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[54] **INSERTION PHASE TRIM METHOD**

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[52] **U.S. Cl.** .... **333/31 A;** 333/24.1
[51] **Int. Cl.**[2] **H01P 1/18;** H01P 1/40
[58] **Field of Search** ...... 333/24 G, 24.1, 24.3, 31 A

[56] **References Cited**

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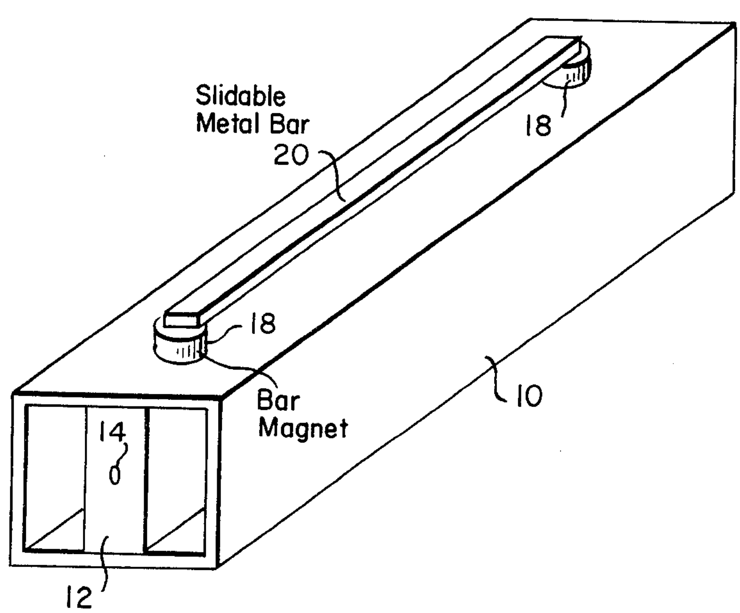
[57] **ABSTRACT**

The insertion phase of a ferrimagnetic phase-shifter is trimmed to a reference value by attaching permanent magnets to the outside of the waveguide to vary the flux linkages through the ferrimagnetic core.

In one embodiment, rubber-magnet tape is applied to the outside top of the waveguide both to add flux linkages through the core and to compensate for any stray magnetic fields so as to give the trim the same effect in either direction of propagation along the waveguide.

In a second embodiment, two permanent bar magnets are positioned uprightly on the waveguide above each end of the toroid core and a metallic bar is slidably placed across the top of the magnets. The metallic bar may be slid across the tops of the upright magnets varying the surface area contact between the bar and the magnets and thus varying the flux linkages running through the toroid core from the magnets. Varying the flux linkages varies the phase-shift of the toroid core.

8 Claims, 2 Drawing Figures



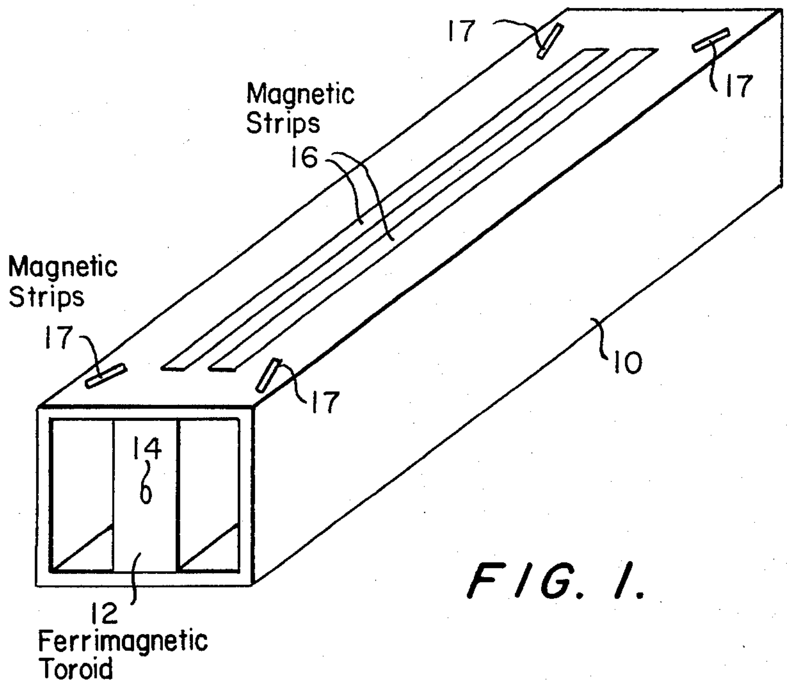

17
Magnetic
Strips
16
17
Magnetic
Strips
17
17
10
14
12
Ferrimagnetic
Toroid

FIG. 1.

