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Radding et al.

[11] **3,886,502**

[45] **May 27, 1975**

[54] **BROAD BAND FIELD DISPLACEMENT ISOLATOR**

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[52] **U.S. Cl.**.................... **333/24.2**; 333/9; 333/22 R
[51] **Int. Cl.**.. **H01p 1/32**
[58] **Field of Search**.......................... 333/1.1, 9, 24.2

[56] **References Cited**

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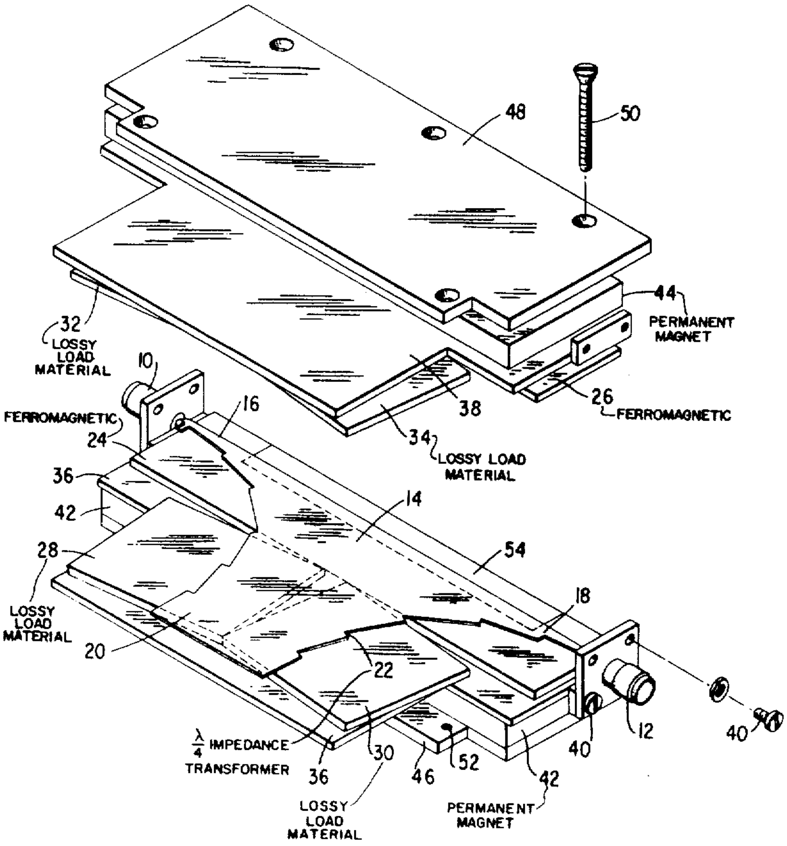
Primary Examiner—Paul L. Gensler
Attorney, Agent, or Firm—Spencer & Kaye

[57] **ABSTRACT**

A broad band field displacement isolator of the strip-line type. The isolator includes a conductive planar circuit which has three outwardly narrowing legs extending from a common portion with a first and a second of the legs being an input and output port respectively and the third leg being provided with a load. The circuit is symmetrical with respect to an axis extending through the third leg with at least the circuit extending between the joining the first and second legs with the third leg each constituting a series of stepped quarter wavelength linear tapered impedance transformers. Bodies of gyromagnetic material are symmetrically disposed on opposite sides of the circuit overlying substantially the entire portion of the circuit extending between the input and the output ports and layers of dielectric load material are disposed on opposite sides of the circuit overlying the third leg and coplanar with the bodies of gyromagnetic material.

