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UTILIZING A RESILIENT WAVEGUIDE WALL

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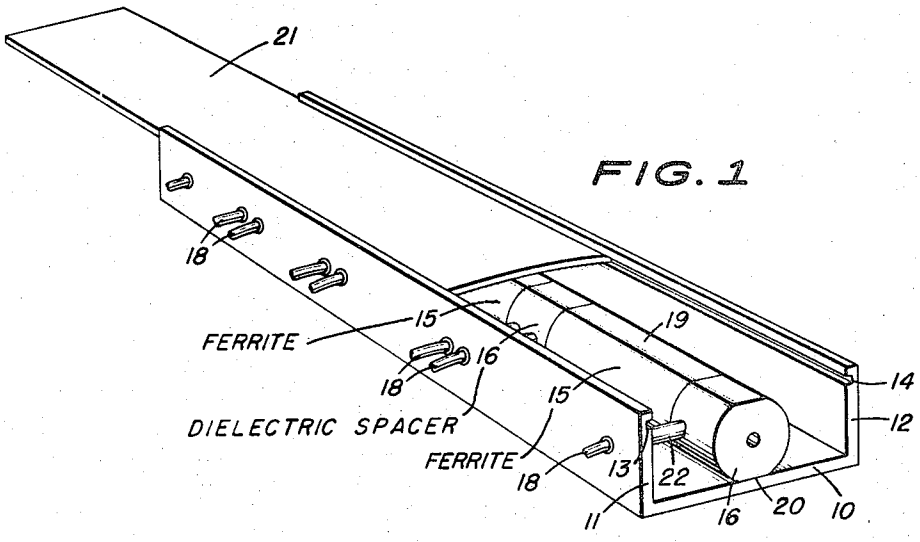


FIG. 1

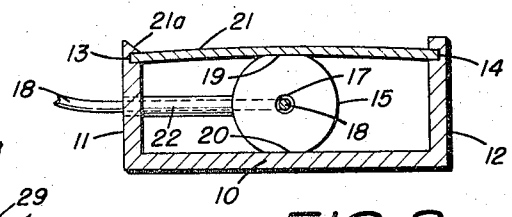


FIG. 2

FIG. 3

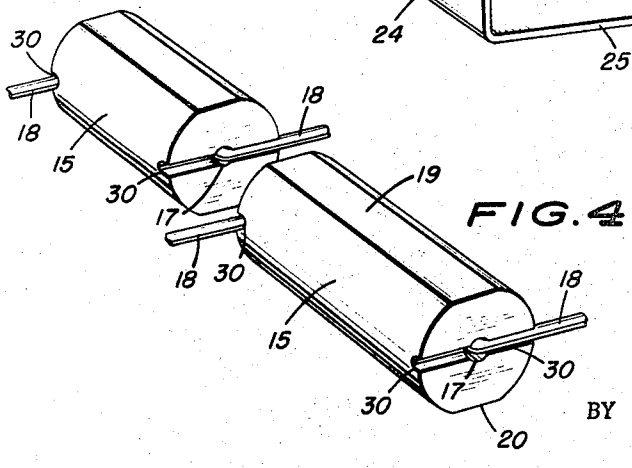


FIG. 4

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UTILIZING A RESILIENT WAVEGUIDE WALL

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ABSTRACT OF THE DISCLOSURE

Generally speaking, the present invention relates to microwave phase shifters and more particularly pertains to a latching ferrite phase shifter structure which is relatively inexpensive to manufacture and easy to assemble, requires low switching current and yet is efficient in operation. More specifically, the proposed phase shifter comprises a waveguide containing a plurality of aligned latching type ferrite elements, of varying lengths and adapted to be pulsed in digital fashion, to impart variable phase shift to input microwave energy. Each of the ferrite elements has a substantially circular cross-section and is formed (for example, by extrusion) with a central bore adapted to receive a control wire; the circular cross-section of the ferrite having the effect of permitting complete saturation of the ferrite with minimum control pulse current in the control wire. The phase shifter is moreover constructed such that good physical contact exists between the waveguide and the ferrites in order to reduce spikes in both insertion loss and voltage standing wave ratio. The proposed phase shifter is particularly adapted for use in a phased array antenna system.

The use of ferrite elements in a waveguide member, to impart variable amounts of phase shift to input microwave energy, is well-known. However, heretofore, most of these ferrite elements were rectangular or square in cross-section and/or employed control wires which were wound around the outside of the waveguide member to change the magnetic state of the ferrite elements therein. Consequently, many of the previously proposed ferrite phase shifters were relatively bulky, difficult to assemble and required relatively large operating currents. Moreover, in such prior ferrite phase shifters, good physical contact between the waveguide member and the ferrite elements was difficult to maintain, with the result that insertion loss spikes were relatively high and voltage standing wave ratio spikes were often excessive.

