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[56]

References Cited

UNITED STATES PATENTS

3,339,158	8/1967	Passaro	333/1.1
3,448,409	6/1969	Moose et al.	333/84
3,448,410	6/1969	Parks	333/24.1

OTHER REFERENCES

Jones & Whicker, "Now-Ferrite Microstrip Devices,"
 microwaves Jan. 1969, pp. 32-40, 333-24.1

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[54] **MAGNETICALLY VARIABLE MICROSTRIP
 DIRECTIONAL COUPLER DEPOSITED ON
 FERRITE SUBSTRATE**
 1 Claim, 6 Drawing Figs.

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 333/10
 [51] Int. Cl. H01p 1/32,
 H01p 5/14
 [50] Field of Search 333/1.1, 10,
 24.1, 24.2, 84 M

ABSTRACT: Described is a novel variable coupling,
 directional coupler employing parallel microstrip transmission
 lines deposited on a substrate of ferrite material. Variable
 coupling is achieved by varying a magnetic field applied to the
 ferrite material normal to the direction of wave propagation
 along the microstrip transmission lines.

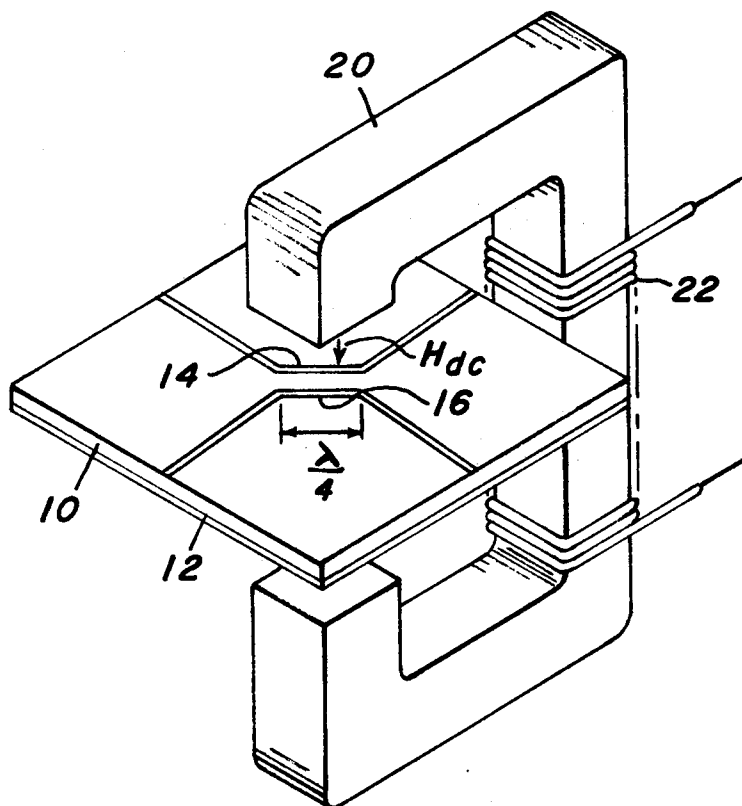


FIG. 1.

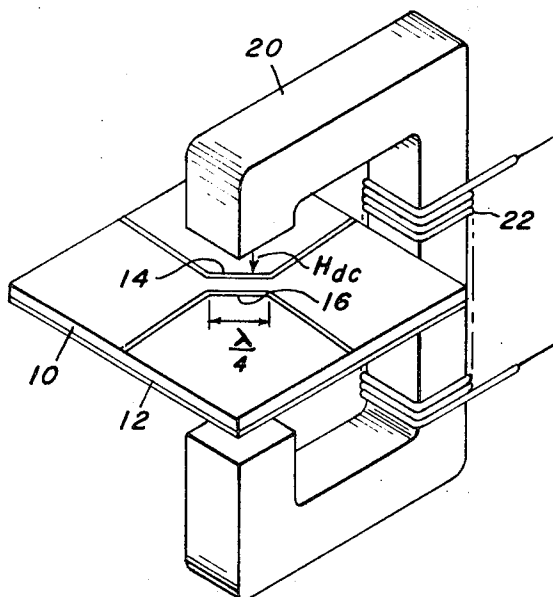


FIG. 2.

