

Sept. 16, 1969

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3,467,918

MICROSTRIP JUNCTION CIRCULATOR WHEREIN THE FERRITE BODY
IS DISPOSED ON THE DIELECTRIC SLAB

Filed Dec. 21, 1967

3 Sheets-Sheet 1

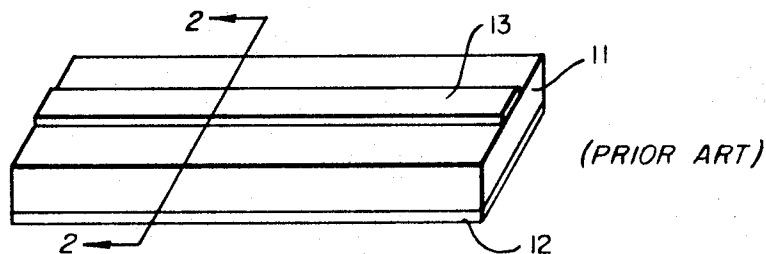


FIG. 1

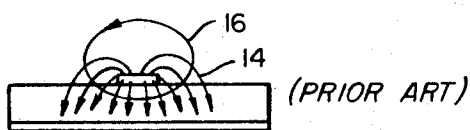


FIG. 2

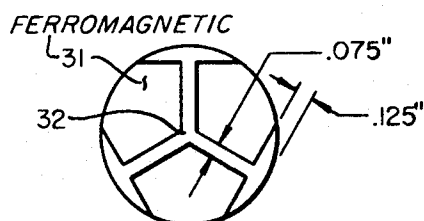


FIG. 5

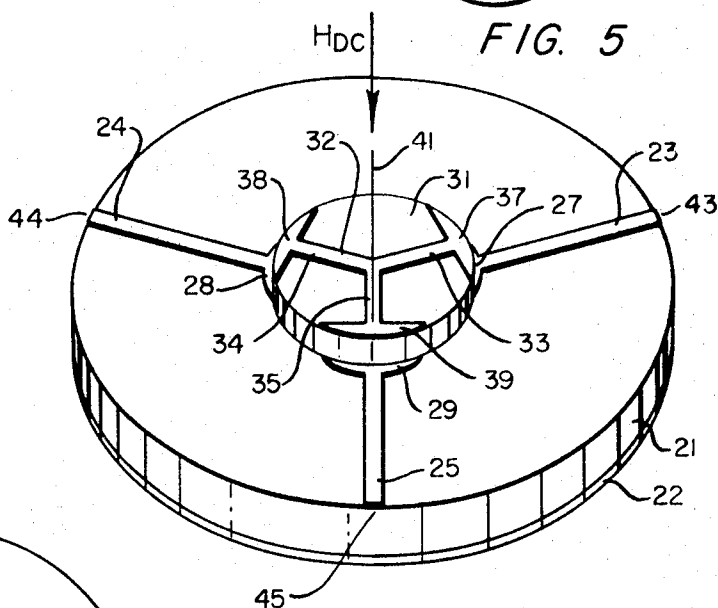


FIG. 3

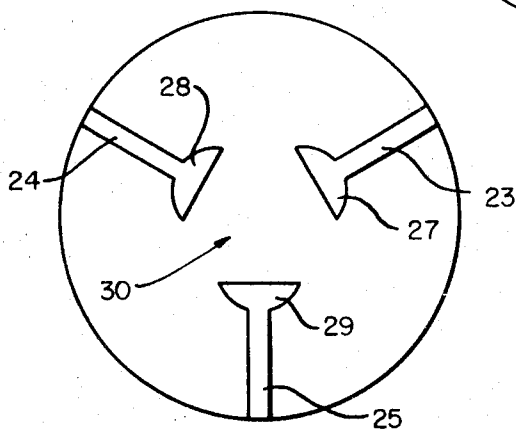


FIG. 4

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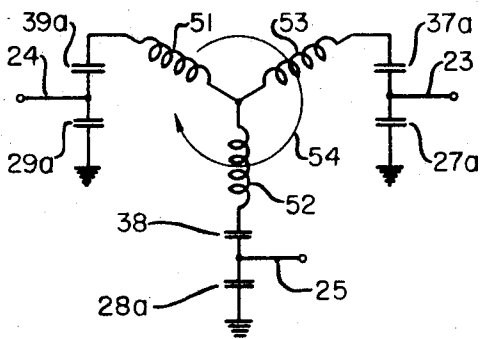