In accordance with the present invention, it is proposed that the ferrite element or elements disposed within the rectangular waveguide member have a substantially circular cross-section; i.e., the ferrites are cylindrical so as to permit most efficient utilization of the applied control current for changing the magnetization state of the ferrite element(s). Moreover, it is proposed in accordance with the present invention to flatten the sides of the ferrite cylinders slightly and to construct the waveguide member such that good physical contact is maintained between the waveguide member and the ferrites. As mentioned previously, this will reduce spikes in both insertion loss and voltage standing wave ratio and moreover help to hold the ferrite assembly firmly in place.

More particularly, the rectangular waveguide member is assembled from two pieces; the first of which is substantially U or channel shaped, to receive the ferrite assembly, and the other of which is secured to the first piece to form the rectangular waveguide and complete the phase shifter assembly. The good physical contact is obtained between the completed rectangular waveguide member and the flattened sides of the ferrites by making the inside

height of the waveguide, when measured along the inside of its two narrower sidewall portions, slightly less than the thickness of the ferrites when measured between the flattened sides thereof. Consequently, when the waveguide is assembled, its two wider wall portions firmly engage against the flattened surfaces of the ferrites. In one embodiment of the proposed phase shifter, the assembling of the waveguide member is facilitated by a flexible top plate which is adapted to be snapped into suitable grooves or slots provided in the U-shaped channel piece.

The ferrite members are mounted within the waveguide in end to end alignment and each having central bore extending therethrough adapted to receive an associated control wire. In this manner, the ferrites can be operated selectively; i.e., the phase shifter is a digital device capable of imparting different discrete values of phase shift to the input microwave energy in accordance with the selective pulsing of the individual control wires. As previously mentioned, each ferrite element is of the latching type capable of retaining the magnetic state to which it is operated by a current pulse of the associated control wire after such pulse is terminated and until an opposite polarity pulse is applied. Moreover, because the proposed phase shifter requires relatively low operating or control current, such current can be supplied by inexpensive and relatively fast operating transistorized current driver circuitry.

In one embodiment of the present invention, to be described in detail hereinafter, the aligned ferrite elements are separated from one another by dielectric spacers which provide a means of exit for the control wires and prevent any possibility of interaction between the adjacent ferrites. In a further and presently preferred embodiment, these dielectric spacers have been eliminated and the ferrite elements bonded directly to one another, with the control wires exiting through small grooves formed across the ends of each ferrite element, as will be described hereinafter. The latter construction results in a phase shifter which is physically shorter and has lower voltage standing wave ratio due to fewer discontinuities.

In view of the above, one object of the present invention is to provide an improved microwave phase shifter which is relatively inexpensive to manufacture, easy to assemble and efficient in operation.

Another object of the present invention is to provide a microwave phase shifter of the latching ferrite type which is so constructed as to have low insertion losses, voltage standing wave ratio and input current requirements and minimum spikes of insertion loss and voltage standing wave ratio.

Another object of the present invention is to provide a ferrite phase shifter structure wherein a plurality of slightly flattened, cylindrical ferrite elements are disposed within a rectangular waveguide member and wherein the waveguide member is formed by a U-shaped channel member and a flexible top plate adapted to be snap-fitted into suitable grooves or slots formed in the U-shaped member in such a manner that the top plate physically engages the flattened surfaces of the ferrite elements to hold them in firm physical contact with the completed waveguide member.

Another object of the present invention is to provide a digital type ferrite phase shifter comprising a rectangular waveguide containing a plurality of ferrite elements adapted to be selectively magnetized by control current pulses so as to impart discrete phase shifts to input microwave energy.

Another object of the present invention is to provide a microwave phase shifter particularly adapted to be used in great quantity in a phased array antenna system, for example.

Other objects, purposes and characteristic features of the present invention will in part be pointed out as the description of the invention progresses and in part be obvious from the accompanying drawings, wherein:

FIG. 1 is a perspective view of one embodiment of the present invention, with the interior of the waveguide exposed so as to illustrate the aligned ferrite elements therein;

FIG. 2 is a cross-sectional view of one embodiment shown in FIG. 1 but modified slightly to accommodate a snap-fitted top plate member;

FIG. 3 is a perspective view of a second embodiment of the present invention; and

FIG. 4 is an enlarged perspective view illustrating a modified construction of the ferrite elements employed in the microwave phase shifter of the present invention.

