United States Patent

Smith

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[54] **MICROWAVE LOADED LINE FERRITE PHASE SHIFTER**

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[52] **U.S. Cl.** ....**333/31 R,** 333/24.1

[51] **Int. Cl.** **H01p 1/18**

[58] **Field of Search** ....333/24.1, 24.2, 24.3, 31, 31 A

[56] **References Cited**

UNITED STATES PATENTS

3,384,841 5/1968 Di Piazza.................................333/31

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[57] **ABSTRACT**

An agile microwave phase shifter of the loaded line type using ferrite material as the active element. The active ferrite material is fabricated in the shape of an annulus and is disposed in a radial cavity which encircles and terminates a coaxial stub attached to a main coaxial transmission line. The ferrite annulus may be operated between states of magnetization that are either below or above the high-loss resonance region. To achieve low magnetization energy, short switching time, and low losses in signal power, the ferrite annulus is made very thin so that its internal magnetic field is substantially uniform and the total magnetomotive force required to produce a given field is small.

9 Claims, 4 Drawing Figures

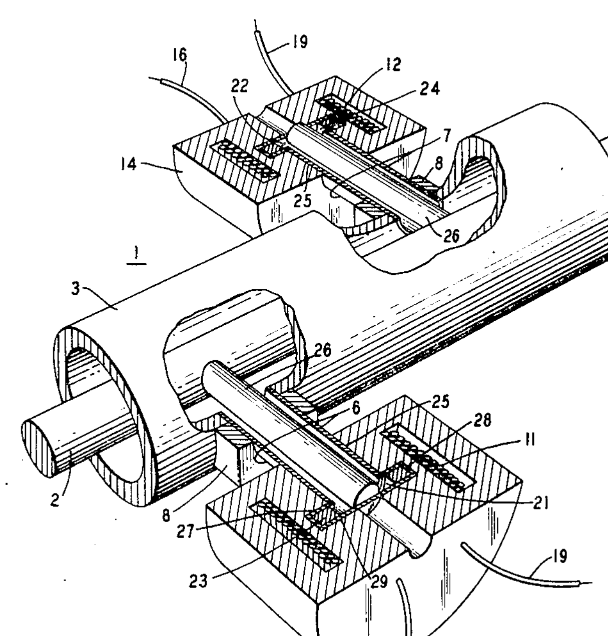

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FIG. 1

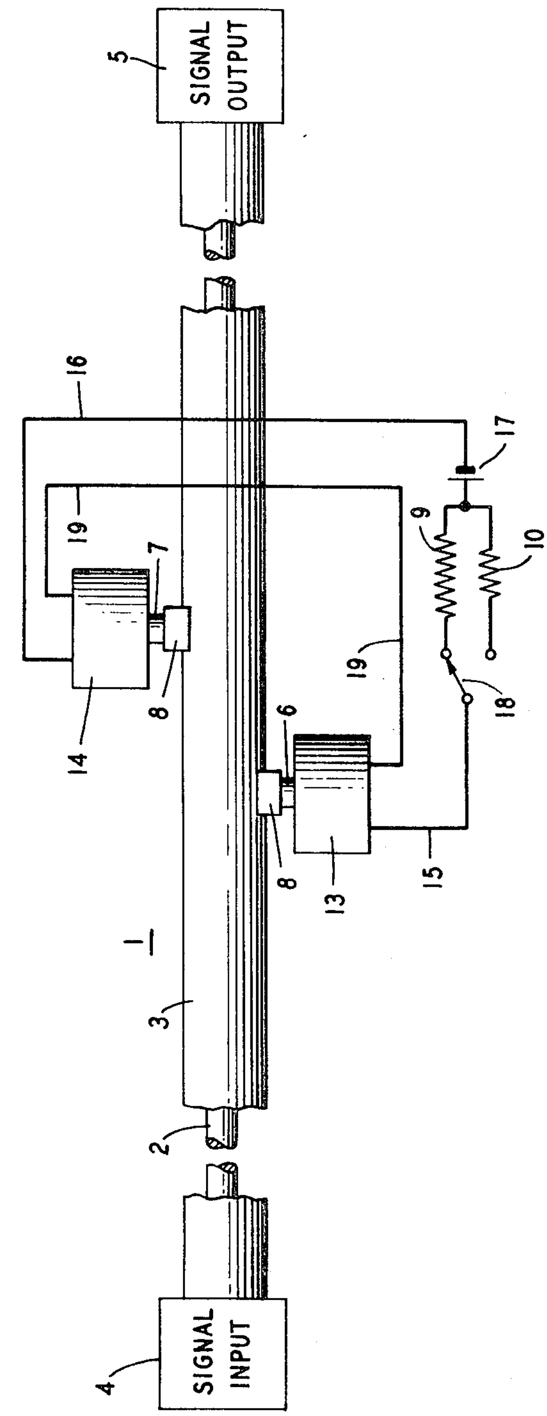

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FIG. 2

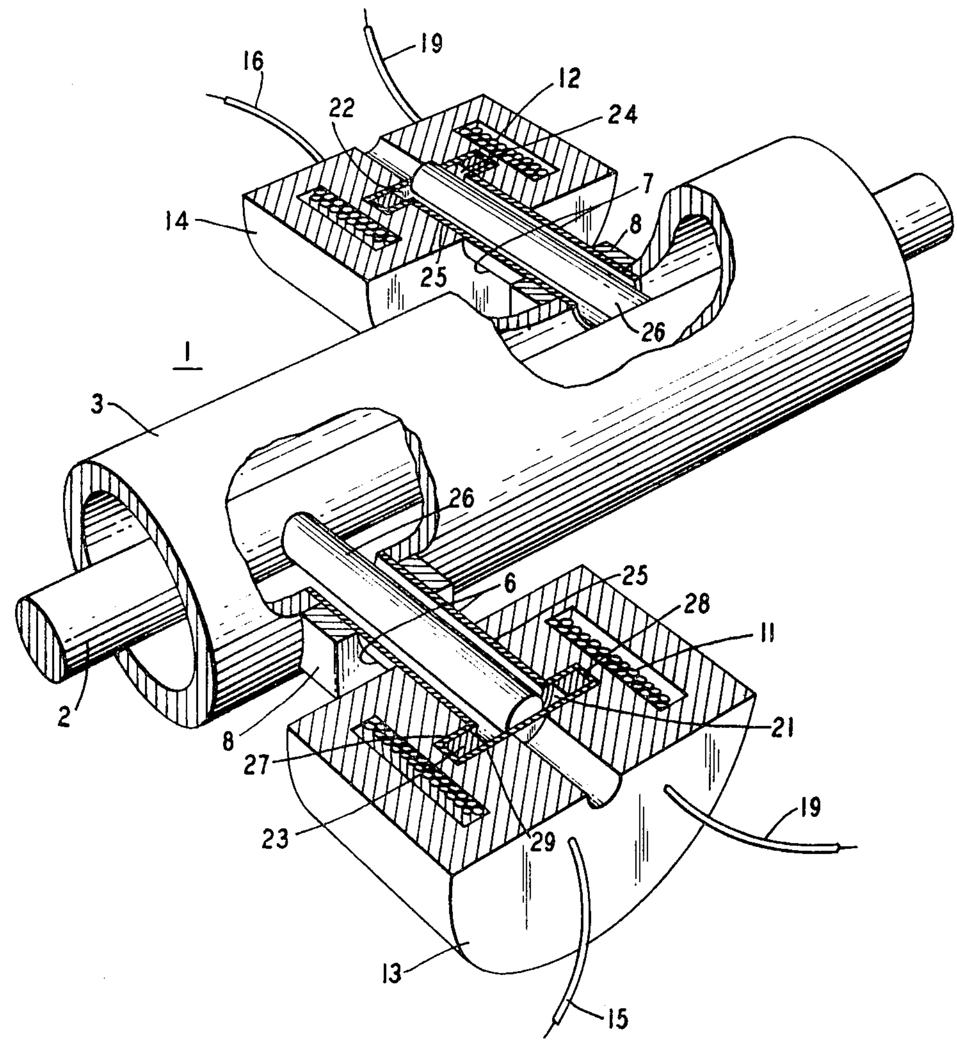


FIG. 3

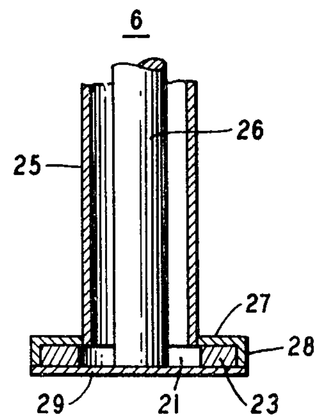
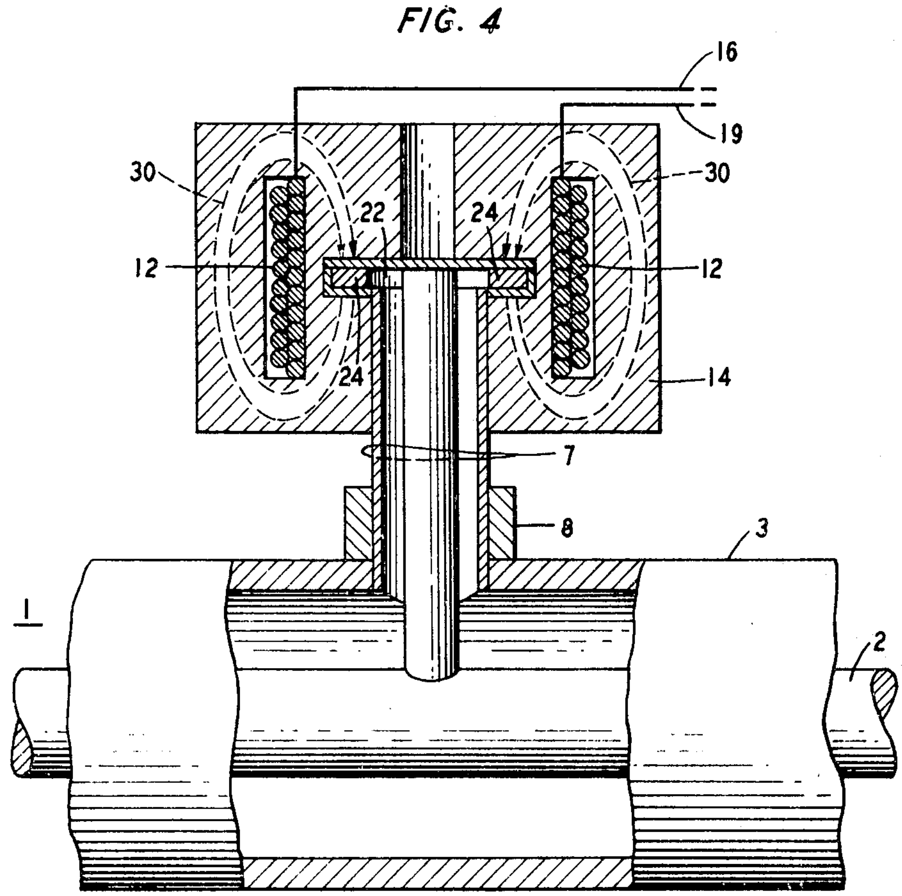


FIG. 4



MICROWAVE LOADED LINE FERRITE PHASE SHIFTER

GOVERNMENT CONTRACT

The invention herein claimed was made in the course of, or under a contract with The Department of the Army.

This invention relates to microwave phase shifters and, more particularly, to a microwave loaded line ferrite phase shifter.

BACKGROUND OF THE INVENTION

Heretofore, some microwave phase shifters have produced changes in phase shift by varying the magnetization vector within one or more magnetic elements incorporated therein. For example, a prior art phase shifter, which is disclosed in U.S. Pat. No. 3,384,841 issued May 21, 1968, to G. C. Di Piazza, has obtained phase shifts by employing ferrite elements for changing the impedance of a pair of coaxial stubs spaced a quarter wavelength apart along a coaxial line. Specifically, this has been accomplished by completely surrounding a portion of the inner conductor of each stub with ferrimagnetic material. The direction of magnetization within the magnetic material is then switched between longitudinal and transverse circular magnetic field configurations. This serves to change the effective length of each stub and, consequently, its input susceptance. Such a change functions to produce a variation in the phase shift that is imposed on a signal wave when it is transmitted along the coaxial line and is propagated past the two stub lines.

