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Tresselt

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[54] **DEPRESSED-PUCK MICROSTRIP CIRCULATOR**

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[52] **U.S. Cl.** .... **333/1.1**, 333/84 M
[51] **Int. Cl.** **H01p 1/32**
[58] **Field of Search**..................... 333/1.1, 24.1, 24.2

[56] **References Cited**

UNITED STATES PATENTS

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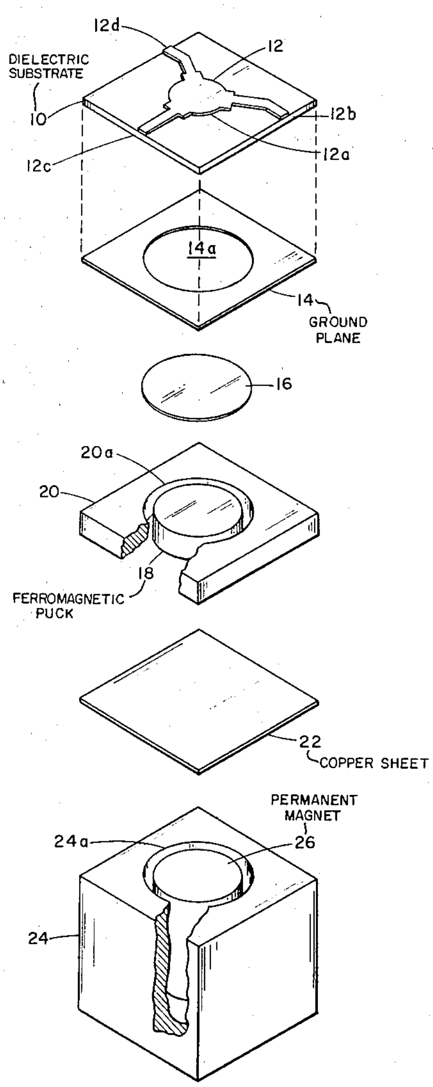
[57] **ABSTRACT**

A microstrip circulator has a ferromagnetic puck located beneath the microstrip substrate, in a cavity in a ground plane and includes a d.c. magnetic field applied in a direction which is perpendicular to the puck.

11 Claims, 4 Drawing Figures



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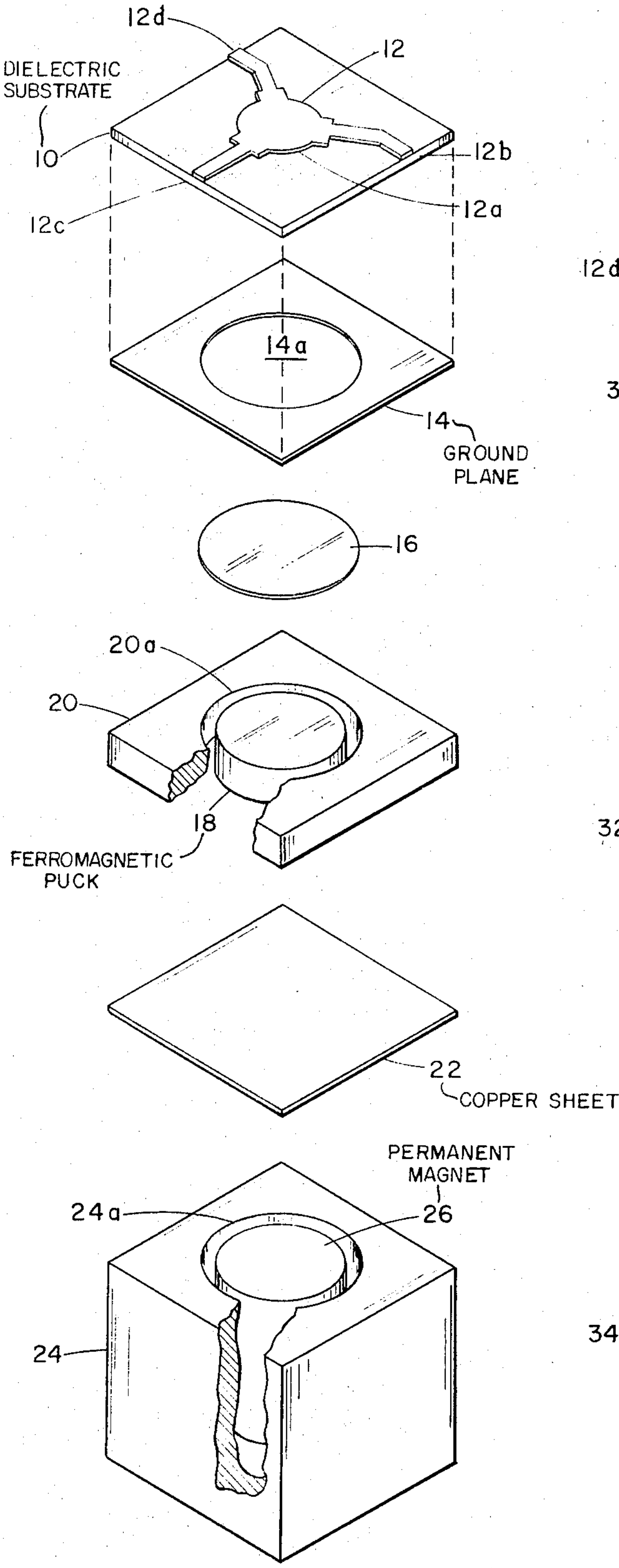