Referring now to the drawings, the embodiment shown in FIGS. 1 and 2 comprises a substantially U-shaped or rectangular channel waveguide member made of aluminum, for example, and having a bottom wall portion **10** and sidewall portions **11** and **12**. The inner surfaces of the sidewall portions **11** and **12** are formed with notches **13** and **14** respectively, running longitudinally therealong adjacent the extending or upper edge thereof.

Disposed, in end-to-end alignment, within the waveguide channel member **10–12** are a plurality of substantially cylindrical ferrite elements **15**, separated from one another by dielectric spacers **16** in order to reduce interaction between the elements **15**. Each of the ferrite cylinders **15** is formed, preferably by the well-known extrusion process, from any suitable latching type material with a central bore **17** (see FIG. 2) adapted to receive an associated control wire **18** which is threaded therethrough and is selectively energized with current pulses effective to change the magnetic state of the ferrite element **15** so as to impart the desired phase shift to microwave energy applied to the waveguide assembly. Because the ferrites **15** are formed by extrusion, machining costs are kept to a minimum.

Moreover, each of the ferrite elements **15** (as well as the dielectric spacers **16**) is flattened slightly as shown at **19** and **20** throughout the drawings. The distance or thickness of the ferrite element **15** between the flattened surfaces **19** and **20** is slightly greater than the distance from the inner surface of the bottom wall portion **10** of the waveguide channel to the notches **13** and **14** in the sidewalls **11** and **12** respectively. These notches **13** and **14** are adapted to receive a flexible top plate member **21** which is fitted therein to complete the waveguide assembly. As will be noted best in FIG. 2, when the top plate **21** is inserted in place, it is in good physical contact with the upper flattened surface **19** of the ferrite assembly and acts to resiliently bias the lower flattened surface **20** of such ferrite assembly into good physical contact with the inner surface of the bottom wall portion **10**.

The particular manner in which the top plate **21** is secured in the notches **13** and **14** depends upon what type of metal is used for the top plate **21**. For example, if the top plate **21** is made of brass, it could be inserted slidably into the notches **13** and **14** and therefore the top side edges of the channel waveguide member **10–12** could be configured as shown in FIG. 1. On the other hand, if the top plate **21** is made of aluminum, it would be difficult to slide it within the slots **13** and **14**. Therefore the channel waveguide member **10–12** may, if desired, be formed with at least one of its top edges beveled, as shown at **21***a* in FIG. 2, such that the top plate **21** could be readily snap-fitted into the grooves **13** and **14**, for example, by inserting one edge of the top plate **21** into groove **14** and then pressing the other edge of the top plate **21** into the groove **13**.

As heretofore discussed, insertion loss and voltage standing wave ratio, as well as the so-called insertion and differential phase quantities, are all critically dependent upon the quality of contact between the waveguide walls and the ferrite surfaces. A gap of as little as 0.0001 inch over a short length of the phase shifter assembly can cause undesirable spikes of insertion loss and voltage standing wave ratio at several frequencies in the operating band. Moreover, such gaps also result in sensitivity to mechanical pressure on the waveguide walls and in unpredictable insertion and differential phase quantities. The above-described construction of the proposed phase shifter overcomes these problems by maintaining good physical contact between the waveguide and the ferrites **15** and also helps hold the ferrite assembly firmly in place.

The ends of each of the individual control wires **18** which thread through an associated ferrite cylinder **15** are brought out through the adjacent dielectric spacers **16** and are insulatedly supported relative to the waveguide member and to one another by suitable sleeving **22**. By making the ferrite elements **15** substantially circular in cross-section, most efficient use is made of the current pulses applied to the control wires **18**; i.e., the magnetization state of a ferrite element **15** can be effectively varied with a minimum input current pulse on the associated control wire **18**. This feature permits the phase shifter of the present invention to be controlled by inexpensive and relatively fast operating transistorized current driver circuitry.

As also mentioned previously, the aligned ferrite elements **15** are of different lengths and therefore capable, when selectively pulsed, of imparting distinct phase shifts to the input microwave energy. In one practical embodiment of the present invention, four such ferrite elements are employed in order to impart phase shifts of 22.5 degrees, 45 degrees, 90 degrees and 180 degrees respectively to the input microwave energy, when the associated control wires **18** are individually pulsed. By employing these four different lengths of ferrite cylinders **15**, sixteen discrete phase shift combinations are available; ranging from 0° to 337.5° in steps of 22.5°.