SUMMARY OF THE INVENTION

The present invention is designed to provide a microwave phase shifter with several improvements over the above-described phase shifter. This is accomplished by terminating each of the coaxial stub lines in an encircling radial cavity containing a thin annulus composed of ferrite material. Due to the thinness of the annulus, an advantageous reduction in the cost of the relatively expensive ferrite material is obtained because only a very low volume of ferrite material is required. Another important improvement is that, because of the thin configuration of the annulus, the internal magnetization field in the ferrite material will be exceptionally uniform. Still another desirable improvement resulting from this construction is that the current required for magnetization of the ferrite material is relatively small.

An additional advantage derived from this phase shifter is that signaling energy transmitted through it has very low power losses. As this phase shifter utilizes a loaded line, it produces reciprocal phase shifts. Furthermore, the combination of annular cavities and stub lines facilitates adjustments of the design parameters for obtaining various desired phase characteristics at different operating frequencies. Most importantly, since uniform magnetization of the ferrite annulus is obtained by employing only minimal magnetizing current, this serves to maximize the rapidity of the switching action of this phase shifter in switching the magnetizing coils and the ferrite annulus alternatively from one state of magnetization to a different state of magnetization.

BRIEF DESCRIPTION OF THE DRAWING

The features of this invention are more fully discussed hereinafter in connection with the following detailed description of the drawing in which:

FIG. 1 is a plan view of a loaded line ferrite phase shifter constructed in accordance with this invention;

FIG. 2 is a partly sectionalized perspective view of the phase shifter of this invention;

FIG. 3 is a sectionalized side view, drawn on an enlarged scale, of the ferrite annulus in one of the radial cavities which terminates one of the stub coaxial lines shown in FIG. 2; and

FIG. 4 is a schematic diagram showing the configuration of the magnetic field applied to a ferrite annulus in one of the radial cavities.

DETAILED DESCRIPTION

A specific exemplary embodiment of the invention is represented in FIG. 1 as being applied to a main transmission line which is represented as a coaxial line 1 having an inner conductor 2 and an outer conductor 3. A signal input 4 is connected to one end of the main line 1 for propagating microwave signal waves thereover and a signal output 5 is connected to the other end of the line 1. Two coaxial stub lines 6 and 7, which are substantially identical, are attached to the main line 1 by conventional securing means 8. The stubs 6 and 7 are spaced apart along the line 1 by a distance which is substantially equal to a quarter of a wavelength of the operating frequency.

As is shown in FIG. 2, each of the end portions of the coaxial stubs 6 and 7 is encircled by a magnetizing coil 11 and 12, respectively. Each of the coils 11 and 12 is encased within a respectively associated housing 13 and 14. One side of the coil 12 is connected by a lead 16 to one side of a source 17 of electric current that is represented in FIG. 1. The other side of the coil 12 is joined by a lead 19 to one side of the other coil 11. The other side of the coil 11 is coupled by a lead 15 to the pivot point of a transfer switch 18. The switch 18 is adapted to make alternative connections with two resistors 9 and 10 which are connected in parallel to the other side of the current source 17. The resistors 9 and 10 are selected to have different values of resistance.

Accordingly, when the switch 18 is in the position shown in FIG. 1, the magnetizing current applied from the source 17 and through the resistor 9 to the coils 11 and 12 will have one value. Similarly, when the switch 18 is in its alternative position, the coils 11 and 12 will be supplied by the source 17 and the resistor 10 with magnetizing current having a different value. Thus, the coils 11 and 12 will be alternatively energized in two different states of magnetization for alternatively producing magnetic fields having two different values. In other words, the switch 18 constitutes switching means for alternatively switching the magnetizing fields from one state of magnetization to a different state of magnetization. It is to be understood that, if desired, more than two different states of magnetization can be obtained by employing a different type of switch for making selections between three or more different resistors.

