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STRIP LINE CIRCULATOR

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FIG. 1

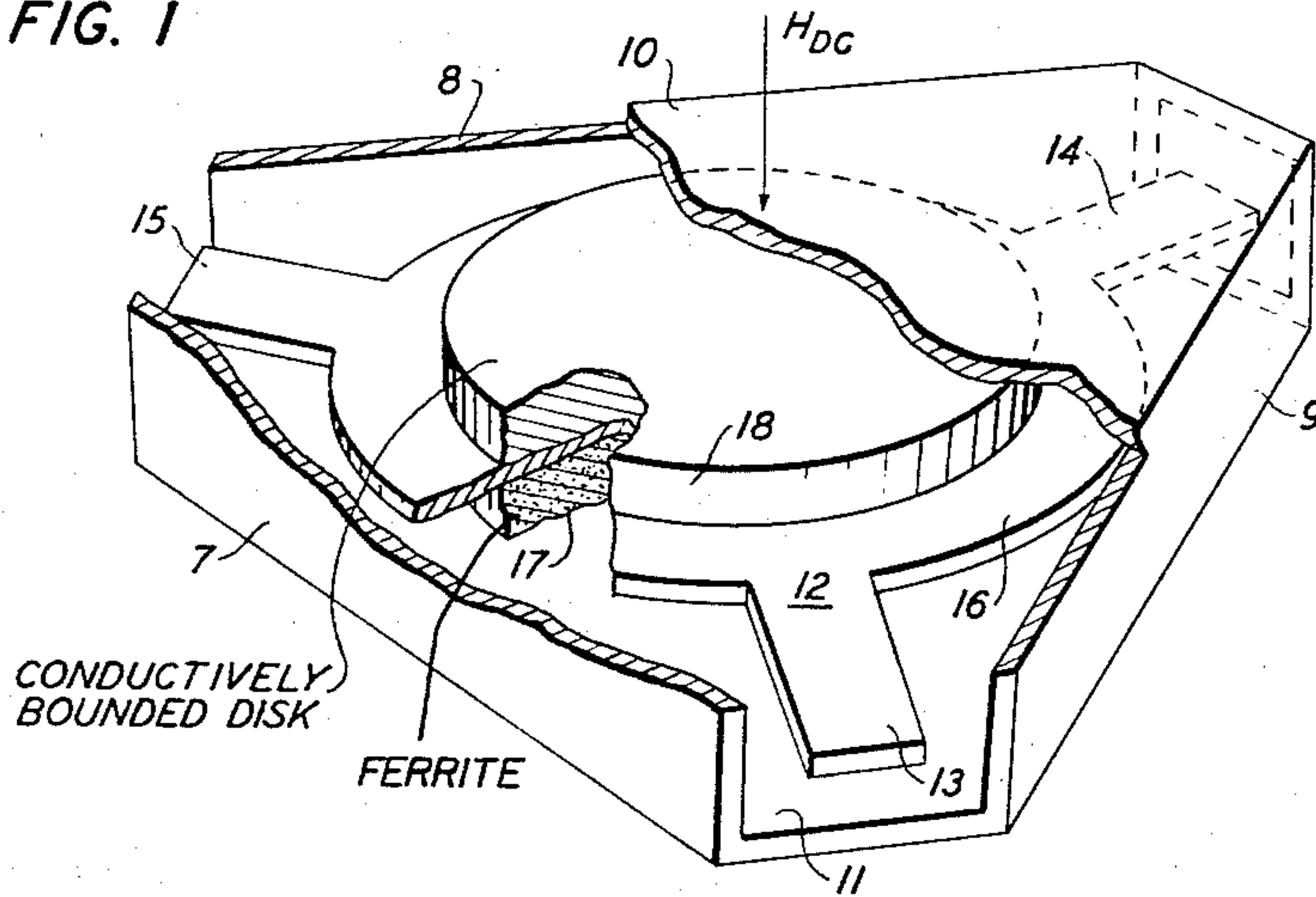


FIG. 2

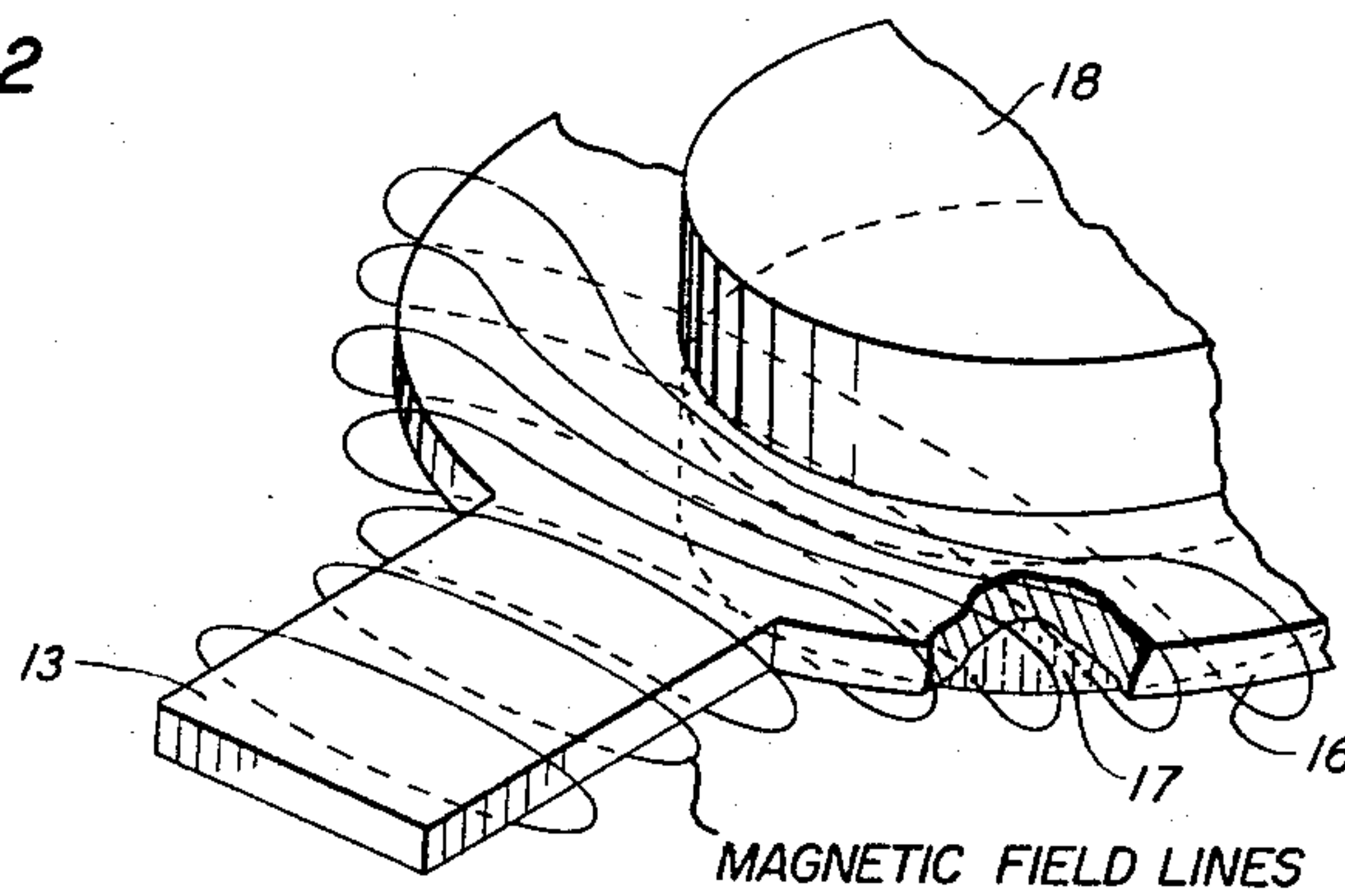
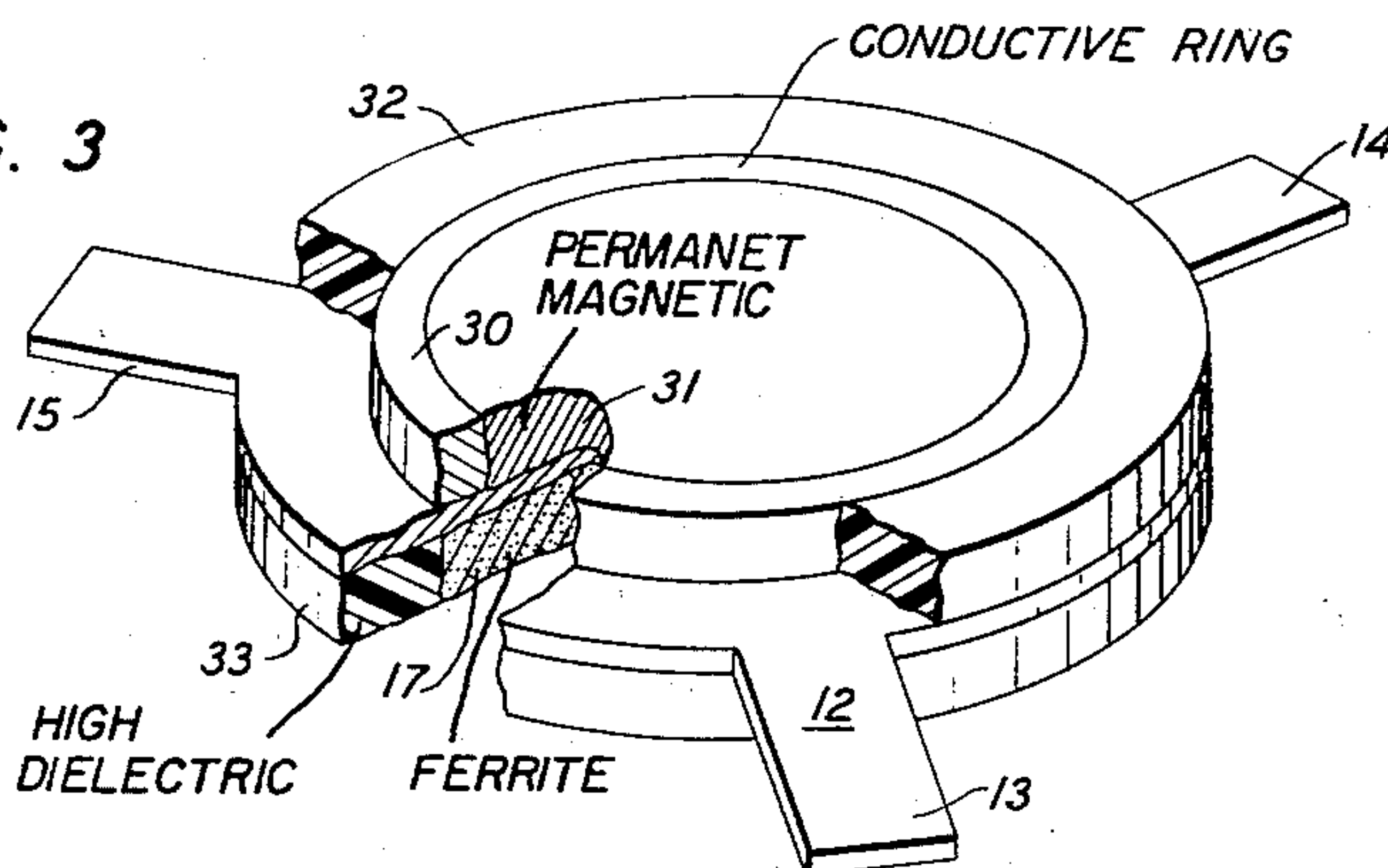