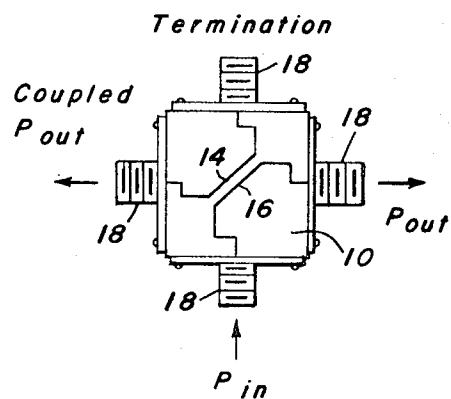


FIG. 3.

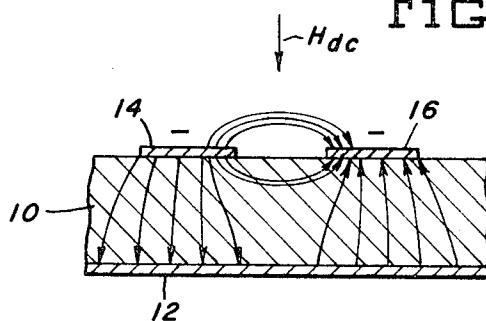
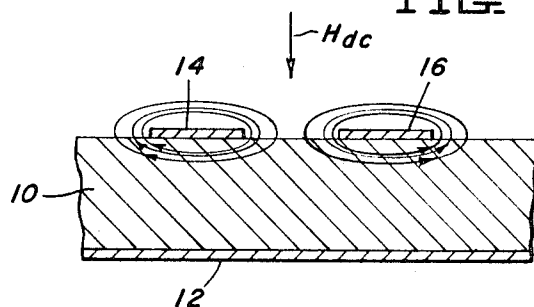


FIG. 4.



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FIG. 5.

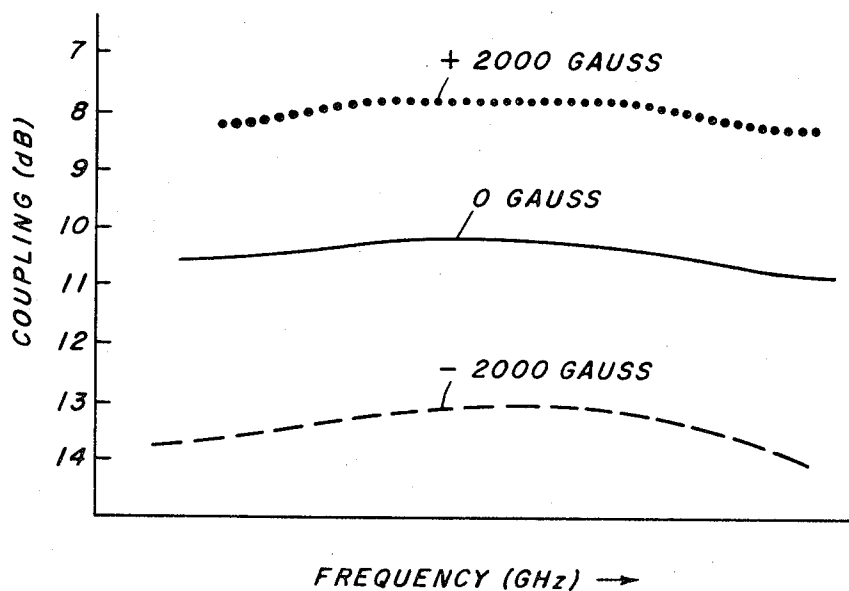
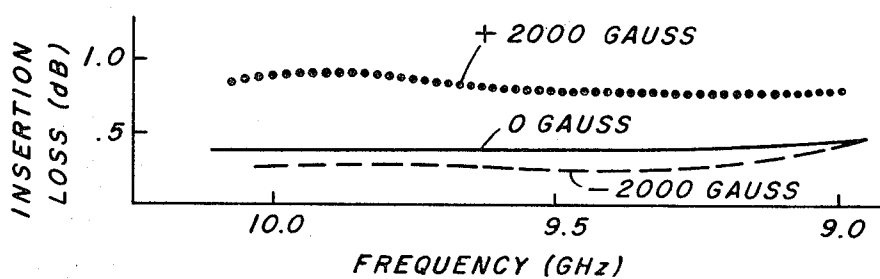


FIG. 6.