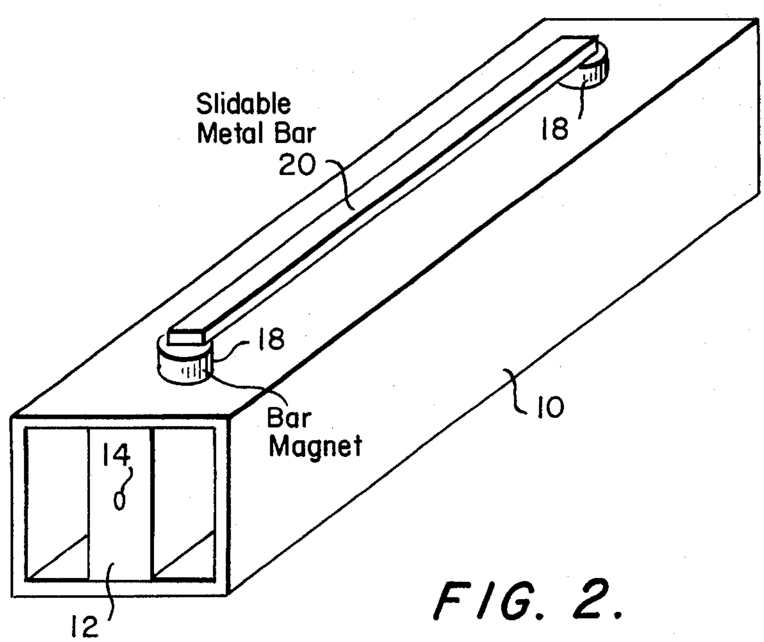

Slidable
Metal Bar
20
18
18
Bar
Magnet
10
14
12

FIG. 2.

INSERTION PHASE TRIM METHOD

BACKGROUND OF THE INVENTION

1. Field of Invention

The present invention relates generally to microwave phase-shifters and in particular to antenna phase-shifters utilizing ferrimagnetic materials.

2. Description of the Prior Art

Ferrimagnetic phase-shifters have been widely used for some time, most notably in antenna array applications. Typically, such arrays comprise thousands of small ferrite phase-shifters spaced ½ λ apart to form a beam. In order to generate the proper beam shape, each phase shifter is set to a different predetermined phase. This is only possible if at some reference current all the phase-shifter units have an identical insertion-phase length. Prior art methods for obtaining a common-reference insertion-phase initially are costly and time consuming. The present invention provides a method and a means to alleviate the basic problems encountered in the prior art in initializing of the insertion-phase.

Generally ferrite phase-shifters comprise a rod of ferrimagnetic material mounted within a waveguide section and means for producing a magnetic field surrounding the material. By varying the strength of this magnetic field the phase shift due to the ferrimagnetic rod may be varied.

In the phase shifter used to illustrate the present invention, a hollow rectangular ferrimagnetic toroid is mounted longitudinally within a rectangular waveguide. A wire mounted in a dielectric slab is inserted in the space within the hollow ferrimagnetic toroid. The phase is varied by sending a current pulse through the wire which acts to induce a magnetic flux in the toroid. When the current pulse has dissipated and thus $H = o$, there will still be some remanent magnetic flux density B in the toroid due to hysteresis effects. This remanent flux density change will cause a change in the propagation constants in the toroid. Thus the microwave signal will pass through the ferrimagnetic toroid either faster or slower depending on whether the flux density is increased or decreased from its last level. This change in the electrical length of the toroid will cause the phase shift in the mirowave signal. The flux density is proportional to the size of the current pulse through the wire. Thus the phase shift can be varied by varying the size of the current pulse.