The coaxial stub lines 6 and 7 may have any electrically required length and each is reactively terminated, as is shown in FIG. 2, in a respectively associated radial cavity 21 and 22 positioned externally at the end thereof. The cavities 21 and 22 are substantially identical and each encloses a respectively associated and substantially identical annulus 23 and 24 composed of a suitable ferrite material. Although the ferrite loaded cavity may be located at any of a number of points along the stub lines 6 and 7, the preferred location is in a region of high current, such as that which occurs in the vicinity of the short circuits which terminate the stub lines 6 and 7. It should be noted that each annulus 23 and 24 is made very thin so that only a low volume of the relatively expensive ferrite material is required. Furthermore, the thinness of the ferrite material enables it to be uniformly magnetized by means of a relatively small magnetic field as is discussed hereinafter.

The nature of the cavities 21 and 22 can be better understood by referring to FIG. 3 which is a sectionalized view, drawn on an enlarged scale, of the coaxial stub line 6 and its associated cavity 21 and ferrite annulus 23. It can be seen in FIG. 3 that the stub line 6 has an outer conductor 25 concentrically disposed with respect to an inner conductor 26. That end of the outer conductor 25 which is furthest from the main coaxial line 1 is expanded in a radial direction so as to constitute a flange member 27.

The flange 27 may conveniently be made as a separate piece which is joined by any appropriate means, such as by welding, to the outer conductor 25. A hollow cylindrical member 28 has its upper edge suitably attached to the flange 27. If desired, the flange 27 and the cylindrical member 28 can be fabricated by plating a thin electrically conductive coating on the surface of the ferrite material. The lower edge of the cylindrical member 28 has a disc member 29 fastened thereto. Thus, the flange 27, the cylinder 28, and the disc 29, which are each made of electrically conductive material, provide a radially disposed hollow cylindrical enlargement, or cavity, 21 at the end of the stub coaxial line 6 and function as housing means for housing the ferrite member 23. Alternatively, the walls of the cavity 21 may be fabricated as a single unitary integral structure which is an integral portion of the outer conductor 25 of the stub line 6.

As can be seen in FIG. 3, the cylindrical cavity 21 has its axis coincident with the axis of the stub line 6. Also, the axis of the cylindrical cavity 21 is disposed perpendicularly to the axis of the main coaxial line 1. The length or height of the cylindrical cavity 21 is considerably less than its diameter. For example, in this exemplary embodiment of the invention, the length or height of the cylindrical enlargement or cavity 21 is 0.05 inch and its diameter is 0.50 inch. In other words, the diameter of the cavity 21 is larger than its thickness by a ratio of 10:1.

Since, in this embodiment of the invention, the diameter of the outer stub conductor is 0.20 inch, it follows that the diameter of the cavity 21 is wider than the diameter of the outer stub conductor 25 by a ratio of 5:2. As the thickness of the walls of the cavity 21 are only 0.004 inch thick and as the ferrite annulus 23 completely fills all but the central portion of the cavity 21, it can be understood that the ferrite annulus 23 has a diameter which is larger than its thickness by a ratio of approximately 10:1 and that its diameter is larger than the diameter of the outer stub conductor 25 by a ratio of approximately 5:2.

Since the cavities 21 and 22 are substantially identical, and since the ferrite members 23 and 24 are also substantially identical, the same ratios apply to the cavity 22 and also to the ferrite annulus 24.

It should be noted that the central portion of the disc member 29 is suitably connected to the inner conductor 26 of the stub coaxial line 6. Accordingly, the disc 29 also functions as a shorting member for connecting the outer stub conductor 25 to the inner stub conductor 26.

The ferrite annulus 23 may conveniently be placed within the cavity 21 before the disc 29 is attached to the cylindrical member 28. This ferrite annulus 23 is fabricated with a central hole for receiving therein the end of the inner conductor 26 of the stub line 6. Preferably, the hole in the ferrite annulus 23 is slightly larger than the outer conductor 25 so that the ferrite material is external to the stub line 6 and is therefore in a uniform magnetizing field. This is desirable because, in a uniform magnetizing field, the whole volume of the ferrite material is in the same state of magnetization. Accordingly, resonance may be approached from either above or below with significantly lower losses of signal power than would be incurred if some domains within the ferrite material should be magnetized by fringing fields to either a higher or lower state than the main body of the ferrite material.

It is to be understood that the other coaxial stub line 7 and its associated cavity 22 and ferrite annulus 24 are constructed in a manner similar to that of the coaxial stub line 6 and its cavity 21 and ferrite annulus 23.