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MAGNETICALLY VARIABLE MICROSTRIP DIRECTIONAL COUPLER DEPOSITED ON FERRITE SUBSTRATE

CROSS-REFERENCES TO RELATED APPLICATIONS

U.S. application, Ser. No. 809,669, filed Mar. 24, 1969, by Herbert W. Cooper and Robert Q. Maclay, entitled "Variable Coupling, Microstrip Parallel-Line Directional Coupler," and assigned to the assignee of the present application

BACKGROUND OF THE INVENTION

With the availability of microwave transistors and other semiconductor devices usable at microwave frequencies, the microstrip transmission line has found wide application because of its compatibility with the fabrication and installation of passive components and active devices on the same substrate with the transmission line. Essentially, a microstrip transmission line consists of a strip of conductive material, corresponding to the center conductor of a coaxial transmission line, deposited on one side of a dielectric or semiconductive substrate by photoresist techniques. The opposite side of the substrate is covered with a layer of conductive material comprising a ground plane and corresponding to the outer cylindrical conductor of a coaxial transmission line. With this configuration, and assuming that a source of wave energy is applied across the strip and ground plane on opposite sides of the substrate, and electric field is established between the two.

While parallel-line couplers utilizing microstrip circuitry have been devised in the past, most of these are limited in the degree of electromagnetic energy coupling obtainable. That is, most prior art couplers of this type require that any improvement in the degree of coupling between the branch lines be obtained by decreasing the perpendicular distance between the two microstrips, or require dielectric overlays to increase the coupling. Spacings on the order of about 0.0001 inch are required for a 3 db. coupling coefficient. As will be appreciated, this is very difficult to accomplish repeatedly with present photoresist techniques.

In the copending application, Ser. No. 809,669, a microstrip parallel-line coupler is described which eliminates the necessity for extremely close spacing between microstrip transmission lines by insertion of a PN junction in a semiconductive substrate between the two. By applying a bias across the PN junction and by varying that bias (forward up to the contact potential and reverse to breakdown), the depletion-layer capacitance of the junction can be varied as well as the total coupling capacitance between the parallel microstrip transmission lines.

While microstrip parallel-line directional couplers utilizing a PN junction between the two to obtain a variable coupling effect are very satisfactory for their intended purpose, they do have high insertion losses. These are believed to be due primarily to a lowering of the semiconductive substrate resistivity during processing to obtain the PN junction.

SUMMARY OF THE INVENTION

As an overall object, the present invention seeks to provide a microstrip parallel-line coupler in which the coupling effect can be varied by means of an applied magnetic field, and wherein the coupler is capable of achieving a high degree of coupling between the branch lines without resorting to extreme close spacing between branch lines.

Another object of the invention is to provide a microstrip parallel-line coupler wherein the coupling coefficient between branch lines can be varied, within limits, without changing the geometry of the microstrip branch lines.

Still another object of the invention is to provide a variable coupling microstrip parallel-line coupler formed on a ferrite substrate on which other circuit elements such as circulators and isolators can be formed.

In accordance with the invention, microstrip transmission lines are deposited, by photoresist etching techniques, in parallel side-by-side relationship on a ferrite substrate. The microstrip transmission lines extend parallel to each other through a distance equal to a quarter wavelength of the wave energy to be coupled. By applying a magnetic field across the ferrite in the region of the coupler and normal to the direction of wave propagation through the coupler, the effective permeability of the ferrite can be made to vary with variations in applied field. This change in permeability, in turn, is used to change the propagation constant and even mode impedance of the transmission lines deposited on the ferrite, thereby resulting in a variation in the coupling coefficient of the coupler.

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:

FIG. 1 is a perspective view of the magnetically variable parallel-line directional coupler of the invention;

FIG. 2 is a top view of the appearance of the microstrip parallel-line directional coupler of the invention showing the manner in which it can be connected to coaxial transmission lines;

FIG. 3 is a cross-sectional view taken through the coupler of FIG. 1 showing the manner in which wave energy is coupled from one parallel microstrip transmission line of the coupler to the other;

FIG. 4 illustrates the magnetic fields associated with the electric fields of FIG. 3;

FIG. 5 is a plot of coupling versus frequency for a parallel directional coupler fabricated in accordance with the teachings of the invention; and

FIG. 6 is a plot of insertion loss versus frequency for a coupler fabricated in accordance with the teachings of the invention.

With reference now to the drawings, and particularly to FIGS. 1, 3, and 4, the microstrip parallel-line directional coupler of the invention comprises a wafer 10 of ferrite material having its lower surface covered with a layer of metal 12 comprising a ground plane. The layer 12 may typically comprise gold; and the ferrite substrate typically consists of one of a number of different compounds, such as iron, zinc, manganese, magnesium, cobalt, aluminum and nickel-oxides. The ferrites are usually manufactured by pressing into shape the required mixture of finely divided metallic oxide powders and then firing the shaped mixture at an elevated temperature. The product is a ceramic with a high electrical resistance.