FIG. 7

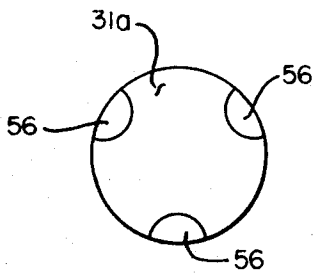


FIG. 9

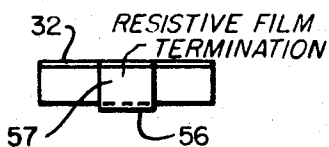


FIG. 10

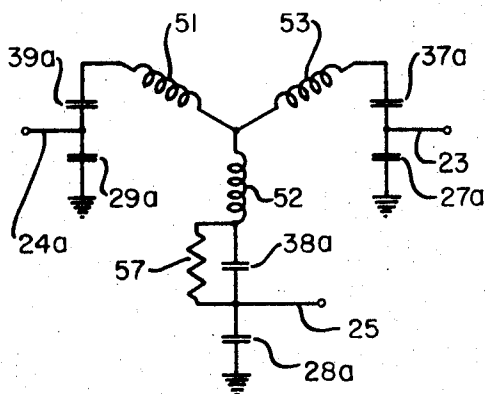


FIG. 12

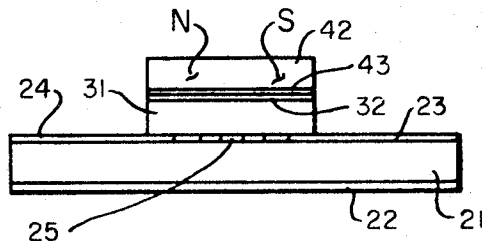


FIG. 6

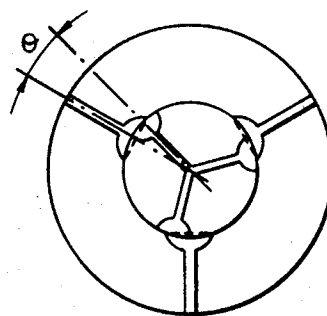


FIG. 8

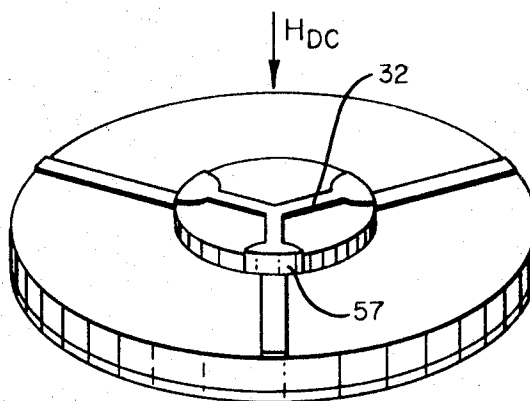


FIG. 11

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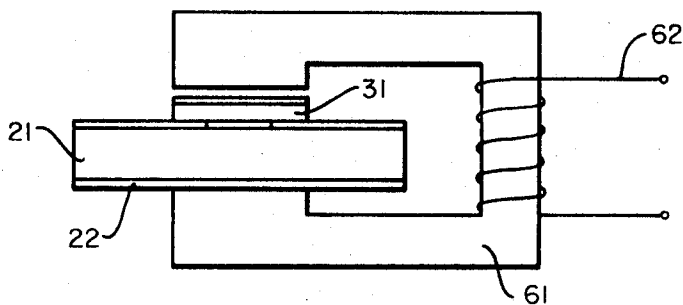