When a signal wave is transmitted along the main coaxial line 1, its phase can be shifted by employing control means for changing the effective permeability of each ferrite annulus 23 and 24 which, in turn, changes the reactance presented by the radial cavities 21 and 22 to their respectively associated stub lines 6 and 7. Since the reactance which terminates each stub line 6 and 7 is transformed by the length thereof to a normalized susceptance across the main line 1, maximum phase shift can be obtained by producing a maximum change in the reactance of the radial cavities 21 and 22.

This is accomplished in accordance with this invention by operating the switch 18 in time sequence to change the magnetization within each ferrite annulus 23 and 24 between two low-loss states of magnetization, each state having widely different effective permeability. With the switch 18 in the position shown in FIG. 1, magnetizing current from the source 17 will flow through the resistor 9 over obvious circuit paths to the magnetizing coils 11 and 12. Considering, for example, the coil 12, which is schematically illustrated on an enlarged scale in FIG. 4, it can be seen that, when the magnetizing current from the source 17 flows through the coil 12, it creates a magnetizing field 30 which is parallel to the axis of the stub line 7. When the switch 18 is in its alternative position, current from the source 17 will flow through the resistor 10 to the coils 11 and 12 and will create similar magnetic fields which will also be parallel to the axes of the respectively associated stub lines 6 and 7 but which will have a different state of magnetization than the fields 30. Thus, the switch 18, the current source 17, the resistors 9 and 10, and the coils 11 and 12 constitute control means for changing the phase shift through providing alternative magnetic fields parallel to the axis of each of the stub lines 6 and 7.

Since the ferrite annulus 24 is external to the main body of the coaxial stub line 7, its entire area lies completely within the lines of force of the magnetic field 30 as is represented in FIG. 4. A similar condition also exists for the other ferrite annulus 23 that is associated with the other stub line 6.

Because each ferrite annulus 23 and 24 is so constructed as to be very thin, and because each lies completely within its respectively associated magnetic field 30, the internal magnetization field within the ferrite material will be exceptionally uniform and, therefore, the power loss in a signal wave transmitted through this phase shifter will be relatively small. As only a low volume of the expensive ferrite material is needed, a beneficial reduction in cost is effected. An additional advantage derived from this thin construction of each ferrite annulus 23 and 24 is that the current required for their magnetization is relatively small. Furthermore, by varying the dimensions of the ferrite material and the cavities 21 and 22, various adjustments of the design parameters can be obtained for providing a range of desired phase characteristics at different operating frequencies of the signal waves transmitted through this phase shifter.

A most important consideration concerning the operation of ferrite phase shifters is that, when a large volume of ferrite material is required for producing a given phase shift, correspondingly large magnetomotive forces are required and this results in increasing the time required to switch from one magnetization state to another. Conversely, when only small magnetomotive forces are needed, the necessary magnetization currents are correspondingly small thereby effecting a reduction in the time required to switch from one state to another.

This latter condition is obtained in a maximum manner by this invention because the phase shifting effects produced by the ferrite material 23 and 24 are maximized per unit volume due to the extended diameters of the radial enlargements 21 and 22 that terminate the stub lines 6 and 7. Since the enlargements or cavities 21 and 22 are constructed to be very thin, the ferrite material 23 and 24 is also very thin with the beneficial result that each ferrite annulus 23 and 24 is uniformly magnetized throughout its entire extent. Furthermore, as this is accomplished by employing minimal magnetizing currents, the rapidity of the switching action of the phase shifter is maximized to an extent that has not heretofore been obtainable. In other words, the ferrite filled cavities 21 and 22 constitute maximizing means for maximizing the permissible rapidity of the alternative switching action performed by the switch 18. In addition, the above-described specific construction of the ferrite members 23 and 24 constitutes minimizing means for minimizing the magnitude of the magnetizing fields 30 required to produce the desired phase shifts of the microwave signaling energy.

