United States Patent [19]

Orime et al.

[11] **3,835,420**

[45] **Sept. 10, 1974**

[54] **ISOLATOR**

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[21] Appl. No.: **381,623**

[30] **Foreign Application Priority Data**

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Aug. 4, 1972 Japan 47-78148
Nov. 10, 1972 Japan 47-112715

[52] **U.S. Cl.** .... **333/24.2,** 333/84 M
[51] **Int. Cl.** **H01p 1/32**
[58] **Field of Search** .... 333/24.1, 242, 73 S

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Primary Examiner—Paul L. Gensler
Attorney, Agent, or Firm—Oblon, Fisher, Spivak, McClelland & Maier

[57] **ABSTRACT**

An isolator has a dielectric substrate such as a composite substrate or a single ferrimagnetic substrate; a magnetic material inserted in a hole of the dielectric substrate in the thickness direction thereof; a single plate conductor placed on one surface of the dielectric substrate; a main line conductor placed on the other surface of the dielectric substrate and over the magnetic material; a branch line conductor and a subbranch line conductor branching from the main line conductor; wherein one end of the line conductor is opened and the other end of the line conductor is connected to the single plate conductor.

8 Claims, 17 Drawing Figures

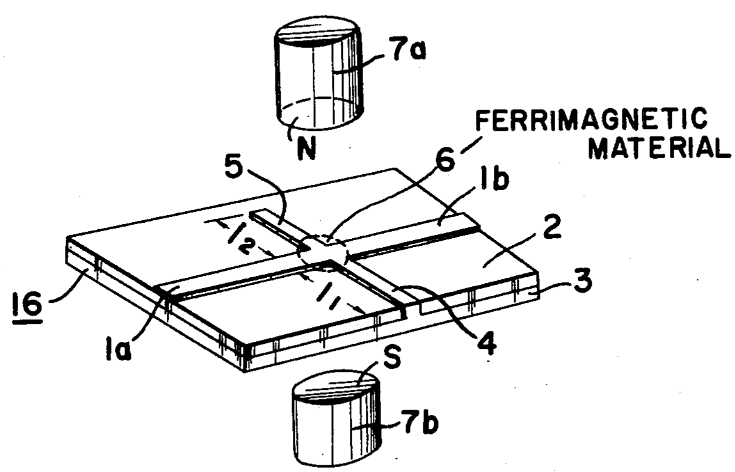
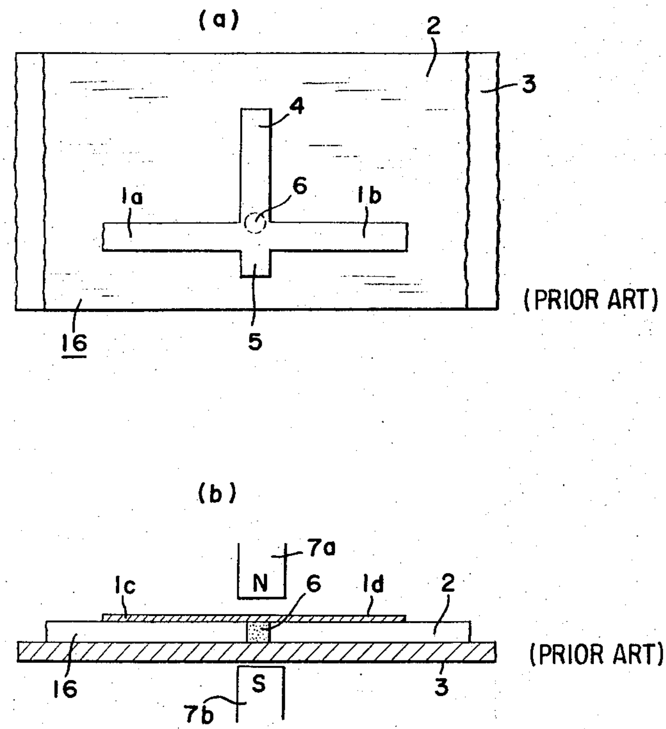


FIG. 1


(a)
2
3
4
6
1a
1b
(PRIOR ART)
16
5
(b)
7a
N
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1d
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(PRIOR ART)
16
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S
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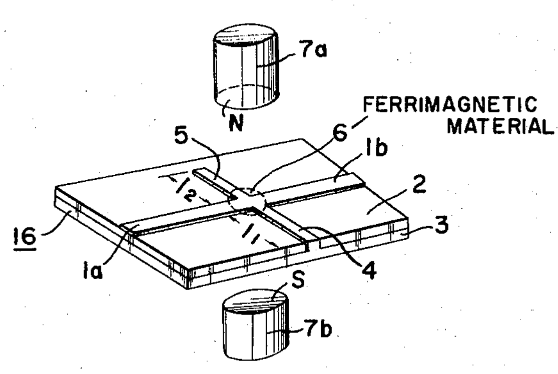
FIG. 2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FERRIMAGNETIC MATERIAL
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1a
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FIG. 3