FIG. 3



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STRIP LINE CIRCULATOR

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9 Claims. (Cl. 333-1.1)

This invention relates to circulators and more particularly to junction circulators of improved and simplified design.

Circulators are now well known and practically indispensable components in the microwave transmission art. In general they are nonreciprocal junctions having coupling characteristics which derive their nonreciprocity from a magnetically polarized element of gyromagnetic material located in the junction. Usually, the gyromagnetic element is a ferrimagnetic material such as ferrite or garnet. One of the popular circulator forms is the strip line, three branch or Y-junction type, the basic principles and uses of which may be found in various texts such as "Microwave Ferrites and Ferrimagnetics," by Lax and Button, 1962, pages 517 and 609; in publications such as Fay and Comstock, "Operation of the Ferrite Junction Circulator," 13 IEEE Transactions MT & T, pages 15-27, January 1965; and in patents such as Davis, 3,063,024, Nov. 6, 1962.

As described in these references, the strip line form generally comprises a flattened center conductor which has symmetrical strips radiating from a common center portion. The center conductor is then spaced between a pair of conductive ground planes, and a pair of nonconductive gyromagnetic elements are located, respectively, above and below the common portion thereof. A magnet external to the ground planes supplies the required magnetic polarization. An expensive part of such a circulator is generally the gyromagnetic elements thereof, and much of the bulk of the circulator derives from the magnet.