FIG. 1

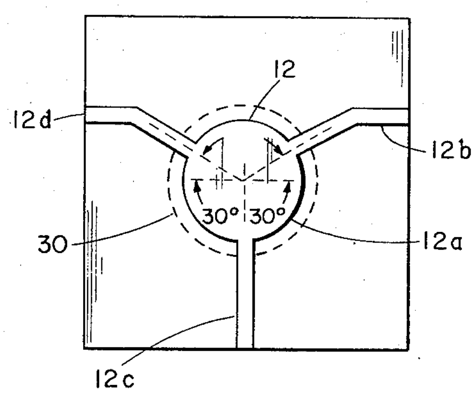

FIG. 2

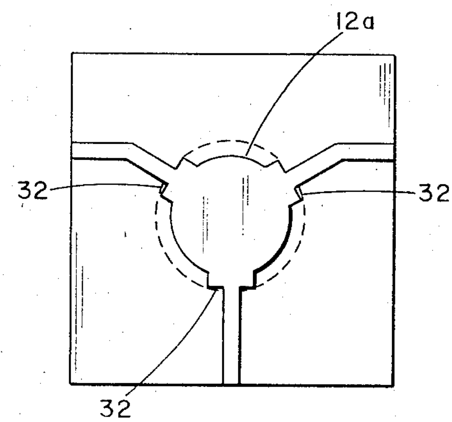

FIG. 3

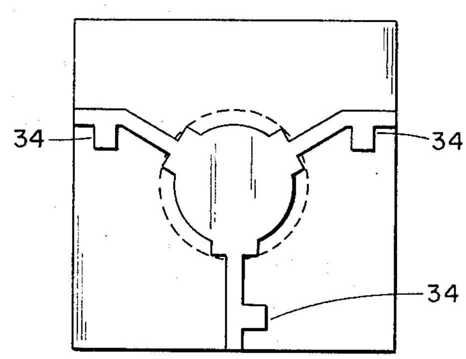

FIG. 4

DEPRESSED-PUCK MICROSTRIP CIRCULATOR

BACKGROUND OF THE INVENTION

This invention relates to circulators built in accordance with microstrip transmission line techniques.

A microstrip transmission line generally comprises a ground plane and a conductor 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 between the conductor and the ground plane. 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 sapphire, beryllia, polystyrene or alumina. This type of transmission line permits making intricate microwave circuits by conventional masking and etching techniques.

In circulators of the prior art built in accordance with microstrip transmission line techniques a disc-shaped piece of ferromagnetic material, normally termed a puck, is placed in a hole drilled through the dielectric slab. A conductive pattern is disposed over the ferromagnetic material and the dielectric material to form a circulator junction. The ends of the conductors are adapted to be connected to associated further transmission lines. The disadvantage of this type of circulator is that the dielectric is difficult and expensive to machine, generally requiring precision diamond drilling or grinding in the harder alumina or sapphire substrates. In addition, the conductive junction must be bonded in a separate operation to the connecting transmission lines.