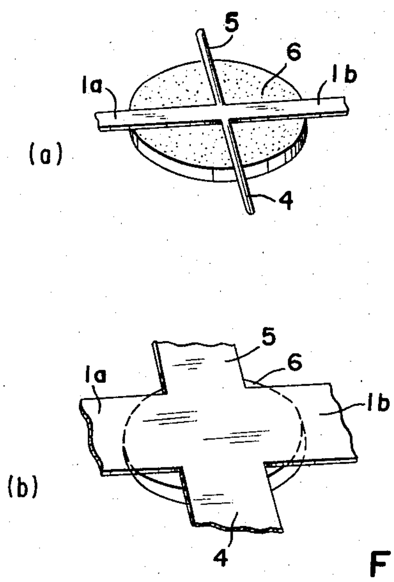


FIG. 4

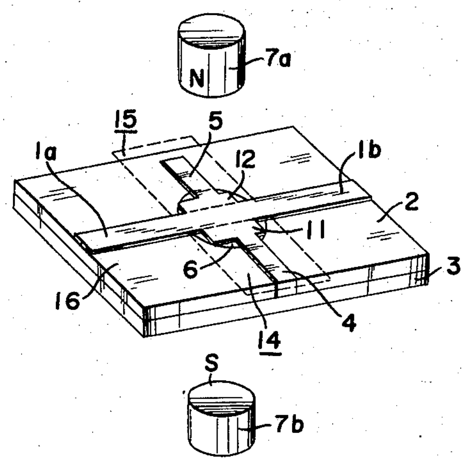
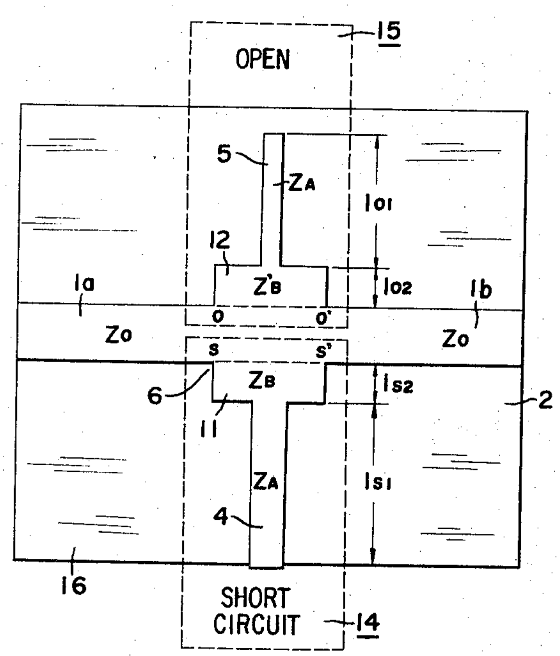
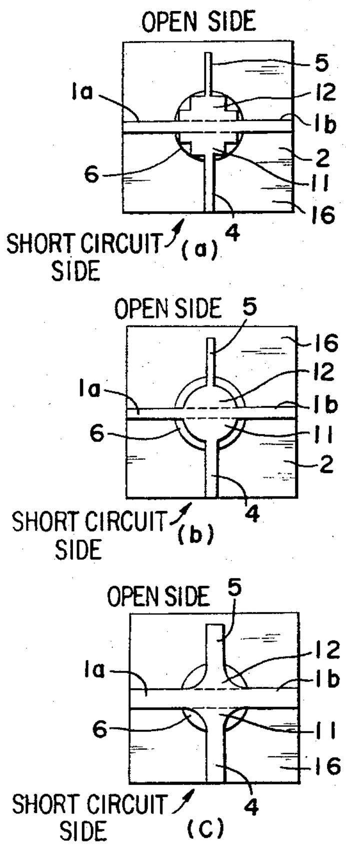