8 Claims, 4 Drawing Figures



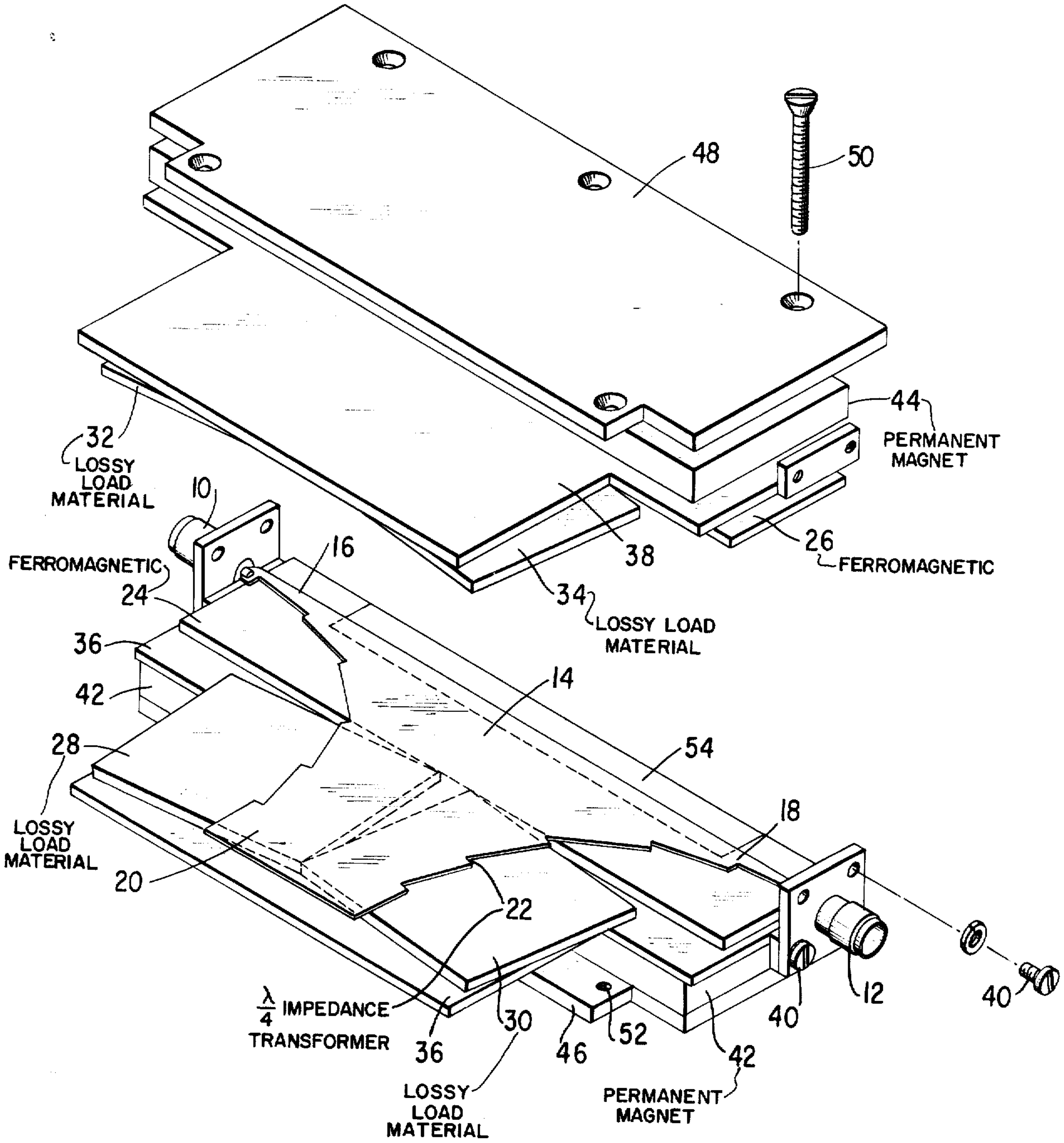

48
50
44
PERMANENT MAGNET
32
LOSSY LOAD MATERIAL
10
38
26
FERROMAGNETIC
FERROMAGNETIC
16
24
34
LOSSY LOAD MATERIAL
36
14
42
28
54
LOSSY LOAD MATERIAL
18
20
22
λ/4 IMPEDANCE TRANSFORMER
36
30
LOSSY LOAD MATERIAL
46
52
40
12
40
42
PERMANENT MAGNET