A technique for eliminating the hole in the microstrip substrate involves placing the ferrite puck on the top surface of the microstrip. A special semi-lumped capacitor/inductor pattern is photo etched on the ferrite disc to provide coupling to the conductors on the substrate proper. A circulator of this type is described in U.S. Pat. No. 3,467,918. It should be recognized, however, that the top region above a high dielectric substrate is relatively low in field strength, with limited coupling ability. Thus, even with the conductor pattern used and described in the aforementioned patent, the activity level is low, leading to rather narrow band performance.

SUMMARY OF THE INVENTION

There will be described herein a microstrip circulator in which the circulator conducting circuit is disposed on one surface of the microstrip substrate and a ground plane is disposed on the opposite surface thereof. A ferromagnetic puck is located in a recess in the ground plane, generally underlying the circulator circuit. A perpendicular d.c. magnetic field is applied across the ferromagnetic puck to complete the essential elements of the invention. Means are shown in the conducting circuit for tuning the circulator to provide operation at desired frequencies.

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

It is another object of this invention to provide a microstrip circulator which includes tuning means to provide optimum operation at desired center frequencies.

It is a further object of this invention to provide a circulator made in accordance with microstrip transmission line techniques that does not require drilling a hole in the substrate, or metallizing the surface of the ferrite.

It is a still further object of this invention to provide a microstrip circulator which has a relatively wide bandwidth.

Another object of this invention is to provide a microstrip circulator which has relatively high power handling capability.

These and other objects of the invention will become apparent by an understanding of the following description of the preferred embodiment and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an exploded view of a depressed puck microstrip circulator which illustrates the principles of this invention.

FIGS. **2, 3** and **4** illustrate circulator circuit geometries used in a practical C-band depressed puck circulator wherein the geometry of FIG. **2** provides loosely coupled input lines, the geometry of FIG. **3** provides more tightly coupled input lines producing double tuned characteristics and wherein FIG. **4** is generally similar to FIG. **3** with tuning tabs for optimizing operation.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Refer first to FIG. **1** which shows an exploded view of one form of the depressed puck microstrip circulator. The substrate **10**, usually of a material such as alumina, sapphire, beryllia or polystyrene, has the conducting circuit **12** disposed on the top surface and a ground plane **14** disposed on its bottom surface. Unprocessed substrates are normally available with the top and bottom surfaces premetallized. Conducting circuit **12** and hole **14**a in ground plane **14** are almost invariably provided by photo etching the premetallized substrate. Conducting circuit **12** comprises the circulator conducting circuit and includes a central disc **12***a* and radiating transmission lines **12***b*, **12***c* and **12***d*.

A disc **16** of dielectric material such as mylar is sized so to fit within hole **14***a*. In an alternate embodiment disc **16** might represent a metallic disc or two discs, one dielectric and one metallic, overlying one another. Disc **16** might also represent an air gap between a ferromagnetic puck **18** and the bottom surface of substrate **10.** The circulator ferromagnetic puck **18**, suitably of ferrite or garnet material, is arranged to fit closely into hole **14***a* against disc **16** so as to generally underlie disc **12***a*. A metallic spacer **20**, suitably of aluminum, and having hole **20***a* which is slightly larger in diameter than the diameter of puck underlies and is in contact with ground plane **14** and has a thickness which is generally equal to the thickness of the puck. A thin copper sheet **22** in intimate contact with the bottom surface of spacer **20** forms the R.F. ground plane beneath the puck. Means are then provided to apply a d.c. magnetic field perpendicular to the plane of the ferromagnetic puck and generally coaxial therewith. The magnetic field can be applied by means such as a permanent magnet or an electromagnet. In this particular embodiment, a permanent magnet **26** underlying puck **18** provides the magnetic field. The magnet is positioned within spacer **24**, suitably a metallic spacer of aluminum having a hole **24***a* into which the magnet fits.

Substrate **10**, ground plane **14**, spacers **20** and **24** and sheet **22** are generally of like planar size and underlie one another to form a box-shaped structure. Means which should now be obvious to one skilled in the art are provided for holding the various elements together and in relatively intimate contact with one another.