What is claimed is:

1. A loaded line ferrite phase shifter having two ferrite members and adapted for shifting the phase of microwave signals propagated over a main transmission line;

said phase shifter comprising at least two stub transmission lines, each having an inner and an outer conductor, coupled to said main line in such a manner as to be energized in phase quadrature by said signals,

said stub lines having terminating reactances at the ends thereof adapted to be transformed by said stub lines into input susceptances which are presented to said microwave signals for imposing a phase shift thereon when propagated past said stub lines,

control means adapted for changing said phase shift by changing said reactances,

said control means including magnetizing means comprising two magnetizing coils each being so disposed as to encircle an end portion of a respectively different one of said stub lines,

said magnetizing means being adapted for providing magnetizing fields parallel to the axis of each of said stub lines for magnetizing said ferrite members,

switching means adapted for alternatively switching said magnetizing fields from one state of magnetization to a different state of magnetization whereby said ferrite members are switched between two magnetically saturated levels,

and maximizing means for maximizing the rapidity of said alternative switching action of said switching means,

said maximizing means comprising minimizing means for minimizing the required magnitude of said magnetizing fields,

said minimizing means comprising said two ferrite members with each ferrite member being so disposed as to encircle a respectively different one of said stub lines,

and each of said ferrite members being fabricated in the shape of a thin annulus having an outer diameter which is larger than the diameter of either of said stub lines.

2. A loaded line ferrite phase shifter in accordance with claim 1 wherein each ferrite annulus has an outer diameter which is wider than the diameter of either of said stub line outer conductor by a ratio of approximately 5:2.

3. A loaded line ferrite phase shifter in accordance with claim 1 and wherein each ferrite annulus has an outer diameter which is larger than its thickness by a ratio of approximately 10:1.

4. A loaded line ferrite phase shifter in accordance with claim 1 wherein said main transmission line is a coaxial line,

and further comprising means for placing each of said ferrite members completely within a respectively different one of said magnetizing fields for creating uniform magnetization fields in each of said ferrite members so that all domains in each ferrite member will be uniformly magnetized,

said last-mentioned means including means defining a central hole formed in each ferrite member,

and each of said central holes having a diameter which is at least slightly larger than the diameter of its respectively associated outer stub coaxial conductor.

5. A loaded line ferrite phase shifter in accordance with claim 1 and further comprising:

at least two housing means each adapted for housing a respectively different one of said ferrite members,

each of said housing means being fabricated in the shape of a thin hollow cylinder of electrically conductive material encircling a respectively different one of said stub lines and disposed with its axis coincident with the axis of its respectively associated stub line,

and each of said housing means being adapted to be completely filled with its respectively associated ferrite annulus except for the central portion thereof.

6. A loaded line ferrite phase shifter in accordance with claim 5 wherein said main transmission line is a coaxial line,

and wherein each of said housing means is at least partly constituted by an enlarged integral portion of the outer conductor of its respectively associated stub transmission line,

each of said enlarged portions having a diameter that is larger than the diameter of the other portion of its respective outer conductor.

7. A loaded line ferrite phase shifter in accordance with claim 1 wherein each of said stub lines is provided with means defining an encircling radial cavity adapted for receiving therein the respectively associated ferrite annulus,

each of said radial cavities having a diameter that is larger than the diameter of its respectively associated stub line outer conductor.

8. A loaded line ferrite phase shifter in accordance with claim 7 wherein the diameter of each of said radial cavities is larger than the diameter of its respectively associated stub line outer conductor by a ratio of 5:2.

9. A loaded line phase shifter having at least two ferrite members and adapted for shifting the phase of microwave signals propagated over a main transmission line,

each of said ferrite members being fabricated in the shape of a thin annulus,

said phase shifter comprising at least two stub transmission lines, each having an inner and outer conductor coupled to said main line in such a manner as to be energized in phase quadrature by said signals,

said stub lines having terminating reactances at the ends thereof adapted to be transformed by said stub lines into input susceptances which are presented to said microwave signals for imposing a phase shift thereon when propagated past said stub lines,

and control means adapted for changing said phase shift by changing said reactances,

said control means being further adapted for providing magnetic fields parallel to the axis of each of said stub lines for the purpose of magnetizing said ferrite members and also for changing the state of magnetization of said ferrite members,

each of said ferrite members being so disposed as to encircle a respectively different one of said stub lines,

and each of said ferrite members being so constructed and so disposed in relation to a respectively different one of said magnetic fields as to be uniformly magnetized thereby with a minimum of magnetic energy.

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