FIG. 1

FIG. 2

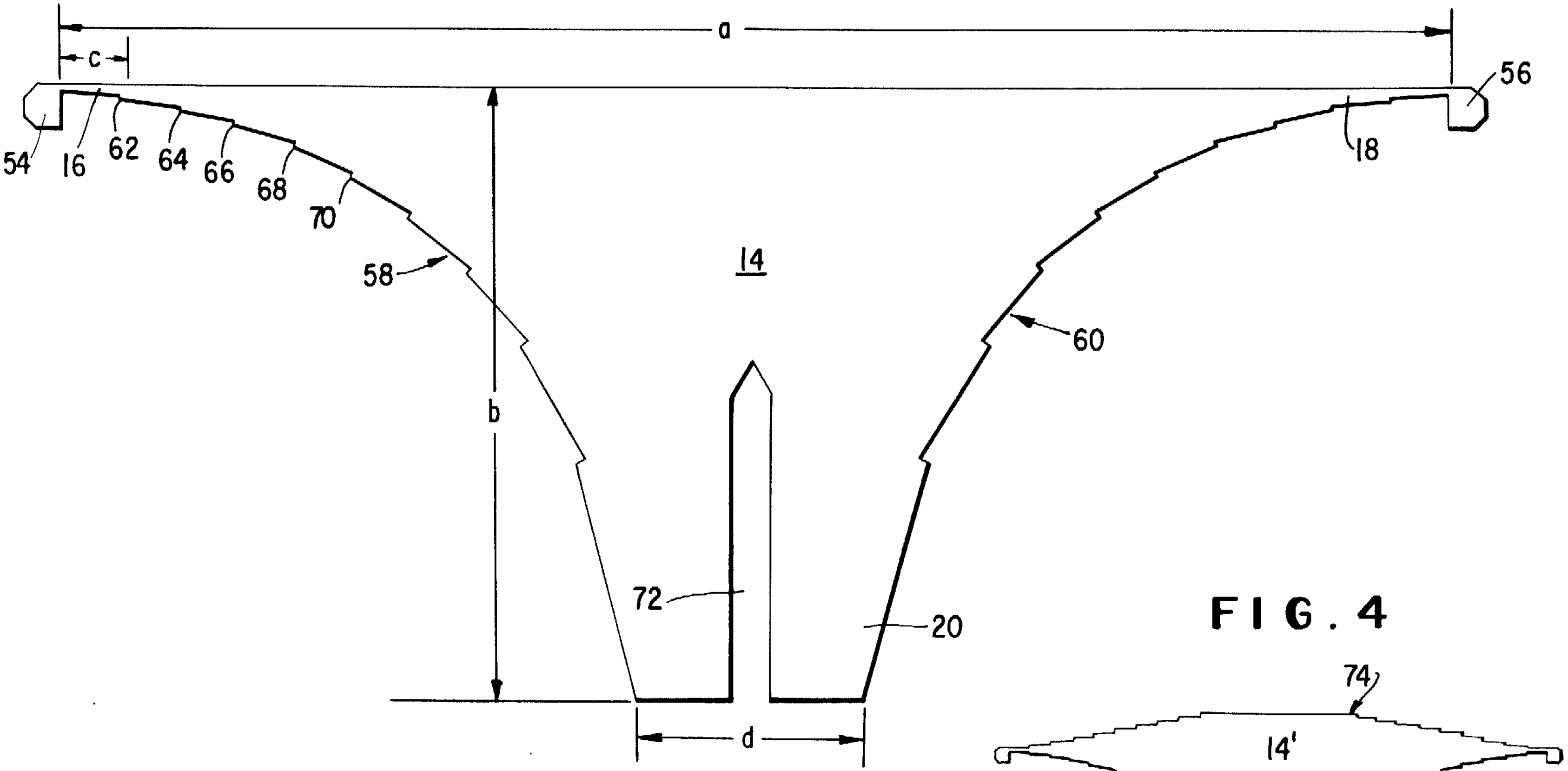


FIG. 4

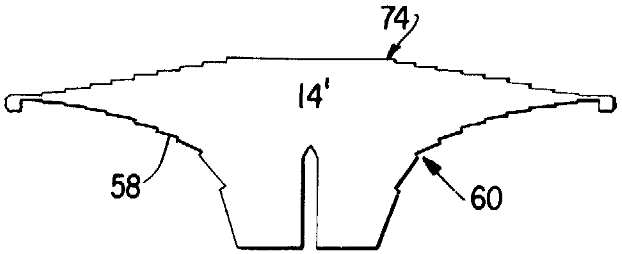
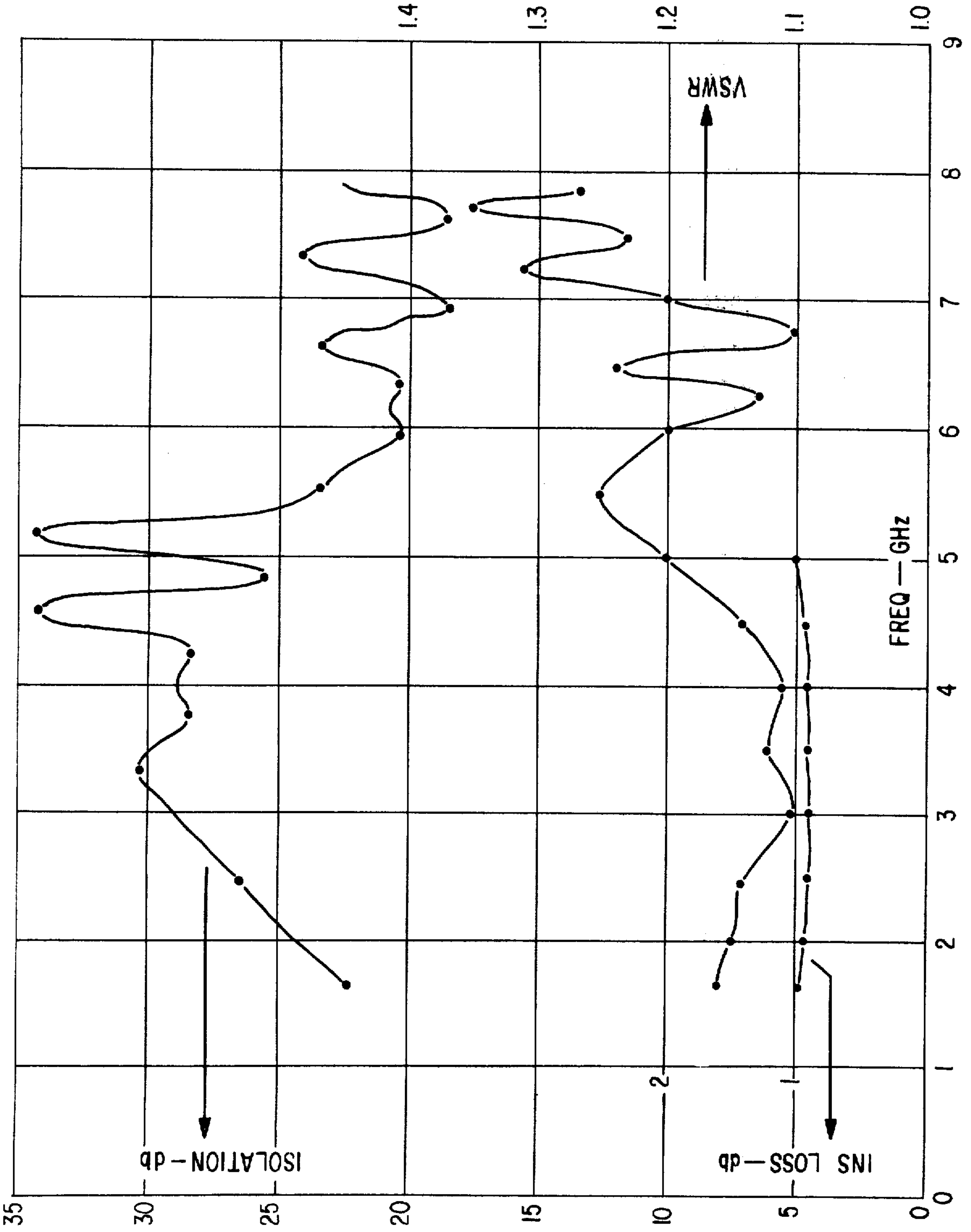


FIG. 3


ISOLATION — db
INS LOSS — db
VSWR
FREQ — GHz
0
5
10
15
20
25
30
35
1
2
1.0
1.1
1.2
1.3
1.4
0
1
2
3
4
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BROAD BAND FIELD DISPLACEMENT ISOLATOR

BACKGROUND OF THE INVENTION

The present invention relates to a broad band isolator of the field displacement type. More particularly, the present invention relates to a broad band isolator of the field displacement type which is constructed according to the strip-line technique.