It should be noted that ground plane **14**, spacer **20** and sheet **22** form a single electrical unit which comprises the ground plane for the circulator and into which the ferromagnetic puck is recessed. As an alternative embodiment, these three elements might be combined into a single element comprising the ground plane. In this case, of course, the substrate would not be premetallized on the bottom surface. Of course, an embodiment such as this might not be practical in certain applications since it is desirable that the ground plane be in very intimate contact with the substrate in a manner best accomplished by metallizing the substrate. As a second alternative embodiment, spacer **20**, sheet **22** and spacer **24** might be combined into a single machined unit having two recesses therein into which the ferromagnetic puck and the permanent magnet are disposed.

In this later embodiment, the single unit and recessed puck would be used with the ground plane **14**. This would be of particular value when the circulator is but one element of a much larger integrated circuit, using a common, large ground plane.

Dielectric disc **16** forms a portion of the R.F. matching means of the circulator and can be eliminated entirely in some versions of the invention. In other versions of the design, a metallic disc can be utilized to similar advantage, by itself, or in conjunction with a dielectric disc. Such a metal disc is usually smaller in diameter than a dielectric disc, and is etched out of the bottom metallization, leaving an annular gap in the metallization.

The hole or recess in the ground plane allows the E and H fields of the microstrip transmission system to flow down past the metal disc and through the dielectric disc, if either is present, and into the ferromagnetic puck which is recessed into the ground plane. The puck is suitably centrally located within the hole in the spacer and ground plane and surrounded by a narrow ring of air. A possible alternate embodiment includes a puck which is large enough in diameter to fill the central hole, or, as another embodiment, with the annular air space either partially or fully replaced by a solid dielectric such as a teflon ring.

It should also be noted that the depressed puck circulator as described herein permits reasonably thick ferromagnetic pucks to be used. A thicker puck, of course, permits the circulator to have greater power handling capabilities. In addition, separation of the conducting circuit from the ferromagnetic puck by the substrate provides even higher power handling characteristics in addition to providing manufacturing economies.

Refer now to FIG. **2** which shows one form of the conducting circuit which can be used with a microstrip circulator built in accordance with this invention. Dash line **30** indicates the outline of the ferromagnetic puck which underlies conducting circuit **12.** As before, the conducting circuit is comprised of a central disc **12***a* with radiating transmission lines **12***b*, **12***c* and **12***d*. In this figure there is a direct junction of the radiating transmission lines with the central disc **12***a* which results in loose coupling of the conducting circuit with the ferromagnetic puck and hence a moderately narrow bandwidth of the circulator. In FIG. **3**, reference to which should now be made, the transmission lines are connected through an enlarged portion or step **32** to central disc **12***a*. Step **32** extends approximately to a projection of the outer circumference of the ferromagnetic disc and results in closer coupling of the conducting circuit with the puck. This, of course, will result in a broader operating bandwidth of the circulator upon application of a higher d.c. magnetic field than that normally used in a circulator using a conducting circuit of FIG. **2.** The use of tabs along the radiating line such as tabs **34** in the conducting circuit of FIG. **4** can provide either a somewhat narrower bandwidth design capable of operating with a lower magnetic bias field or a broader band design with changes in some of the parameters of the design. Other tuning elements such as resonant stubs or even lumped elements could be employed for purposes of broad banding, and the use of such elements should be obvious to one skilled in this art.

A circulator was built in accordance with this invention for use around the 5.2 GHz region of the C-band. Specifically, the circulator covered the region from about 4.8 to 5.6 GHz with 20 db minimum isolation, which corresponds to a 15.4 percent bandwidth. An off-the-shelf alumina substrate was used which was 0.025 inch thick and was metallized with 0.15 to 0.20 mils of gold which adhered to the alumina by the action of an ultra thin coating of chromium. The top conducting circuit and the hole in the bottom conductor, that is, the hole in the ground plane, were produced by photo etching. Prior to photo etching, the top and bottom surfaces, photo resisted, are exposed simultaneously, using a flap of two negatives for the exposure. This is a standard photo resist exposure process which produces good registry between top and bottom patterns are low cost. Two separate etchings are required to remove the gold and chromium layers from the substrate.