A second embodiment of the present invention is illustrated in FIG. 3 and comprises a sidewall member **23** and a substantially U-shaped or channel waveguide member having short sidewall portion **24** and relatively wide sidewall portions **25** and **26**. The member **23** is formed with twist tabs **27** which mate in corresponding slots **28** adjacent the extending or right-hand edges of the wide wall portions **25** and **26**, to form the completed waveguide. The ferrite assembly (including ferrite elements **15** and dielectric spacers **16**) is secured to the side plate member **23** by suitable insulating eyelets **29**. Here again, the ferrite assembly is flattened slightly at **19** and **20** and the height or width of sidewall portion **24** and member **23** is slightly less than the distance between surfaces **19** and **20**, so that good physical contact is attained between the assembled waveguide and the ferrites **15**.

In the embodiment shown in FIGS. 1 and 3, suitable dielectric spaces **16** were interposed between adjacent ferrite members **15**. However, in practice, it may be desirable to shorten, as much as possible, the overall phase shifter length. A suitable manner of accomplishing this is shown by the modification of FIG. 4, wherein the ends of each ferrite element **15** are provided with suitable grooves or slotting **30** adapted to receive the extending ends of the control wires **18** in such a manner that the ferrite members **15** can be placed end to end, in abutting relationship, within the waveguide assembly. This has the effect of lowering the voltage standing wave ratio by reducing the number of discontinuities along the ferrite assembly.

Many other modifications, adaptations and alterations of the present invention are possible in the light of the above teachings. It is therefore to be understood at this time that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. In a microwave phase shifter including a rectangular waveguide member formed with first and second wall

pairs, said first wall pair having a width greater than said second wall pair, the combination of,

a substantially cylindrical ferrite means disposed within said rectangular waveguide member and extending longitudinally therein,

said substantially cylindrical ferrite means being configured with an axial bore extending longitudinally between the ends of said ferrite means and with diametrically opposed flattened surfaces abutting against each of the wider walls of said rectangular waveguide member.

at least one of the wider walls resiliently biasing the flattened surfaces on said ferrite means firmly into contact with each of said wider walls, and

a control wire means threading through said axial bore and being energizable to vary the magnetic state of said ferrite means for shifting the phase of microwave energy applied to said rectangular waveguide.

2. The phase shifter specified in claim **1** wherein said rectangular waveguide member comprises,

a substantially U-shaped channel member having a first wall portion and a pair of second wall portions each of which is of less width than said first wall portion,

each of said second short wall portions being formed with a groove that extends longitudinally along the inner surface of said short wall portions adjacent the extending edge thereof, at a distance from the inner surface of said first wall portion that is slightly less than the width of said ferrite means between the flattened surfaces thereof, and

a resilient plate member slidably mounted in the grooves in said second wall portions in contact with one flattened surface of said ferrite means for biasing the other flattened surface of said ferrite means into contact with the first wall portion of said U-shaped channel member.

3. The phase shifter specified in claim **2** wherein the extending edge of at least one of said second short wall portions is bevelled, whereby said resilient plate member can be snap-fitted into said grooves.

4. The phase shifter specified in claim **1** wherein said rectangular waveguide member comprises,

a substantially U-shaped channel member having a first wall portion and a pair of second wall portions each of which is wider than said first wall portion,

said first wall portion having a width slightly less than the distance between the flattened surfaces of said ferrite means,

each of said wider second wall portions being formed with a plurality of spaced, longitudinal slots adjacent the extending edge thereof, and

a plate member of substantially the same width as said first wall portion and having twist tabs adapted to be inserted through the spaced, longitudinal slots in said wider second wall portions for fixedly securing said plate member in substantially spaced parallel relationship to said first wall portion and each of said second wall portion in contact with the one of the flattened surfaces of said ferrite means.

5. The phase shifter specified in claim **1** wherein,

said ferrite means comprises a plurality of substantially cylindrical ferrite elements aligned end to end, each of different length and each having diametrically opposite flattened surfaces biased against the wider walls of said waveguide and an axial bore extending longitudinally therethrough, and

said control wire means includes a plurality of control wires, one of which is threaded through the axial bore of each of said ferrite elements, said plurality of control wires being selectively energized to control the magnetic state of said ferrite elements in accordance with the desired phase shift to be imparted to input microwave energy applied to said phase shifter.

6. The phase shifter specified in claim **5** wherein said ferrite elements are aligned end to end abutting one another and the ends of each of said ferrite elements are formed with transverse slots extending between the axial bore and the edges of said ferrite elements to receive the ends of the control wire threading through said ferrite element.

7. The phase shifter specified in claim **5** and further including a substantially cylindrical dielectric spacer member interposed between adjacent ferrite elements and having diametrically opposed flattened surfaces coextensive with the flattened surfaces on said ferrite elements.

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