Microwave devices, including isolators, operating according to the phase displacement mechanism have been long and well known in the art. For example, such devices are discussed in a book by B. Lax and K. Button, *Microwave Ferrites and Ferrimagnetics*, McGraw Hill(**1962**), pages **375** to **379**, and in an article, *Reciprocal And Nonreciprocal Modes of Propagation In Ferrite Stripline and Microstrip Devices*, Hines, IEEE Transactions on MTT, Vol. MTT **19**, No. 5, May 1971. As is well known in the art, such devices rely on the nonreciprocal properties of the ferrite or other gyromagnetic material to provide a maximum electric field in one direction of propagation and a minimum electric field in the reverse direction of propagation at the ferrite-dielectric interface. If the field displacement device is to be an isolator, then as is further well known in the art, a resistance card is placed at the ferrite-dielectric interface.

Although field displacement isolators are known which have been built according to the waveguide technique and according to the coaxial technique, such devices are generally considered to be narrow band devices. Moreover, field displacement isolators constructed according to the strip-line technique have generally not been attempted since it is generally considered that the strip-line technique does not readily lend itself to isolators of the field displacement type, particularly when broad banded devices are desired.

SUMMARY OF THE INVENTION

It is therefore an object of the invention to provide a broad banded field displacement isolator which is constructed according to the strip-line technique.

The above object is achieved according to the present invention by providing an isolator having a conductive planar circuit with three outwardly narrowing legs extending from a common portion with a first and a second of the legs being an input and an output port respectively. The circuit is symmetrical with respect to an axis extending through the third leg and the edge of the circuit extending between and joining the first and third legs and the edge of the circuit extending between and joining the second and the third legs are each formed by a series of stepped quarter wavelength linear tapered impedance transformers. Bodies of gyromagnetic material, for example, ferrite, are symmetrically disposed on opposite sides of the conductive circuit and overlie substantially the entire portion of the circuit extending between the input and the output ports. A layer of dielectric load material is disposed on each of the opposite sides of the circuit overlying the third leg and are coplanar with the respective bodies of the gyromagnetic material. Finally, as in conventional in strip-line technique devices, spaced parallel ground planes are provided overlying the bodies of gyromagnetic material and the layers of load material respectively and a magnetic field generating means is provided adjacent the layers of gyromagnetic material to bias same.

According to a further feature of the invention, it has been found that in order to provide proper impedance matching between the input and output impedance of the device, which are typically 50 ohms, and the impedance of the load, which is typically in the order of 2 to 5 ohms, while maintaining low VSWR over the full operating bandwidth of the device, the length of the quarter wavelength linear tapered transformer should be determined at a frequency from 1.2 to 2.4 times the frequency at the lower end of the operating band, and in the dielectric medium of the ferrite. This results in a minimum number of from 5 to 10 transformers being provided along the edge of the circuit, with preferably a minimum of 10 transformers being provided.

According to further features of the invention, the edge of the circuit extending between the input and output ports is preferably a straight line and a layer of dielectric material with a high dielectric constant is provided coplanar with gyromagnetic material and along a portion of the straight edge in order to reduce fringing fields along this edge which tend to limit the higher end of the operating frequency range.

According to still a further feature of the invention, each of the layers of load material is divided into two portions which are positioned relative to the adjacent edge of the respective layer of gyromagnetic material so as to maximize the quantity of energy transferred to the load material over a broad band, and thus optimize the isolation response.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an exploded perspective view of a strip-line field displacement isolator according to the invention.

