United States Patent

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[54] **MICROWAVE FERRITE FILM CIRCUIT CONFIGURATION**
5 Claims, 4 Drawing Figs.

[52] **U.S. Cl.** **333/84,** 333/24.1
[51] **Int. Cl.** **H01p 3/08,** H01p 1/32
[50] **Field of Search** ..... 333/1.1, 24.1, 24.2, 24.3, 84 (M), 84

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ABSTRACT: Described is microwave miniaturized signal processing circuitry for radar and the like applications employing ferrite films capable of effecting a phase shift in wave energy passing through the circuitry, and wherein the insertion loss of the device is minimized. This is accomplished by providing a structure wherein the wave energy need not pass through a ceramic or the like substrate, but rather is confined essentially within the ferrite material itself.

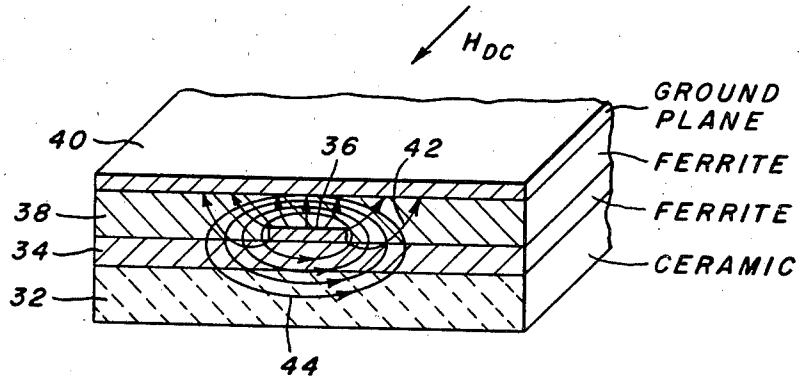


FIG. 1A.

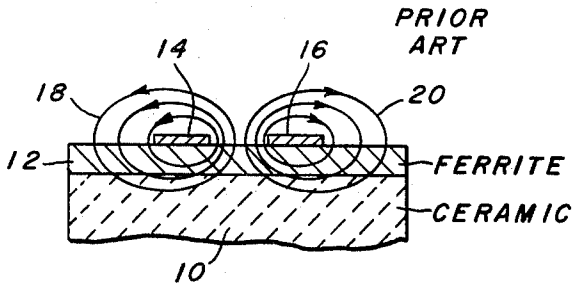


FIG. 1B.

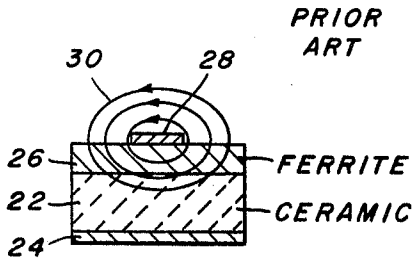


FIG. 2.

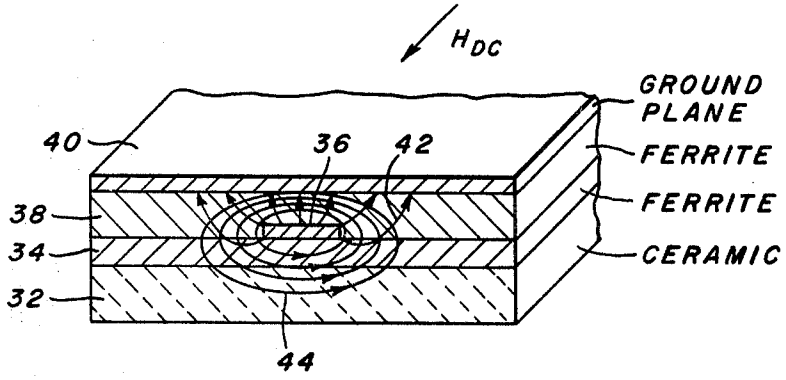
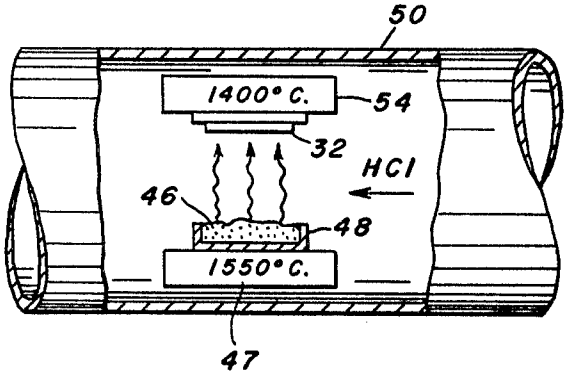


FIG. 3.