Deposited on the surface of the ferrite wafer 10, by conventional photoresist etching techniques, are parallel strip conductors 14 and 16 which may, for example, have a width of about 0.010 inch and a length equal to a quarter wavelength of the wave energy which is to be coupled. Opposite ends of the two parallel strips 14 and 16 may be connected as shown in FIG. 2 to the center conductors of couplers 18 adapted for connection to coaxial wave transmission lines. The outer cylindrical conductors of the transmission lines are threaded onto the couplers 18 and are connected to the lower gold layer 12 comprising a ground plane. As a specific example, the wafer 10 may be 1 inch square and have a thickness of about 0.025 inch.

On opposite sides of the wafer 10, in the region of the two parallel microstrip transmission lines 14 and 16 forming the coupler, are opposite ends of a C-core 20 shown in FIG. 1 and provided with an encircling coil 22 adapted for connection to a variable source of a direct current, not shown. This source of direct current can, therefore, produce a varying direct current field, H_{dc} , which passes through the area of the parallel-line directional coupler comprising transmission lines 14 and 16 in a direction normal to the direction of wave propagation through the coupler.

The electric field lines of the wave energy passing through the coupler are shown in FIG. 3. It can be seen that most of the

field lines pass between ground plane 12 and an associated one of the parallel microstrip transmission lines 14 and 16. However, assuming that wave energy is coupled into one end of the strip 16, for example, a portion of that wave energy will be coupled over to the other transmission line 14.

In FIG. 2, it can be seen that wave energy coupled into one end of the strip 16 will be divided between the right and left ports 18, the upper port 18 comprising a termination for one end of the strip 14. Magnetic fields produced by the wave energy circulate around the strips 14 and 16 as shown in FIG. 4 and are, for the most part, perpendicular to the applied magnetic field, H_{dc} . The wave energy, therefore, travels in a quasi-TEM mode wherein both the electric and magnetic vectors are perpendicular to the direction of wave propagation. The voltage coupling coefficient, K , of the coupler is equal to:

$$K = \frac{Z_{oe} - Z_{oo}}{Z_{oe} + Z_{oo}}$$

where:

Z_{oe} equals the even mode impedance of the coupled lines; and

Z_{oo} equals the odd mode impedance of the coupled line. It will be noted from FIG. 4 that the applied magnetic field, H_{dc} , will interact with the horizontal component of the radio frequency magnetic fields surrounding the microstrip transmission lines 14 and 16. This interaction produces a change in the effective permeability of the ferrite substrate 10 which, in turn, varies the quantities Z_{oe} , Z_{oo} , and K , the coupling coefficient, in the foregoing equation.

FIGS. 5 and 6 are plots of coupling in db. versus frequency and insertion loss in db. versus frequency for a coupler fabricated in accordance with the teachings of the invention. The coupler was fabricated on a 0.025 inch thick ferrite substrate and designed for a nominal coupling of 10 db. with no applied field at the center frequency of about 9.5 gigahertz. The upper dotted lines in FIGS. 5 and 6 illustrate the coupling

and insertion loss, respectively, for an applied magnetic field of +2 kilogausses. The center, solid lines illustrate the coupling and insertion loss, respectively with no applied external magnetic field H_{dc} ; and the lower broken lines illustrate the coupling and insertion loss, respectively, with the magnetic field reversed and at an intensity of -2 kilogausses. It can be seen from FIGS. 5 and 6 that the coupling and insertion losses remain essentially constant over the frequency range of 9 to 10 gigahertz. Furthermore, as the magnetic field is decreased from its positive maximum through zero and the increased in the negative direction, the coupling increases while the insertion loss decreases.

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 as our invention:

1. A parallel-line directional coupler comprising a substrate of ferrite material having deposited on one surface thereof parallel microstrip transmission lines, the microstrip transmission lines extending parallel to each other for a distance equal to a quarter wavelength of the energy to be coupled, conductive material deposited on the other side of the substrate and forming a ground plane, means for applying a magnetic field across said ferrite material in a direction normal to the direction of the wave propagation through said microstrip transmission lines and through said ferrite substrate in the area of said parallel microstrip transmission lines whereby the effective permeability of the ferrite material is determined by the magnetic field as well as the degree of coupling between the parallel transmission lines, and means for varying said magnetic field to vary the coupling coefficient between the parallel microstrip transmission lines.

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