FIG. **2** is a detailed plan view of an embodiment of the preferred configuration for the planar circuit or center conductor of the field displacement isolator of FIG. **1.**

FIG. **3** is a plot of the VSWR, isolation and insertion loss versus frequency for the field displacement isolator shown in FIG. **1** with the circuit configuration of FIG. **2.**

FIG. **4** is a plan view of an alternate circuit configuration which may be utilized in the field displacement isolator according to the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. **1**, there is shown the basic construction of a preferred embodiment of a strip-line broad band field displacement isolator according to the invention. The device includes a pair of opposed coaxial connectors **10, 12,** which constitute the input and output ports of the device and each of which is connected to a respective leg of a planar conductive circuit or center conductor **14.** In general, circuit **14** has three outwardly narrowing legs **16, 18** and **20** extending from a central portion thereof and the circuit is symmetrical with respect to a center line through the leg **20** which constitutes the internally terminated port of the isolator. Legs **16** and **18** are connected to the coaxial connectors **10** and **12** respectively and as shown, the edge of the circuit **14** extending between and joining the leg **16** and **18,** i.e., the edge of the circuit extending between the connectors **10** and **12,** is preferably formed as a straight line. The edges of the circuit extending between and joining the leg **16** with the leg **20** and the leg **18** with the leg **20** are, however, as shown formed by a series of stepped λ/4 linear tapered impedance transformers **22**, five of which are shown in the drawing along each of the edges in question.

Symmetrically disposed on either side of the circuit **14** and generally overlying the entire portion thereof extending between the connectors **10** and **12** is a pair of gyromagnetic bodies, for example, ferrite or garnet, **24**, **26**. The particular compositions of the gyromagnetic or ferromagnetic bodies **24**, and **26** is not critical in carrying out the invention. However, preferably material having a 4πMs rating of from approximately 400 gauss to approximately 5000 gauss is utilized (for example, Trans Tech material G610).

In order to terminate the leg **20** of the circuit **14** as is required in order to provide an isolator of the field displacement type, first and second layers of a lossy load material are provided on either side of the leg **20** and coplanar with the respective gyromagnetic bodies **24** and **26**. Although each of the layers of lossy material may be a single layer which abuts the adjacent edge of the respective gyromagnetic body **24** or **26**, preferably as shown in FIG. **1**, each of the layers of lossy materials is formed of two separate blocks **28, 30**, and **32, 34** respectively. Segmenting of the load in this manner has the advantage that it is now possible to "match" the fairly sizable discontinuity occurring at the load/ferrite interface, which discontinuity arises from the very high permeability and permittivity factors of the bulk load material as compared to the moderate dielectric constant and low permeability of ferrite materials, and thus effectively reduce the discontinuity and maximize the amount of energy that transfers into the load over as broad a band as possible. This matching process is accomplished by adjusting the position of the individual segments **28, 30** and **32, 34** relative to the edge of the respective gyromagnetic bodies **24, 26** with a typical position being shown in the figure. The primary effect of this adjustment is to increase the isolation at the higher frequencies, thus extending the bandwidth of the device.

In order to complete the device according to the conventional strip-line technique, a pair of spaced parallel ground planes **36, 38** are provided which overlie the respective bodies of gyromagnetic material **24, 26** and the layers of load material which are coplanar thereto. As shown, the ground planes **36** and **38** are connected to the connectors **10** and **12** via screws **40**. Finally, respective permanent magnets **42, 44** are placed adjacent the respective ground planes **36, 38** overlying the gyromagnetic bodies **24, 26**, and conductive cover plates **46, 48** are provided over the respective magnets **42, 44** so as to both hold the respective magnets in contact with the ground planes and to provide a magnetic circuit return. As illustrated, the cover plates **46**, and **48** are held in place by screws **50** which extend through a plurality of openings in the cover plate **48** and engage corresponding threaded holes **52** in the cover plate **46**.