The conducting circuit illustrated in FIG. **3** was used with the basic disc **12***a* being 0.410 inch in diameter. The transmission lines were 0.025 inch wide and steps **32** were 0.165 inch wide, centered on such transmission line, by 0.030 inch extending beyond the edge of disc **12***a*. The hole etched in the bottom ground plane was 0.500 inch in diameter. Pucks having a diameter of 0.470 inch, thickness from 0.05 to 0.10 inch, and nominal saturation magnetization $4\Pi M_s$ in the range 1200 to 1400 gauss were found to operate satisfactorily. A mylar disc, corresponding to disc **16** of FIG. **1** of 0.5 inch diameter and 0.004 inch thickness was used. The puck was centrally located in a 0.532 inch diameter hole in an aluminum spacer corresponding to spacer **20** of FIG. **1** which was 0.104 inch thick. The 15.4 percent bandwidth design was biased by an inexpensive alnico-8 magnet 0.52 inch in diameter and 0.625 inch high which was located in tight proximity with the thin copper sheet ground plane corresponding to sheet **22** of FIG. **1.** The copper sheet was 0.004 inch thick. The planar dimensions of the substrate were 1.0 inch by 1.0 inch. Two of the transmission lines, similar to lines **12***b* and **12***d* of FIG. **1,** were formed to be perpendicular to the edges of the substrate to facilitate connection of these lines to connectors (not shown) mounted on a circulator shielded enclosure or box. A connector was also provided for line **12***c*.

In an alternate embodiment the magnet beneath the ground plane was eliminated and the magnetic field was supplied by a magnet locacted in the air about one-eighth inch above the conducting circuit. This separation was sufficient to avoid significant disturbance of the R.F. fields. The circulator was enclosed in a fully shielded box, one side of which was raised one-eighth inch above the conducting circuit. The magnet in this case was attached to that side.

It should be realized that the equivalent magnetic gap in the design of the circulator of FIG. 1 corresponds to the 0.004 inch thickness of the copper sheet and that this is a much more efficient design with respect to the magnetic field than the alternate embodiment wherein the magnet is located one-eighth inch above the conducting circuit.

Another embodiment of the invention might include a magnet placed as shown in FIG. 1 together with another magnet located above the conducting circuit to augment the magnetic field. Further modifications and alterations to the invention should now be obvious to one skilled in the art. Accordingly, this invention is limited only by the scope and spirit of the appended claims.

The invention claimed is:

1. A circulator comprising:

- a slab of dielectric material having first and second surfaces;
- a conducting circuit carried on said first surface, said conducting circuit having at least three transmission lines converging in a common conductive region;
- a ground plane having a recess therein intimately contacting said second surface;
- a ferromagnetic body means disposed in said recess but not in said dielectric slab;
- means for applying a magnetic field to said ferromagnetic body means, in a direction generally perpendicular to the first and second surfaces of the slab of dielectric material.

2. The circulator of claim **1** wherein said conducting circuit common conductive region comprises a generally disc-shaped conductive material, said at least three transmission lines being disposed generally radially therefrom and equally spaced from one another.

3. The circulator of claim **2** wherein said disc-shaped conductive material includes enlarged portions at the periphery of said disc-shaped conductive material forming the junction of said transmission lines with said disc-shaped conductive material.

4. The circulator of claim **2** wherein said ferromagnetic body means underlies said disc-shaped conductive material.

5. The circulator of claim **1** wherein said ground plane comprises:

- a thin sheet of conductive material carried on and generally covering said second surface except having a hole disposed therein to expose said second surface;
- a conductive spacer underlying said thin sheet and in intimate and electrical contact therewith and having a hole therein generally coaxial with the hole in said thin sheet, said ferromagnetic body means being disposed in said hole; and,
- a second thin conductive sheet underlying said ferromagnetic body means and in intimate and electrical contact with said spacer so as to form a ground plane for said ferromagnetic body means.

6. The circulator of claim **4** wherein said ferromagnetic body means is generally disc-shaped and disposed in said recess to underlie the disc-shaped conductive material.

7. The circulator of claim **6** wherein said ferromagnetic body means includes a ferromagnetic puck and a relatively thin dielectric spacer between a surface of said puck and said second surface.

8. The circulator of claim **6** wherein said ferromagnetic body means includes a ferrite puck.

9. The circulator of claim **6** wherein said ferromagnetic body means includes a garnet puck.

10. The circulator of claim **6** wherein said ferromagnetic body means includes a ferromagnetic puck and a relatively thin metallic disc spaced between a surface of said puck and said second surface.

11. The circulator of claim **6** wherein said ferromagnetic body means includes a ferromagnetic puck spaced away from said second surface by at least a relatively thin metallic spacer.

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