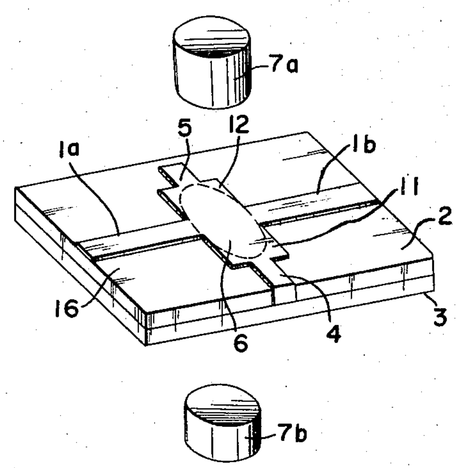
FIG. 5



F I G. 6



F I G. 7



F I G. 8

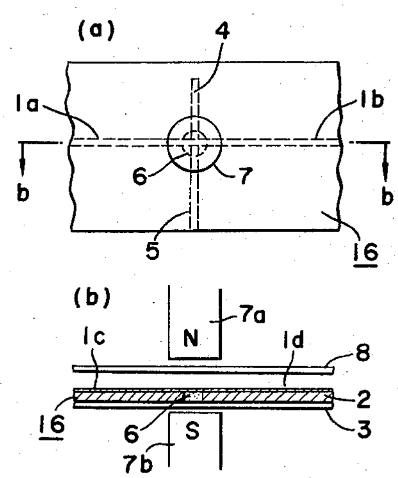


FIG.9

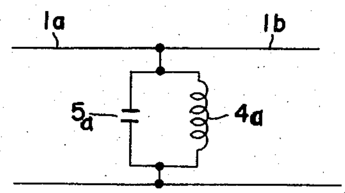


FIG.10

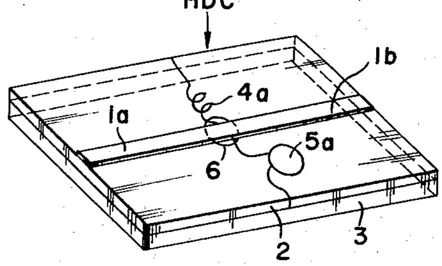
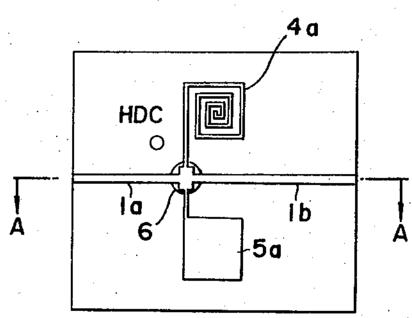
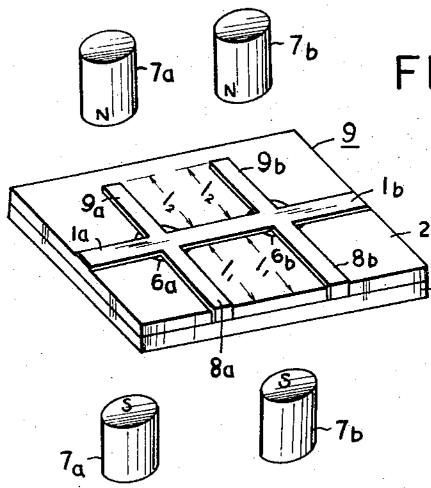


FIG.11




7a
7b
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N
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9b
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1a
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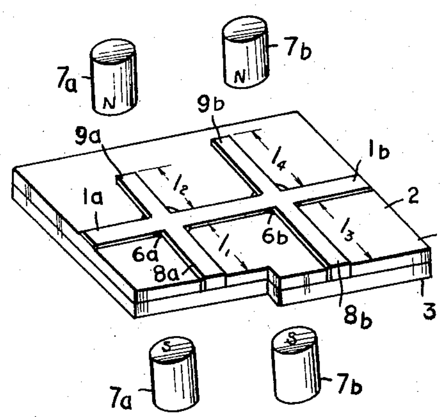
6b
8b
6a
3
8a
S
S
7a
7b

FIG. 12

FIG. 13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ISOLATOR

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to an isolator that is a unilateral attenuator in which microwaves are propagated in one direction.

2. Description of the Prior Art

Heretofore, as shown in FIGS. **1**(*a*) and **1**(*b*), a strip line type isolator has a structure which included a main line (**1***a*) and (**1***b*), a branch line (**4**), and a sub-branch line (**5**) for counterbalancing any reflection caused by the branch line (**4**). A ferrimagnetic material (**6**) such as aferrite, yttrium-iron-garnet was placed on a dielectric substrate (**2**) at a junction point such that a magnetic field H_{DC} for causing magnetic resonance absorption could be applied externally to the ferrimagnetic material.

In order to form circularly polarized waves at the junction point, a length of the branch line (**4**) was selected to be three-eighths of a wavelength and in order to counterbalance the branch line (**4**), the length of the sub-branch line (**5**) was selected to be one-eight of a wavelength.

Accordingly, in the past when the frequency of operation of said structure was to be low, the length of the branch line (**4**) had to be long and resulted in an impractical size.

Moreover, the prior art structure had a Figure of merit, which is important for deciding characteristics of the isolator, which was low and the making of the isolator was somewhat difficult and complex

SUMMARY OF THE INVENTION

Accordingly, it is an object of this invention to provide a new and improved unique isolator, which is of a compact and miniature size.

It is another object of this invention to provide a new and improved unique isolator having an advantageous Figure of merit for deciding isolator characteristics.