It is therefore an object of the present invention to reduce the cost and bulk of strip line circulators.

More specifically, it is an object of the invention to reduce by at least one-half the amount of gyromagnetic material required, to reduce substantially the magnetic structure required, and in one embodiment, to eliminate altogether the presence of a magnetic structure external to the ground planes.

These objects are accomplished in accordance with the invention by replacing one of the gyromagnetic elements in a structure according to the above-described prior art by a conductively bounded member which electrically short circuits the center conductor to one of the ground planes. It has been discovered that the operation of the circulator is not much changed by the substitution and yet only one gyromagnetic element is required. It has been further discovered that the dimensions of the conductively bounded member may be quite large compared to the rest of the structure, being for example at least comparable to the replaced gyromagnetic element or having a diameter at least several times the width of the strip line center conductors. Having this substantial size, therefore, it is possible to include material of low magnetic reluctance within the conductive boundary and thereby to reduce substantially the air gap in the magnetic circuit of the circulator, correspondingly reducing the required size of the external magnet. Finally, by including a permanent magnet within the conductive boundary, the magnet external to the ground planes is eliminated.

Other objects and features, the nature of the present invention and its various advantages, will appear more

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fully upon consideration of the specific illustrative embodiments shown in the accompanying drawings and described in detail in the following explanation of these drawings, in which:

FIG. 1 is a perspective view of a circulator in accordance with the invention with the biasing magnetic field being shown schematically for clarity;

FIG. 2 is a diagrammatic view of the lines of magnetic field in a portion of the structure of FIG. 1; and

FIG. 3 is a perspective view of a modification of a portion of the structure of FIG. 1.

Referring more particularly to FIG. 1, an illustrative embodiment is shown comprising a pair of flat, electrically conductive ground plane members 10 and 11 extending parallel to and spaced apart from each other. Angularly related conductive side walls 7, 8 and 9 connect and support members 10 and 11 and enclose a cavity that is a right triangular prism having truncated points forming ports opening into the cavity. Centrally spaced between and parallel to the ground planes in a center conductor or spider member 12 comprising a plurality of strips 13, 14 and 15 radially extending toward the truncated points or ports of the cavity from and in the same plane with a circular common region 16. Three strips are illustrated, equally spaced by 120°, to form a Y-junction circulator, but it should be understood that more than three symmetrically positioned strips in an appropriately modified cavity can be employed. Furthermore it should be understood that the straight sided triangular cavity wall construction is preferred only because of its structural simplicity and that these walls may be curved outwardly to form a cavity of cylindrical shape or, alternatively, curved inwardly or according to any other form and shape.

In accordance with usual practice each of strips 13, 14 and 15 has a width proportioned with respect to the spacing between ground planes 10 and 11 to produce a desired strip line characteristic impedance, usually 50 ohms, at the intended operating frequency. Center region 16 for the ultimate purposes of the invention has a diameter that is at least twice the strip width. It has been determined empirically that desirable characteristics are obtained if the minimum distance between the edge of region 16 and each of side walls 7, 8 and 9 is substantially equal to the distance between a ground plane and the center conductor. The radial ends of each of the strips may be connected through suitable transformers or impedance matching devices to associated strip line components or may be terminated in coaxial connectors.

Located between ground plane 11 and spider 12 and substantially centered on circular common portion 16, is a disk 17 of gyromagnetic material such as any substantially nonconductive ferrimagnetic or ferromagnetic material, for example, yttrium iron garnet or ferrite. Disk 17 preferably has a thickness that fills the space between conductors 11 and 16 and a diameter that is preferably less than that of common portion 16 but greater than the width of strips such as 13. However, these relationships are matters of design and do not appear to be critical. Opposite disk 17 and between portion 16 and ground plane 10 is a disk 18 of solid copper, brass, or other conductive material, or alternatively, a disk of base material suitably clad, coated or plated on at least its cylindrical surface by a conductive material. In either case disk 18 has a diameter that is less than that of common portion 16 so that the extending edge of portion 16 forms a "ledge." This relationship appears to be critical in order to obtain the magnetic field distribution to be described below. In view of other proportions specified above, disk 18 will therefore have a diameter that is greater than the width of the strips such as 13. Thus, disk 18 has di-

mensions substantially comparable to those of gyromagnetic disk 17 in its preferred proportion. Disk 18 electrically connects ground plane 10 and common portion 16 together and may be held in firm electrical contact with them by pressure or appropriate soldering. In accordance with normal practice, means not shown are provided for supplying a steady direct current biasing field through disk 17 in a direction perpendicular to the plane of the disk as represented by the vector H_{dc} .