FIG. 13

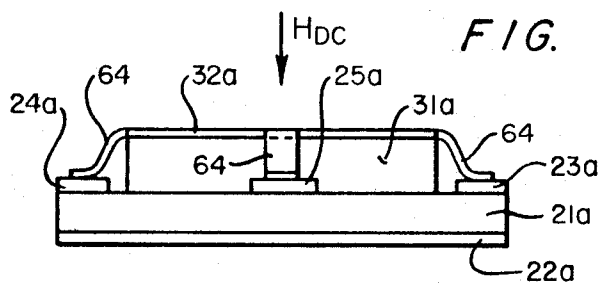


FIG. 14

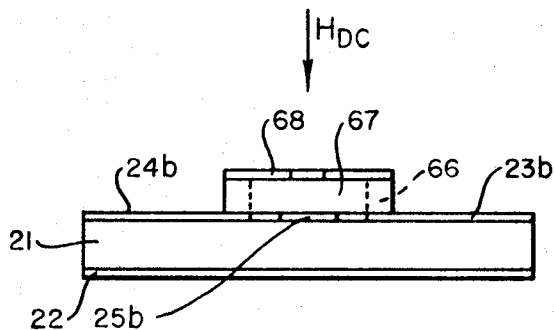


FIG. 15

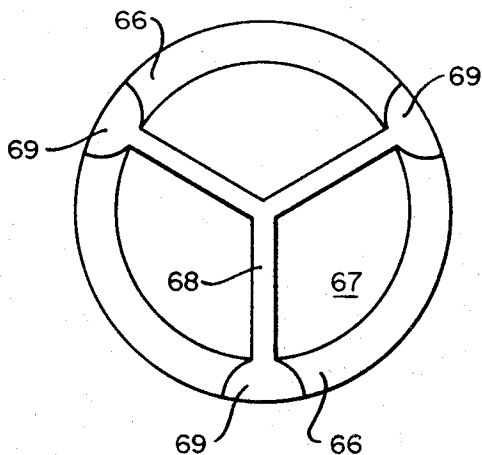


FIG. 16

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MICROSTRIP JUNCTION CIRCULATOR WHERE- IN THE FERRITE BODY IS DISPOSED ON THE DIELECTRIC SLAB

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Int. Cl. H01p 1/32

U.S. Cl. 333—1.1

7 Claims

ABSTRACT OF THE DISCLOSURE

A circulator for use with microstrip transmission lines in which ferromagnetic material is disposed above and coupled to microstrip transmission lines and a D-C magnetic field is applied in a direction which is perpendicular thereto.

BACKGROUND OF THE INVENTION

This invention relates generally to a circulator and more particularly to a circulator employing microstrip transmission lines.

A microstrip transmission line generally comprises a ground plane and a conductor (usually rectangular in cross-section) mounted in spaced relationship with respect thereto. Usually, the conductor is carried on a dielectric slab which is carried on the ground plane and which serves to maintain the spacing. The dimensions of the conductor are selected to give desired impedance characteristics to the transmission line. The dielectric used may be any one of a number of dielectric materials known in the art, such as beryllia, polystyrene or alumina.

This type of transmission line permits making intricate microwave circuits by conventional masking and etching techniques.

In microstrip circulators of the prior art a hole is drilled in the dielectric slab and ferromagnetic material placed in the hole. The conductors are then formed over the ferrite and dielectric material to form a circulator junction. The ends of the conductors are adapted to be connected to associated transmission lines.

Disadvantages of this type of circulator are that the dielectric is difficult and expensive to machine, the device is large, and because of the different dielectric constants involved, impedance matching is poor.

SUMMARY OF THE INVENTION AND OBJECTS

The present invention provides a microstrip circulator in which the ferromagnetic material carries a conducting circuit on one surface thereof and is placed with its other surface on a microstrip transmission line having conductors extending towards a common region. Means are provided to couple the ferromagnetic circuit to the transmission line conductors. A perpendicular D-C magnetic field is applied across the device.

It is an object of this invention to provide a simple, inexpensive and easily manufactured microstrip circulator.

It is another object of the present invention to provide a microstrip circulator which can be easily tuned to provide optimum operation at desired center frequencies.

It is another object of the present invention to pro-

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vide a circulator for microstrip geometry that does not require drilling a hole in the dielectric.

These and other objects of the invention will become more apparent in connection with the following description and drawings.

Brief description of the drawing

FIGURE 1 is a perspective view of a prior art microstrip transmission line.

FIGURE 2 is a sectional view taken along line 2—2 of FIGURE 1.

FIGURE 3 is a perspective view of a microstrip circulator in accordance with the present invention.

FIGURE 4 is a plan view of the microstrip portion of the circulator of FIGURE 3.

FIGURE 5 is a plan view of the ferromagnetic portion of the circulator of FIGURE 3.

FIGURE 6 is a side elevational view of the circulator shown in FIGURE 3 together with a magnet for providing the D-C magnetic biasing field.

FIGURE 7 is the equivalent circuit of the circulator shown in FIGURES 3—6.

FIGURE 8 is a plan view of a circulator showing one means for tuning.

FIGURES 9 and 10 are side elevational and plan views of another ferromagnetic assembly for use in the invention.

FIGURE 11 is a perspective view of a circulator incorporating a ferromagnetic assembly of the type shown in FIGURES 9 and 10.

FIGURE 12 is the equivalent circuit for the circulator of FIGURE 11.

FIGURE 13 shows a circulator having the D-C magnetic field provided by an electromagnet.

FIGURE 14 shows another circulator in accordance with the invention.

