of ferrite material. The plates 174a, 174b are placed in series with two other ferrite plates 176a, 176b made of ferrite material having high remanent magnetization characteristics. Plates 176a, 176b are abutted at their outer sides to wider sides 175a, 175b of the waveguide and at their ends abut plates 174a, 174b. Two metal conducting shields 178a, 178b abut the inner sides of plates 176a, 176b and at the ends contact inner opposing sides of plates 174a, 174b. Phase shifter 170 is composed of composite ferrite loops.

There have been described above various multi-stable microwave phase shifters for a variety of wave transmission purposes in the higher frequencies above 4,000 megacycles. For efficient operation these phase shifters and other variations thereof, devised in accordance with the principles of the invention, should have the following features:

(1) The remanent magnetization should be a large portion of the saturation magnetization in each particular ferrite geometry.

(2) The remanent magnetization should be oriented normal to a portion of the microwave magnetic field in the active ferrite region.

(3) It is preferred that the control wires be on the surfaces normal to the microwave electric field.

(4) It is preferred that discontinuities between elements be eliminated as much as possible in multi-stable structures.

What is claimed and sought to be protected by Letters Patent is:

1. A multi-stable microwave phase shifter device, comprising a hollow waveguide, a plurality of toroidal pipes disposed in axial alignment with each other and extending axially inside the waveguide, a first wire extending axially through the aligned pipes, and branch wires extending laterally from the first wire at opposite ends of the pipes, said branch wires extending laterally of the waveguide and terminating outside of the waveguide, each of said

pipes being formed of an insulating magnetic material having high remanent magnetization as compared with its saturation magnetization.

2. A bi-stable microwave phase shifter device, comprising a hollow waveguide having opposing end walls and opposing side walls perpendicular to the end walls, a plurality of toroidal pipes disposed in axial alignment with each other and extending axially inside the waveguide, each pipe being generally rectangular in cross-section and having an axial passage therethrough, opposite narrow sides of each pipe being spaced from the end walls of the waveguide, opposite side walls of each pipe being juxtaposed to the side walls respectively of the waveguide, a first wire extending axially through the passages of the aligned pipes, one end wall of the waveguide having holes spaced apart longitudinally of the waveguide, and branch wires extending laterally of the waveguide between the pipes, said wires extending through the holes respectively in said one end wall of the waveguide, each of said pipes being formed of an insulating magnetic material having high remanent magnetization compared with its saturation magnetization.

3. A multi-stable microwave phase shifter device, comprising a hollow waveguide, a plurality of plate-like elements disposed in alignment with each other axially of the waveguide and spaced apart at their ends, each of said elements having two parallel passages extending therethrough laterally spaced from the axis of the element, said passages defining two lateral walls and a central wall in each element, a pair of main wires respectively extending through the aligned passages in the elements on each side of the central walls, and branch wires extending from main wires laterally outward of said elements between opposing ends thereof, each of said elements being formed of an insulating magnetic material having high remanent magnetization compared with the saturation magnetization of each element, whereby each of said elements has three different stable states of magnetization.

4. A circularly polarized microwave phase shifter device, comprising a rectangular waveguide having a metallic ridge extending longitudinally inwardly of one side thereof, a series of plates extending longitudinally of the waveguide, each of said plates extending partially under the ridge and partially laterally thereof, each of said plates having an axial passage therethrough, said plates being spaced apart longitudinally of the waveguide, wire loops extending through the passages and laterally of the plates, and a dielectric slab abutting a face of each plate, said slab being disposed partially under the ridge and partially laterally thereof, each of said plates being formed of an insulating magnetic material having high remanent magnetization compared with its saturation magnetization, whereby each plate at the interface of the plate and slab is magnetized in either of two directions to cause permeability of the plate to assume positive and negative circular polarization values respectively.

5. A linearly polarized multi-stable microwave phase shifter, comprising a rectangular waveguide having a metallic ridge extending longitudinally inwardly of one side thereof and spaced from an opposite side, a series of plates extending longitudinally of the waveguide, each of said plates having a central portion disposed centrally under the ridge and lateral portions extending laterally outward on both sides of the ridge, said plates being spaced apart longitudinally of the waveguide, each of the lateral portions of the plate having a hole therein, wires extending axially of the holes and through said opposite side of the waveguide, each of said plates being formed of an insulating magnetic material having high remanent magnetization as compared with its saturation magnetization.

6. A phase shifter for circularly polarizing microwaves, comprising a pair of parallel metal plates, a magnetic plate disposed between the metal plates, said magnetic

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plate having outer sides abutting respective inner sides of the metal plates, a dielectric slab disposed between the metal plates and having one side abutting a side of the magnetic plate, connecting slots formed centrally in the magnetic plate and slab, a metal strip in the connecting slots, said magnetic plate being formed with two spaced holes extending parallel to the metal plates, and wires passing axially through the holes respectively, said magnetic plate being formed of an insulating magnetic material having high remanent magnetization as compared with its saturation magnetization.

7. A linearly polarized microwave phase shifter, comprising a pair of parallel metal plates, a pair of magnetic plates disposed between the metal plates with outer sides of the magnetic plates abutting inner sides of the metal plates, a metal strip disposed between and separating the magnetic plates, said strip being located at centers of the magnetic plates, each magnetic plate having two holes spaced laterally on opposite sides of the centers thereof, and wires passing through aligned holes in the magnetic and metal plates, said magnetic plates being formed of an insulating magnetic material having high remanent magnetization as compared with its saturation magnetization.

8. A microwave polarization rotator, comprising a

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square waveguide having ridges at each face, a magnetic plate having four arms radiating from a central longitudinal portion, said magnetic plate being disposed in said waveguide and extending longitudinally thereof with said arms disposed in diagonal planes of the waveguide, each of said arms having a central hole, and wires extending through said holes respectively and disposed coplanar with each other in a plane perpendicular to the axis of the waveguide, said plate being formed of an insulating magnetic material having high remanent magnetization as compared with its saturation magnetization.

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