Since neither the ferrimagnetic cores nor the waveguide sections can be manufactured to have exactly identical physical properties, each phase-shifter must be trimmed to a reference phase when under a reference condition. Mechanical, as well as electrical, methods have previously been used to obtain the desired trim to give each unit the same electrical length under a reference condition. The reference condition is usually a pulse, having a certain strength and a certain time period, through the drive wire contained with the ferrimagnetic toroid core.

The electrical method of insertion trimming comprises varying the strength of the current pulse and its time period through the drive-wire. By properly varying the reference-current pulse strength and time, the electrical length, and thus the phase-shift, may be varied to any value.

The basic problem with the method is that, after this reference calibration, the electronic circuitry for that driver must always be used with that phase-shifter. Due to this mating requirement, if there is a malfunction of the phase-shifter or the driver circuitry when located in the phase-shifter array, both the phase-shifter and the driver circuitry must be replaced.

Mechanical methods of insertion trimming generally comprise the insertion of something inside the waveguide to change the R.F. propagation characteristics of the waveguide. The something inserted is usually a machined piece of dielectric or metal. Slots must be cut into the sides of the waveguide in order to permit this insertion. The machining, inserting, evaluating and testing required in such a method make it very expensive and time-consuming.

The basic problem with this method is that the cutting of slots and the insertion of dielectric or metallic materials changes the slope of the electrical length (phase-shift) vs. frequency curve. Thus this phase-shifter can only properly be trimmed at one frequency, usually the center of a band. At the end of the band, due to the different slope in each of the phase-shifters, there is a large insertion phase error.

SUMMARY OF THE INVENTION

To alleviate the above-staed production problems in trimming the insertion phase of a ferrite phase-shifter to a reference value, the present invention has been developed. Briefly, permanent magnets are attached to the outside of the waveguide to alter the flux linkages within the ferrite core, thus varying its R.F. permeability and thus varying its phase-shift. In one embodiment, magnetic rubber (rubber or vinyl impregnated with magnetic powder) strips may be cut and shaped to provide the proper magnetic bias to bring the phase-shift to a reference value. Magnetic rubber strips may also be used to compenate any stray magnetic fields, thus allowing the phase-shifter to have reciprocal properties for either direction of waveguide propagation.

In a second embodiment, two permanent magnets are attached to the outside of the waveguide and a metal bar placed between to connect them. The bar may be slid across the magnets to vary the surface area contact between the bar and the magnets. Varying the surface area contact varies the flux linkage path and thus the flux linkages through the toroid. The varying of the flux linkages varies the insertion phase length.

OBJECTS OF THE INVENTION

An object of the present invention is to trim the insertion phase of a ferrite phase-shifter located in a waveguide from the outside of the waveguide.

A further object of the present invention is to trim the insertion phase of a ferrite phase-shifter while it is in the test assembly during the assembly test procedure.

A still further object is to reduce the time and expense involved in trimming the insertion phase of a ferrite phase-shifter.

Another object is to trim the insertion phase of a phase shifter in such a manner that it will have the same phase properties in either direction of propagation through the waveguides.

Yet another object is to allow a non frequency-dependent trimming of the insertion phase of a phase-shifter thus markedly improving phase-shifter performance at the band edges.

Other objects, advantages, and novel features of the present invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 illustrates the magnetic biasing used in one embodiment of the present invention.

FIG. 2 illustrates the magnetic biasing used in a second embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The basic invention centers around the use of a permanent magnet placed on the outside of the waveguide section of the phase-shifter. The added magnetic flux linkages running through the toroid from the magnet alters the B field in the toroid, thus altering the electrical length and the phase-shift of the ferrimagnetic toroid. Since

$$\left(\begin{array}{l}\text{Resultant magnetic field}\\\text{in ferrimagnetic core}\end{array}\right) = \left(\begin{array}{l}\text{constant magnet}\\\text{bias field}\end{array}\right) + \left(\begin{array}{l}\text{remanent magnetic field}\\\text{due to pulse in drive wire}\end{array}\right)$$

the phase-shift may be varied by varying the magnetic field in the ferrimagnetic core.

FIG. 1 illustrates one embodiment of the present invention. The rectangular waveguide **10**, the ferrimagnetic toroid **12**, and the drive-wire **14** illustrate the well-known ferrimagnetic phase-shifter configuration.