FIGURES 15 and 16 show a circulator including means for improving the capacitive coupling between the ferromagnetic circuit and the microstrip transmission lines.

Description of the preferred embodiments

A typical microstrip transmission line geometry is illustrated in FIGURES 1 and 2. The microstrip transmission line comprises a slab or wafer of dielectric material 11 such as polystyrene, beryllia or alumina. This dielectric slab is plated or coated on one side with a metal film 12 which forms the ground plane for the transmission line. One or more conductors are carried by the other surface of the slab. One conductor 13 is shown. The dimensions of the conductor 13 determine the characteristic impedance of the transmission line formed by the conductor, dielectric slab and ground plane.

FIGURE 2 shows the electric and magnetic fields 14 and 16, respectively, associated with a microwave signal propagating on the microstrip transmission line. It is noted that the higher the dielectric constant of the dielectric material, the greater is the concentration of energy in the dielectric material.

In general, microstrip transmission lines may be formed by coating or plating both surfaces of a slab or wafer 11 with metallic material such as copper, silver or gold. One surface is then masked, such as by silk screen or photographic techniques, and subsequently etched to remove the unprotected metal and leave the desired conductive pattern on the surface. By this means, relatively complex microwave circuits can be formed. Techniques

of this type are well known in the electronic art, particularly in the printed circuit, microcircuit and integrated circuit art.

A circulator in accordance with the present invention is illustrated in FIGURES 3-6. The circulator comprises a slab of dielectric material 21 including a ground plane 22. Three transmission lines are defined by the converging conductors 23, 24 and 25 carried on the other surface of the slab 21. Each of the transmission lines defined by the conductors 23-25, dielectric 21 and ground plane 22 ends in an open circuit in the region 30. This is more clearly illustrated in FIGURE 4. The ends of the conductors 23, 24 and 25 may be enlarged as shown at 27, 28 and 29, respectively. This increases the capacitance between the conductors and the ground plane. The conductors and enlarged areas may be formed by masking and etching as described above.

A disc 31 of ferromagnetic material, such as ferrite or yttrium-iron-garnet, is disposed over the region 30 above each of the enlarged areas 27, 28 and 29. The top surface of the ferromagnetic material carries a conductive circuit 32. In this particular instance, the circuit includes arms 33, 34 and 35 which join at the center of the disc 31 and extend radially outwardly to the edge. Enlarged areas 37, 38 and 39 are formed at the ends of the arms 33, 34 and 35, respectively. The areas 37, 38 and 39 capacitively couple to the enlarged areas 27, 28 and 29, whereby the ferrite circuit 32 is electrically coupled to the conductors 23, 24 and 25. The circuit 32 is coupled to the ground side of the transmission line 22 through the ferromagnetic material 31 and dielectric material 21 to form transmission lines. The dimensions of the conductive pattern 32 formed on the surface of the ferromagnetic material can be selected whereby there is an impedance match between the transmission line circuit including conductor 32 and the converging transmission lines including conductors 23, 24 and 25.

A D-C magnetic field 41 is applied perpendicular to the plane of the ferromagnetic disc. This can be applied by a permanent magnet or by an electromagnet. Referring particularly to FIGURE 6, there is shown a permanent magnet 42 disposed on the ferromagnetic disc and having north and south poles as indicated. An insulating dielectric 43 is sandwiched between the magnet and ferrite disc so that the circuit 32 is not electrically shorted.

The circulator provides a circulator action in accordance with well known theory. Referring particularly to FIGURE 3 and with the magnetic field indicated: energy indicated at port 43 will emerge from port 44; energy incident at port 44 will emerge from port 45; and energy incident at port 45 will emerge from port 43. As previously described, the impedance and capacitance of the various areas are selected to give the desired frequency response and circulator characteristics.

An equivalent circuit for the circulator illustrated in FIGURES 3-6 is shown in FIGURE 7. The ferrite material is regarded as a non-reciprocal inductance and is illustrated by the inductors 51, 52 and 53, and arrow 54. The capacitance formed between the pads or enlarged areas 27, 28 and 29 and ground is indicated by the capacitors 27a, 28a and 29a. The coupling capacitance between the transmission line portions 27, 28 and 29 and the enlarged portions 37, 38 and 39 of the ferrite circuit 32 is indicated by the capacitors 37a, 38a and 39a. Explanation of the operation of circulators of this type is described fully in U.S. Patent No. 3,286,201.