Operation of the circulator can be understood on the basis of the analysis given in the above-noted publication of Fay and Comstock after recognizing the nature of the magnetic field pattern in the structure of FIG. 1. Thus, it has been determined that when one strip, such as 13, is excited by the usual TEM mode, the magnetic field pattern in the vicinity of the disks is similar to that schematically represented in FIG. 2. Thus, the magnetic field lines above and below the circular common portion 16 lie in planes parallel to the plane of the portion. On the top side in the vicinity of conductive disk 18 the lines curve around the circumference of disk 18 and are concentrated in the "ledge" formed between disk 18 and the extending edge of portion 16. The lines then curve over the edge of portion 16 and continue on the back side along curved arcs that start generally normal to the periphery of portion 16. Thus, the lines extend through ferrite disk 17 on one side of portion 16 in the same pattern in which they were found by Fay and Comstock to exist on both sides of a similar common portion in a structure having nonconductive ferrite disks on both sides of this common portion. It has been further determined that despite the nonsymmetrical nature of this field, it sets up a pair of counter rotating field patterns traveling around portion 16 in either direction at velocities different from each other by an amount dependent on the value of H_{dc} in the same way as did the symmetrical field. Electric field nodal points are produced where the two rotating fields are of opposite phase and for the proper value of H_{dc} , a nodal point will be formed at the position of, for example, strip 14, and at the same time strip 15 will be remote from any nodal point. Thus, electromagnetic waves will be transmitted from strip 13 to strip 15. The coupling is nonreciprocal, however, to the extent that wave energy entering on strip 15 will set up a new pattern having a node that coincides with strip 13 but couples to strip 14. In similar manner, energy applied to strip 14 will be transferred to strip 13 and strip 15 will be isolated. For further consideration and a detailed mathematical analysis of the phenomenon described, reference may be had to the publication of Fay and Comstock.

The advantages residing in the present invention will become apparent when it is compared to the prior art forms having two gyromagnetic disks. Thus, the requirement of only one gyromagnetic disk 17 substantially reduces the cost of the device. Not so apparent is the fact that the substituted conductive disk 18 changes only slightly the impedance of the junction region and presents no serious impedance matching problems to the connected transmission system. Furthermore, disk 18 may be made large enough that by forming it of high permeability steel which has been clad, plated or otherwise coated at least on its cylindrical surface by highly conductive material, the high reluctance gap between the poles of an external magnet is reduced by approximately one-half.

FIG. 3 shows how further advantage is taken of the size of the conductivity enclosed area within disk 18 to simplify the magnetic circuit by means of the illustrated modification of FIG. 1. Corresponding reference numerals have been employed to designate corresponding components and the ground plane structure has not been shown in order to simplify the drawing. Modification will be seen to reside in the use of conductive ring 30 having an outside diameter that corresponds to that of disk

18 in FIG. 1. Included in the space within ring 30 is a permanently magnetized disk 31 which supplies the required polarizing field H_{dc} to gyromagnetic disk 17. Thus, a very compact component is provided by utilizing space between the ground planes themselves to contain the magnet. The use of a separate conductive ring 30 and magnetic disk 31 allows the maximum freedom of choice of materials for the components. For example, it is possible to use one of the new ceramic magnets which have little or no electrical conductivity, such as Indox, for disk 31 and a highly conductive material, such as copper or brass, for ring 30. It should be noted, however, that these functions can be combined by using a magnetic steel or a material, such as Alnico, of good conductivity in the form of a single magnetized disk of high conductivity.

Further improvement is obtained in FIG. 3 by the inclusion of members 32 and 33 of material of high dielectric constant, such as alumina, surrounding ring 30 and gyromagnetic element 17, respectively. Members 32 and 33 are illustrated as rings surrounding the respective components but it should be noted that if the layered form of construction familiar to the strip line art is employed, members 32 and 33 will constitute part of the dielectric supports in the layered assembly or may be extended out radially an odd number of quarter wavelengths along strips 13, 14 and 15 for impedance transforming purposes. In either case, the dielectric members tend to concentrate the electromagnetic energy within the gyromagnetic material of disk 17 and correspondingly in the ledge surrounding ring 30, thereby increasing the gyromagnetic interaction with the energy.