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MICROWAVE FERRITE FILM CIRCUIT CONFIGURATION

BACKGROUND OF THE INVENTION

While not limited thereto, the present invention finds particular utility in the fabrication of ferrite phase shifters, circulators and the like where it is necessary or desirable to miniaturize the device. A typical application, for example, might be a miniaturized phase shifter for a phased antenna array. Such an array employs a plurality of radiating elements which are electronically scanned. That is, by varying the phases of the respective signals fed to the individual radiating elements, the composite radiated beam can be caused to scan back and forth without mechanical movement of the antenna itself. However, due to the spacing between the individual radiating elements, conventional wave guide systems and ferrite phase shifters are ordinarily too large and bulky for such applications if any type of compact antenna system is to be achieved.

Efforts have been made to miniaturize ferrite devices, such as ferrite phase shifters, by depositing a ferrite film on a dielectric substrate, usually a ceramic substrate, followed by deposition of microstrip conductors on the ferrite film. The difficulty with this method is that very poor coupling of the radio frequency magnetic field to the ferrite film is achieved. Consider, for example, wave energy in the quasi-TEM mode traveling along a microstrip transmission line deposited on a ferrite film on a ceramic substrate. The radio frequency magnetic field encircles the transmission line; however, only a small portion of this field passes through the ferrite film where interaction with an external magnetic field can cause phase shift, the rest of the field can cause phase shift, the rest of the field passing through the ceramic substrate. As a result, the device must be made relatively long in order to obtain an effective amount of phase shift, but this results in high insertion losses because of the excessive length.

SUMMARY OF THE INVENTION

As an overall object, the present invention seeks to provide a miniaturized ferrite phase shifter employing ferrite films, and wherein the insertion loss of the device is minimized.

More specifically, an object of the invention is to provide a ferrite phase shifter in which a ferrite film is interposed between a microstrip transmission line and a metallic ground plane, whereby the radio frequency magnetic field in the quasi-TEM mode surrounding the microstrip transmission line is confined in the ferrite itself. As will be seen, this greatly increases the efficiency of the device and reduces insertion losses.

In accordance with the invention, a planar circuit electromagnetic ferrite device is provided comprising a first ferrite film deposited on a substrate, preferably a ceramic substrate. Deposited on this ceramic substrate is a first ferrite film; while an electrical strip conductor is deposited on the first ferrite film on the side thereof opposite the substrate. A second ferrite film is deposited over the strip conductor and covers the first film on either side of the substrate to form a complete ferrite magnetic circuit around the strip conductor. Finally, a layer of metallic material is deposited on the second ferrite film and forms a ground plane for the strip conductor whereby radio frequency magnetic lines of flux surrounding the strip conductor in the quasi-TEM mode of wave propagation will be confined in the second ferrite film between the strip conductor and ground plane.

In order to form a ferrite film, the ferrite material is deposited as a mixture of chlorides, nitrates or other ionic compounds at relatively high temperatures. For example, in the case of magnesium-manganese ferrites, the reaction must be carried out at a temperature of about 1400° C. As a result, the material which can be used for the strip line conductor must have a melting point above 1400° C, must have good electrical conductivity, and cannot oxidize at the high temperatures. This confines the available materials to noble

metals having high melting points. In the case of magnesium-manganese ferrites, platinum is a suitable material for this use. On the other hand, when nickel ferrites are employed, the reaction temperature drops to about 600° F. such that gold can be used instead of platinum as the strip line conductor.

The above and other objects and features of the invention will become apparent from the following detailed description taken in connection with the accompanying drawings which form a part of this specification and in which:

FIGS. 1A and 1B are illustrations of prior art microwave ferrite film circuit configurations which inherently have a high insertion loss;

FIG. 2 is an illustration of one embodiment of the present invention; and

FIG. 3 illustrates the manner in which a ferrite film can be grown over a metallic microstrip in accordance with the teachings of the invention.

With reference now to the drawings, and particularly to FIGS. 1A and 1B, the circuit shown includes a ceramic substrate 10 on which a ferrite film 12 is deposited. On top of the ferrite film are a pair of strip conductors 14 and 16 forming a two-wire line which will transmit electromagnetic wave energy in the quasi-TEM mode. That is, both the electric and magnetic fields are transverse to the direction of wave propagation. The magnetic fields surrounding the strip conductors 14 and 16 are indicated by the reference numerals 18 and 20 respectively. It can be seen that very small portions of the magnetic fields pass through the ferrite film 12 where an external magnetic field passing into or out of the plane of the drawing of FIG. 1A can cause a phase shift in the wave energy passing through the two-wire line.