The long flat strips **16** running along the top of the waveguide **10** above the toroid **12** are rubber magnetic strips. Rubber magnet strips called Plastiform are made by the Dielectric Material and Systems Division of Minnesota Mining and Manufacturing Corporation and consist of a rubber or vinyl base ⅛ to 1/16 inch thick and impregnated in lines in the longitudinal direction with a magnetic powder. The rubber-magnet strips may come on a roll like tape and may have a sticky backside. The flux density per inch of the tape may be chosen in accordance with the maximum trim requirement that may be required for the particular application.

The actual trimming operation comprises the steps of:

a. energizing the phase-shifter under test with a reference current pulse;
b. measuring the flux density of said phase-shifter;
c. determining the excess flux density of said phase-shifter over a desired reference flux density corresponding to a reference phase-shift;
d. cutting off a length of magnetic tape which contains sufficient flux density to trim the flux density of said phase-shifter down to said reference flux density;
e. affixing said length of magnetic tape to the outside of the waveguide section enclosing the ferrimagnetic core of said phase-shifter.

It should be noted that the magnetic powder must be impregnated along the length of the rubber-magnet so that, when the tape is cut, each end will be a magnet pole (either north or south). It is important that the tape be positioned to run parallel and adjacent to the ferrimagnetic core, so that the magnetic flux linkages connecting the north and south poles of the tape will run through the ferrimagnetic core, thus modifying the flux density B.

The magnetic tape may be placed anywhere on the outside of the waveguide. But, the farther the tape is from the ferrimagnetic core, the stronger, its magnetic field must be in order to proejct flux linkages through the core. Also, the greater the distance between the magnets and the toroid core, the more stray magnetic fields will be produced. Thus the optimum place to attach the magnetic tape is where the core touches the waveguide wall. In the particular configuration, this could either be the bottom or the top of the waveguide. In arrays of this nature, it is generally convenient to place the magnetic tape along the top of the waveguide. The waveguide top is usually only 20 or 30 thousandths of an inch thick.

The advantages of using a magnetic tape to bias the ferrimagnetic core are:

1. The phase-shifter may be trimmed from the outside while it is positioned in a test fixture during assembly test procedures thus eliminating the need for removal of the phase-shifter for trim modifications. Obviously there is no slot drilling requirements with this method.
2. The insertion phase vs. frequency curve is unaffected by the magnetic tape since it is not placed inside of the waveguide. Thus the problem of large errors at the band ends is obviated. Since the trimming is not frequency-dependent, the phase-shifter may be tested at a number of frequencies;
3. The labor, machining, and drilling steps of the mechanical trimming method are removed thus reducing cost;
4. Each phase-shifter is trimmed independently of its driver electronics. Thus there is no mating requirement and thus driver circuits and phase-shifters are interchangeable.

It has been determined that under a certain condition, when a magnetic bias field is applied at the outside of the waveguide for trimming, it will have the same effect on the electrical length in either direction of propagation along the waveguide. This is a very unusual property not obtainable with prior-art trimming methods. If this reciprocity is achieved, the transmission and reception phase-shifts will become much more uniform, thus giving a substantially greater efficiency to the system.

The condition required to obtain reciprocity is that the magnetic-field-flux lines around the waveguide must run parallel to the longitudinal axis of the waveguide. This condition requires the compensation of any stray magnetic fields around the waveguide.

The strips of tape **17** located on the top of the waveguide of FIG. **1** compensate for stray fields.

A method for accomplishing this compensation comprises the steps of:

energizing the ferrimagnetic phase-shifter under test so that a flux density is generated therein;

measuring the phase-shift of said phase-shifter and determining whether it is reciprocal;

cutting and shaping strips of magnetic tape and experimentally determining where they should be placed so as to effect a phase-shifter reciprocity; and

attaching these pieces of magnetic tape to the outside of the waveguide in the appropriate positions to compensate for the stray magnetic fields.

The use of the rubber-magnet tape makes the magnetic field shaping required for the above method very simple.

A second method and means for trimming a ferrite phase-shifter is shown in FIG. **2.** The rectangular waveguide **10,** the ferrimagnetic toroid **12,** and the drive-wire **14** illustrate again the well-known, phase-shifter configuration.