Although, as discussed in the above mentioned IEEE article, field displacement isolators should theoretically not be frequency sensitive, in reality, such devices are frequency sensitive, particularly at the higher frequencies, due to higher order modes resulting from fringing fields. According to this article, it is further pointed out that these fringing fields have the effect of creating inductance at the edge of the center conductor or circuit and that consequently, to improve the performance at the high end of the operating frequency band, it is desirable to add capacitance to the edge of the circuit extending between the input and the output port. In order to provide this desired capacitance in a simple and compact manner, according to the further feature of the invention, the desired compensating capacitance is achieved by providing a layer of dielectric material **54** with a high dielectric constant, e.g., a constant of **30** or **40**, along and overlying a portion of the straight edge of the circuit extending between the input and output ports, and coplanar with the body of gyromagnetic material **24**. It is to be understood that, although not shown, a similar layer of dielectric material with a high dielectric constant is provided coplanar with the body of gyromagnetic material **26**. A typical material which may be used for the layer **54** is, for example, Trans-Tech Material D-30.

Referring now to FIG. **2** there is shown a preferred embodiment of a circuit **14** according to the invention which is generally drawn to scale. As shown in the drawing, the circuit has three outwardly narrowing legs **16, 18** and **20** extending from a central portion and is symmetrical to a center line through the leg **20**. The leg **16** and **18** which constitute the input and output ports of the circuit, are considerably narrower than the leg **20** since they must be constructed to match the impedance of the transmission system to be connected thereto, typically 50 ohms, while the leg **20** is constructed to match the much lower impedance of the load material, typically 2 to 5 ohms. In order to facilitate the connection of the very narrow ends of the legs **16** and **18** to the coaxial connectors, as is conventional in the art, the end of each of the legs **16** and **18** is provided with an extension **54** and **56** respectively which is not between the layers of gyromagnetic material **24**, 26, and thus has a larger width in order to provide the 50 ohms matching impedance. As a result of the different impedances appearing at the ends of legs **16** and **18** and the leg **20**, the edges **58** and **60** of the circuit **14**, which edges extends between and join the legs **16** and **18** with the leg **20**, must be constructed so as to provide a suitable transformer between the two different impedances if low values of VSWR are to be maintained over the full operating bandwidth of the device. Since the low frequency end of operation of the device is limited by the properties of the gyromagnetic material, a "high pass" form of transformer structure is desirable. Although it is well known in the art that various types of tapers may be utilized to provide a high pass structure, most of the known tapers have a ripple characteristic that increases rapidly in magnitude as the cutoff frequency is approached, which is undesirable. In addition, some of the known tapers, in particular the smooth curvature tapers, are both difficult to generate and to accurately manufacture. Accordingly, since the linear taper has the lowest cutoff frequency for a given length, according to the present invention the edges **58** and **60** of the circuit **14** are each formed of a series of quarter wavelength linear tapers with small abrupt impedance steps at the junction of each taper. The electrical advantage of this arrangement is that some of the uniform ripple characteristics of constant quarter wavelength transformers down to the cutoff frequency of the transformer are obtained, thus maintaining a lower VSWR at the low end of the operating band. The length of the linear tapers of each of the transformers is determined by calculating λ/4 at a minimum of from 1.2 to 2.4 times the frequency of the low end of the operating band in the dielectric medium of the ferrite material used for the bodies **24** and **26**. This results in a minimum number of **5** transformers when 1.2 is used and a minimum number of **10** transformers when 2.4 is used for typical designs. Preferably, the value 2.4 is utilized so that a minimum of 10 transformers is provided.

The magnitude or size of the abrupt impedance step at each junction between adjacent linear taper transformers is in general a compromise between improvement of the VSWR at low frequencies and the degradation at high frequencies due to the "band pass" behavior of abrupt impedance change $\alpha/4$ transformers. The magnitude is also somewhat proportional to the width of the circuit at the particular step in question. Consequently, according to the invention, the magnitude of the abrupt impedance steps increases in size in the direction from the respective legs **16** and **18** toward the leg **20**.

In the specific circuit shown in FIG. **2**, the circuit **14** is formed of half hard brass having a thickness of 0.005 inches and has a length a of 3.59 inches and a width b of 1.625 inches. The magnitude of the abrupt change of the transformer nearest the ends of the legs **16** and **18**, i.e., at the change **62**, is typically 0.002 inches, that of change **64**, 0.004 inches, that of **66**, typically 0.005 inches, that of **68**, typically 0.007 inches, that of **70**, 0.010 inches, with the remaining jumps each increasing by approximately 0.005 inches. The distance c between adjacent impedance jumps is typically in the order of 0.15 inches, and the width *d* of the leg **20** at its end is 0.59 inches. As shown in the figure, the leg **20** is additionally provided with a slot **72** extending along the longitudinal axis thereof, which has a width of approximately 0.10 inches, and serves to prevent undesirable moding in the device.