FIG. 1B illustrates a prior art microstrip transmission line arrangement. A the drawing, substrate 22 is coated on one side with a metallic layer 24 comprising a ground plane. A ferrite film 26 is deposited on the other side of the substrate 22. A strip line conductor 28 is again deposited on the ferrite film 26; but here again only a small portion of the radio frequency magnetic field surrounding the strip conductor 28 passes through the ferrite film 26. Consequently, if it is desired to shift the phase of the quasi-TEM mode wave energy passing along the microstrip transmission line by means of a magnetic field extending into or out of the drawing, the length of the phase shifter must be made excessively long, thereby increasing the insertion loss of the device. The same is true of the device of FIG. 1A. That is, in order to obtain any appreciable amount of phase shift, its length must be increased; whereupon the insertion loss of the device increases also.

The apparatus of the present invention is shown in FIG. 2. The starting material is again a slab or wafer of a ceramic material 32 having a first ferrite film 34 deposited on one face thereof. Deposited on the ferrite film 34 is a microstrip transmission line 36; and covering the strip line conductor 36 and the exposed portions of the first film 34 is a second ferrite film 38. Finally, a layer of metallic material 40 comprising a ground plane is deposited over the second ferrite film 38.

With the configuration shown, the transverse electric field 42 is that shown between the strip line conductor and the ground plane 40. The magnetic field 44, on the other hand, again encircles the strip line conductor 36. However, by virtue of the fact that the magnetic field will not pass through the metallic ground plane 40, it is confined entirely within the ferrite film 38 where an external direct current magnetic field H_{dc}, for example, can effect a phase shift in wave energy traveling along the transmission line. This enables the device to become shorter for a given phase shift and reduces insertion losses.

As was mentioned above, the ferrite materials must be deposited in thin films at extremely high temperatures. In the case of magnesium-manganese ferrites, for example, the reaction temperature is 1400° C. Metals such as copper cannot be used for the microstrip line 36 since they melt at a temperature below 1400° C. Furthermore, the metal must be nonoxidizable or must form a protective oxide coating which will ad-

here to the base metal. In the case of magnesium-manganese ferrites, platinum is the desired material since it melts at a temperature above 1400° C. and will not form an oxide coating. On the other hand, when nickel ferrites are employed, the conductor **36** can be formed from gold which melts at a temperature above 600° F., the reaction temperature for nickel ferrites, and which also does not form an oxide coating. In still other cases, rhodium can be used for the line **36**, this metal having a melting point in excess of 1900° C. The ground plane **40** can be formed from any suitable material such as gold or aluminum after the second ferrite film **38** is deposited.

The manner in which the assembly of FIG. **2** is formed is shown in FIG. **3**. The ferrite material **46**, in the form of a powder, is placed in a container **48** resting on a block **47**. In the case of magnesium-manganese ferrites, the block **47** is heated by suitable means, not shown, to a temperature of about 1550° C. A stream of hydrogen chloride gas is caused to flow through a tube **50** surrounding the block **47** and container **48** such that it will pass over the ferrite powder **46**. In so doing, a mixture of magnesium, manganese and iron chlorides are formed which pass upwardly and onto the surface of the ceramic substrate **32** shown in FIG. **2**, for example. The substrate, in turn, is on the underside of a block **54** maintained at a temperature lower than that of the block **47**, or about 1400° C. Consequently, the chlorides, as they diffuse upwardly, reach a cooler region where the vapors become supersaturated and deposit the ferrite material on the substrate or platinum mounted on block **54**. In the case of nickel ferrites and gold conductors, the temperatures employed will be lower, however the process is essentially the same. Other ferrites which can be used are zinc-doped magnesium-manganese ferrites and the lithium ferrites.

Although the invention has been shown in connection with a certain specific embodiment, it will be readily apparent to those skilled in the art that various changes in form and arrangement of parts may be made to suit requirements without departing from the spirit and scope of the invention.

We claim:

1. A planar circuit electromagnetic ferrite device for electromagnetic wave transmission systems, comprising a first ferrite film deposited on a substrate, an electrically conducting strip disposed on said first ferrite film on the side thereof opposite said substrate, a second ferrite film deposited over said conducting strip and covering said first film on either side of said substrate to form a complete ferrite magnetic circuit around said conducting strip, and a layer of metallic material covering said second ferrite film and forming a ground plane whereby radio frequency magnetic lines of flux surrounding said conducting strip in the quasi-TEM mode of wave propagation will be confined in said second ferrite film between said conducting strip and said ground plane.

2. The planar circuit of claim **1** wherein said first and second ferrite films are formed from a magnesium-manganese ferrite and wherein said conducting strip is formed from platinum.

3. The planar circuit of claim **1** wherein the said ferrite films are formed from nickel ferrites and wherein said conducting strip is formed from gold.

4. The planar circuit of claim **1** wherein said conducting strip is formed from metal selected from the group consisting of gold, platinum and rhodium.

5. The planar circuit of claim **1** wherein said first and second ferrite films are formed from a material selected from the group consisting of magnesium-manganese ferrite, nickel ferrite, zinc-doped magnesium-manganese ferrite and lithium ferrites.