The method comprises the use of two squat bar magnets **18,** stood on end, above each end of the ferrimagnetic toroid core. A metallic bar **20** is placed such thta it slidably rests on protruding ends of the two squat magnets. The bar acts to complete the magnetic path such that flux linkages may run from the first bar magnet through the metallic bar, down through the second magnet, down and longitudinally along the toroid core, and back up into the first magnet. By sliding the bar or moving the magnets the surface area contact between the metallic bar and the top surface of the two magnets may be varied. This varying of the surface area contact varies the flux linkage path crosssection and thus varies the amount of flux linkages running through the toroid core **12.**

Thus magnetic biasing for trimming may be accomplished by varying this surface area contact.

Again, this method is most effective when the magnets and metallic bar are closest to the ferrimagnetic toroid core.

After the bar has been adjusted to obtain the desired phase-shift, the squat magnets **18** and the metallic bar **20** may be glued together and to the waveguide with epoxy.

In order to compensate any stray magnetic fields so as to obtain reciprocity the squat bar magnets would have to be properly shaped. This could be accomplished by grinding them down to the desired shape after first determining the configuration of the field needed for compensation.

In both of the trimming methods described, magnetic flux is added to the toroid core. Thus the phase-shift may only be increased, not decreased. Thus the electrically short units are usually trimmed to the unit with the longest electrical length within reasonable bounds.

Obviously, many modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that, within the scope of the appended claims, the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. A microwave ferrimagnetic phase-shifter comprising:

waveguide means;

ferrimagnetic toroid means contained and extending longitudinally within said waveguide means;

first magnet means attached to the outside surface of one of the longitudinally extending walls of said waveguide means;

second magnet means attached to the outside surface of the same waveguide wall upon which said first magnet means is attached, and placed such that a line connecting said first magnetic means to said second magnetic means would be parallel to the longitudinal axis of said waveguide means;

longitudinally extending electrical conductor means providing a surface area at each longitudinal end, placed so that each end surface area contacts the top surface areas of said first and second magnetic means respectively such that said conductor means may be slid back and forth to vary the surface area contact between the conductor end surfaces and the top surfaces of the two magnetic means and thus vary the flux linkages through the path comprising the two magnet means, said conductor means, and said toroid means, thus varying the permeability of the toroid means and thus the phase shift of the phase-shifter.

2. A microwave ferrimagnetic phase-shifter as in claim **1,** wherein said first and second magnet means are located on the waveguide wall, one above each end of said toroid means.

3. A microwave ferrimagnetic phase-shifter as in claim **1,** wherein said waveguide and said toroid means are rectangular in shape and said toroid means touches the inside surface of the waveguide wall upon which said first and second magnet means are attached.

4. A microwave ferrimagnetic phase-shifter as in claim **3,** wherein said first and second magnet means are bar-shape magnets and are attached to the top of said waveguide, and said electrical conductor means is a flat metal bar.

5. A method for trimming the insertion phase of a microwave ferrimagnetic phase-shifter comprising the steps of:

energizing the phase-shifter and determining its phase-shift relative to a reference;

placing a squat bar-magnet on the waveguide wall adjacent to each end of the ferrimagnetic core;

placing a metallic bar with a flat surface area at each end across the top surface of the two squat magnets;

sliding the metallic bar such that the surface area contact between the metallic bar end surfaces and the top surfaces of the two magnets varies, thus varying the flux linkages through the ferrimagnetic core, and thus varying the phase-shift of the phase-shift, until the desired reference phase-shift is obtained.

6. A method for trimming as in claim **5,** further comprising the step of shaping each of the two squat magnets so that stray magnetic fields are compensated and the only remaining magnetic field runs longitudinally along the waveguide length thus giving this magnetic trimming the same effect in either direction of propagation along the waveguide.

7. A method for trimming as in claim **5,** wherein said squat bar magnets and said metallic bar are placed on the side of the waveguide where the ferrimagnetic core comes closest to the waveguide wall.

8. A method for trimming as in claim **5,** wherein said squat bar-magnets and said metallic bar are placed on the top of said waveguide means.

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