Referring now to FIG. **3**, there is shown a plot of isolation, insertion loss and VSWR versus frequency for the strip-line device shown in FIG. **1** with the circuit as shown in FIG. **2**. The ferrite used for the bodies **24** and **26** were 3.59 inches in length, 0.75 inches in width, and 0.060 inches in thickness, and made of garnet material which has a 4πMs equal to 680 gauss (Trans-Tech material number G610). The lossy material of the load was EMA material 7175 which is an iron loaded epoxy material. As can be seen from FIG. **3**, the device has an isolation of greater than 22db, an insertion loss of 1db or less and a VSWR of from 1.1 to 1.2 between approximately 1.6 and 5GHz.

Although the circuit **14** preferably is constructed as shown in FIGS. **1** and **2** to have a straight edge extending between the input and output ports, it is to be understood that the invention is not limited to this specific type of circuit arrangement. For example, as shown in FIG. **4**, the edge of the circuit extending between the input and output port may likewise be provided with a series of stepped quarter wavelength linear tapered transformers. In such case, the stepped transformers extending along the edge **74** of the circuit should be symmetrical to the quarter wavelength transformers extending along the edges **58** and **60** circuit.

It will be understood that the above description of the present invention is susceptible to various modifications, changes and adaptations, and the same are intended to be comprehended within the meaning and range of equivalents of the appended claims.

We claim:

1. A broad band microwave strip-line field displacement isolator comprising:

a conductive planar circuit having three outwardly narrowing legs extending from a common portion with a first and a second of said legs being an input port and an output port respectively, said circuit being symmetrical with respect to an axis extending through said third leg and at least the edge of said circuit extending between and joining said first and said third legs and the edge of said circuit extending between and joining said second and said third legs constituting a series of stepped $\lambda/4$ linear tapered impedance transformers;

first and second bodies of gyromagnetic material symmetrically disposed on opposite sides of said conductive circuit and overlying substantially the entire portion of said circuit extending between said input and output ports;

first and second layers of a dielectric load material disposed on opposite sides of said circuit overlying said third leg and coplanar with said first and second bodies of gyromagnetic material respectively;

first and second spaced parallel ground planes overlying said first and second bodies of gyromagnetic material and said first and second layers of load material respectively; and

magnetic field generating means adjacent said first and second layers of gyromagnetic material for biasing same.

2. A field displacement isolator as defined in claim **1** wherein the length of said transformers on each of said edges is equal to $\lambda/4$ at a frequency of approximately 1.2-2.4 times the frequency of the low end of the operating band, in the gyromagnetic medium.

3. A field displacement isolator as defined in claim **2** wherein the minimum number of said transformers on each said edge is equal to 5.

4. A field displacement isolator as defined in claim **1** wherein the size of the steps between adjacent transformers of each said series increases in a direction from the input and output ports toward said third leg.

5. A field displacement isolator as defined in claim **1** wherein the edge of said circuit extending between and joining said first and second legs is a straight line.

6. A field displacement isolator as defined in claim **5** further comprising a layer of dielectric material with a high dielectric constant overlying at least a portion of said straight edge and coplanar with said gyromagnetic material.

7. A field displacement isolator as defined in claim **1** wherein the edge of said circuit extending between and joining said first and secon legs is constituted by a series of stepped linearly tapered impedance transformer which are symmetrically arranged with respect to the said series of stepped transformers in said edges joining said third leg with said first and second legs.

8. A field displacement isolator as defined in claim **1** wherein each of said first and second layers of load material is divided into two portions, each of said portions being positioned relative to the adjacent edge of the respective layer of gyromagnetic material to maximize the quantity of energy transferred to said load material over a broad band, and thus provided a more optimum isolation response.

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