A microstrip circulator in accordance with the foregoing was constructed to operate at 1900 mHz. The ferromagnetic material was ferrite comprising aluminum doped yttrium-iron garnet with a saturation magnetization of 300 gauss having a diameter of .80 inch and thickness of .10 inch. The dimensions of the circuit 32 are shown in FIGURE 5. The microstrip transmission line was constructed of alumina dielectric .060 inch thick with the width of the transmission lines 23, 24 and 25 being .070 inch. In operation, the circulator had a

bandwidth of 50 mHz. with a center frequency of 1900 mHz. The insertion loss was 1.6 db and isolation between ports was 20 db.

In certain instances it may be desirable to adjust the capacitances 37a, 38a, 39a to tune the circulator. This may be achieved by rotating the ferrite disc through an angle θ as shown in FIGURE 8. Thus, the enlarged areas 27, 28 and 29 and 37, 38 and 39 are displaced with respect to one another to thereby decrease the coupling capacity.

In FIGURES 9, 10 and 11, there is shown a terminated circulator or isolator which includes a shunting resistance in parallel with one of the coupling capacitors between the ferrite transmission line and the microstrip transmission line. FIGURE 9 shows a view of the bottom of ferrite disc 31a. A conductive pad or area 56 is formed at one port. A resistive film 57 is formed on the edge of the disc, FIGURE 10, and resistively connects the area 56 with the arms of circuit 32. FIGURE 11 is a perspective view showing an assembled circulator.

FIGURE 12 is the equivalent circuit for the circulator shown in FIGURE 11. It is observed that the equivalent circuit is identical to that shown in FIGURE 7 with the exception that resistor 57 is in shunt with the coupling capacitor 38a.

In FIGURE 13, there is shown a circulator in which the field is applied by an electromagnet 61 including coil 62. The circulator may be switched responsive to a change in current. Alternately, the coil material may be chosen to have a high remanent field and in this case the circulator may be made to switch with latching action by application of a current pulse.

FIGURE 14 shows a circulator including a slab 21a, ground plane 22a and a ferromagnetic disc 31a having circuit 32a over the converging conductors 23a, 24a and 25a. The area between the ends of conductors 23a, 24a, 25a is larger than the ferromagnetic material 31 whereby when the ferrite is placed on the dielectric slab 21a, it rests directly on the slab. Electrical connection is made between the circuit 32a and the conductors 23a, 24a and 25a by means of tabs 64 by soldering, welding or otherwise attaching.

FIGURES 15 and 16 illustrate a means for achieving better capacitive coupling between the ferrite circuit and the microstrip transmission line circuit. In this instance, a dielectric ring 66 is formed about the ferrite disc 67. The conductive pattern 68 is then formed on the top surface in the manner previously described. The coupling between the circuit 68 and conductors 23b, 24b and 25b is through the higher dielectric ring and capacitive coupling can be controlled by proper choice of dielectric constant of the ring.

Although the invention has been described and illustrated with reference to specific embodiments, other embodiments will be apparent to persons skilled in the art. The invention is, therefore, only to be limited by the scope of the following claims.

We claim:

1. A circulator comprising at least three transmission lines converging towards a common region, said transmission lines including a common ground plane and at least three conductors, a slab of dielectric material carried on one surface of said ground plane and said at least three conductors carried on the opposite surface of said slab and having ends converging towards said region with the ends spaced from one another, a ferrite body disposed with one surface on said opposite surface of said slab at said region, a conductive pattern carried on the opposite surface of said ferrite body, means for coupling said conductive pattern on the ferrite body to the ends of said conductors, and means for applying a D-C magnetic field substantially perpendicular to said ferrite material.

2. A circulator as in claim 1 wherein said coupling means comprises enlarged portions formed at the ends

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of said conductors and enlarged portions formed on the conductive pattern, said portions being disposed opposite one another.

3. A circulator as in claim 2 wherein said ferrite body may be rotated to adjust the coupling between said enlarged portions.

4. A circulator as in claim 2 wherein said ferrite body includes a ring having a different dielectric constant in the regions of said enlarged portions to thereby increase or decrease the capacitive coupling between the ends of the conductors and the conductive pattern.

5. A circulator as in claim 1 terminated at one point by a resistive film connected between the end of each of the conductors and the conductive pattern.

6. A circulator as in claim 1 wherein the ends of the

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6

conductors and the conductive pattern are conductively connected to one another.

7. A circulator as in claim 1 wherein said means for applying a D-C magnetic field includes an electromagnet.

References Cited

Hershenov: X-Band Microstrip Circulator, Proc. of the IEEE, December 1966, pp. 2022, 2023 cited.

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U.S. Cl. X.R.

333—24.2