While members 17 and 18 and center conductor portion 16 have been described as having circular symmetry in the form of disks as shown and while this shape has advantages from the standpoint of analysis and construction, it should be understood that each or all of these members may have other symmetrical shapes. Included are those having tapered angular apexes which have been shown in Patent 3,104,361, granted Sept. 17, 1963, to have certain broad band advantages.

In all cases it is to be understood that the above-described arrangements are merely illustrative of a small number of the many possible applications of the principles of the invention. Numerous and varied other arrangements in accordance with these principles may readily be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A circulator comprising a conductively bounded cavity having at least three ports and a pair of spaced parallel surfaces, a thin conductor member disposed between and spaced in parallel relationship to said surfaces, said thin conductor member having at least three portions symmetrically extending away from a common portion toward said ports, a single magnetically polarized element of gyromagnetic material disposed between said common portion and one of said surfaces, a single conductively bounded member disposed between and conductively connecting said common portion and the other of said surfaces, said conductively bounded member being of such dimensions relative to said common portion and said parallel surfaces that magnetic field lines of electromagnetic wave energy applied to one of said ports form in the vicinity of said common portion as curves around said conductively bounded member and extend over the edge of said common portion to continue through said gyromagnetic material.

2. A circulator comprising a thin center conductor member disposed between and spaced in parallel relationship to a pair of conductive surfaces, said center conductor member having at least three portions symmetrically extending away from a common portion, a single element of gyromagnetic material disposed between said common portion and one of said surfaces, a single at least partially

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conductively bounded member disposed between and conductively connecting said common portion and the other of said surfaces, said conductively bounded member being of such dimensions relative to said center conductor member and said conductive surfaces that magnetic field lines of electric wave energy conducted by any one of said center conductor portions form in the vicinity of said common portion as curves around said conductively bounded member and extend over the edge of said common portion to continue through said gyromagnetic material, and means for magnetizing said gyromagnetic element with a strength such that electric waves conducted by each center conductor portion couple nonreciprocally to only one other of said portions.

3. A circulator comprising a thin center conductor member disposed between and spaced in parallel relationship to a pair of conductive surfaces, said center conductor member having at least three portions symmetrically extending away from a common portion, an element of gyromagnetic material disposed between said common portion and one of said surfaces, a member of material of high magnetic permeability disposed between said common portion and the other of said surfaces, said member of high permeability being at least partially bounded by material of high conductivity which electrically connects said common portion and said other surface.

4. The circulator as defined in claim 3 wherein said member of high permeability is at least in part comprised of permanently magnetized material.

5. A circulator as defined in claim 3 wherein said member of high permeability together with its partial boundary of conductive material forms a body of substantially the same size and shape as said gyromagnetic member.

6. A circulator comprising a thin center conductor member centrally disposed between and spaced in parallel relationship to a pair of outer conductors, said center conductor member having at least three portions of a first width symmetrically extending away from an enlarged common portion of a second width, a magnetically polarized element of gyromagnetic material disposed between said common portion and one of said outer conductors, a member at least partially conductively bounded

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and having a dimension parallel to said center conductor that is larger than said first width and smaller than said width, said conductively bounded member disposed between and conductively connecting said common portion and the other of said outer conductors.

7. A circulator comprising a plurality of strip transmission lines coupled together at a common point, each line including a center conductive strip disposed between two outer conductive surfaces, a body of magnetically polarized gyromagnetic material disposed at said common point between said center strip and one of said outer surfaces, a body at least partially conductively bounded disposed at said common point and electrically connecting said center strip and the other of said outer surfaces, said center strips being enlarged in width at said common point to form a conductive plane that is larger than said conductive body thereby forming a conductive ledge surrounding said conductive body.

8. The circulator according to claim 7 including material of high dielectric constant substantially filling said ledge and surrounding said gyromagnetic body.

9. A circulator comprising a plurality of strip transmission lines coupled together at a common point, each line including a center conductive strip disposed between two outer conductive surfaces, a body of magnetically polarized gyromagnetic material disposed at said common point between said center strip and one of said outer surfaces, a member of material of high magnetic permeability disposed at said common point between said center strip and the other of said outer surfaces, said member being at least partially surrounded by a boundary of high conductivity which electrically connects said center strip and said other surfaces, said center strip being enlarged in width at said common point to form a conductive plane that is larger than said conductive boundary thereby forming a ledge surrounding said conductive boundary.

No references cited.

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