Briefly, in accordance with this invention, in one aspect, the foregoing and other objects, features and advantages can be attained by providing an isolator which includes a dielectric substrate and a magnetic material inserted in a hole of the dielectric substrate in the thickness direction thereof. A single ground plate conductor is placed on one surface of the dielectric substrate and a main line conductor is placed on the other surface of the dielectric substrate and over the magnetic material. A branch line conductor and a sub-branch line conductor branch from the main line conductor and one end of the line conductor is opened and the other end of the line conductor is connected to the single plate conductor.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete appreciation of the present invention will be obtained as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawing wherein:

FIG. **1**(*a*) is a plan view of a conventional unilateral attenuator except for the magnet element thereof;

FIG. **1**(*b*) is a sectional side view of the conventional unilateral attenuator of FIG. **1**(*a*);

FIG. **2** is a schematic view of one preferred embodiment of an isolator according to this invention;

FIGS. **3** (*a*) and (*b*) are respectively schematic views showing the junction of FIG. **2**;

FIG. **4** is a schmeatic view of another preferred embodiment of an isolator according to this invention;

FIG. **5** is a plan view of the isolator of FIG. **4**;

FIGS. **6** (*a*),(*b*) and (*c*) respectively are plan views of the isolator of FIG. **5**;

FIG. **7** is a schematic view of still another preferred embodiment of the isolator of this inveniton;

FIG. **8** (*a*) is a plan view of yet another embodiment of the isolator of this invention and FIG. **8** (*b*) is a sectional side view of the isolator of FIG. **8**(*a*);

FIG. **9** is a diagram of an electrical equivalent circuit of FIGS. **1**(*a*) and (*b*);

FIG. **10** is a schematic view of one other preferred embodiment of the isolator of this invention;

FIG. **11** is a plan view of another preferred embodiment of the isolator of the present invention;

FIG. **12** is a schematic view of still one more preferred embodiment of the isolator of this invention; and,

FIG. **13** is a schematic view of one further preferred embodiment of the isolator of this invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The drawings will now be referred to wherein like reference numerals designate identical, or corresponding parts throughout the several views.

From the viewpoint of compact and miniature size, unilateral attentuator of an isolator should have the branch line (**4**) at a length of three-eights wavelengths and an end which is opened. As a result thereof, the impedance from the joining point of the main line (**1***a*) and (**1***b*) to the open end, will act as an inductive reactance whose absolute value is equal to the value of the characteristic impedance of the branch line. In order to form a circularly polarized wave, the current passing through the main line (**1***a*) and (**1***b*) should be equal to the current passing around the junction point to the branch line (**4**), so that when a load is equal to the characteristic impedance of the main line (**1***a*) and (**1***b*), the characteristic impedance of the branch line (**4**) should be equal to that of the main line (**1***a*) and (**1***b*).

However, with the present invention, it is unnecessary to use a branch line having a length of three-eights wavelength and whose end is opened in order to provide an inductive reactance equal to the characteristic impedance of the branch line.

As shown in FIG. **2**, the branch line (**4**) has an end which is connected to the base. When the phase constant of the branch line (**4**) is β_1; the characteristic impedance is Z_1; the length is l_1, then the impedance Z_L from the joining point of the main line (**1***a*) and (**1***b*) to the end, can be given as follows assuming a loss free transmission line.

$$Z_L = jZ_1 \tan \beta_1 l_1$$

Accordingly, Z_L is inductive in the range of $0<\beta_1 l_1 (\pi/2) \therefore$

$$0<l_1<(\lambda/4).$$

On the other hand, when the characteristic impedance of the main line (**1***a*) and (**1***b*) is Z_o, the main line

($1a$) and ($1b$) is connected to matched load, and the voltage at the junction of the branch line (**4**) is V; then the current I_m and I_j passing to each line at the junction of the main line ($1a$) and ($1b$) and the branch line (**4**) are given as follows:

$$I_m = V/Z_o \tag{1}$$

$$I_j = V/Z_L = V/jZ_1\ \beta_1 l_1 \tag{2}$$

The condition for forming a circularly polarized wave is

$$|I_m| = |I_j| \tag{3}$$

wherein the phase difference of I_m and I_j is 90°.

Accordingly, the following equation can be derived from the equations (1), (2) and (3).

$$Z_o = Z_1 \tan \beta_1 l_1 \tag{4}$$

This is the condition for forming a circularly polarized radio frequency magnetic field at the junction of the branch line (**4**).

In order to minimize the dimensions of the isolator, l_1 should be decreased. However, in order to satisfy the equation (4), Z_1 should be increased, that is the width of the branch line (**4**) should be decreased in the case of a substrate having a specific thickness.

However, from the viewpoint of processing, the width of the branch line (**4**) should not be too narrow. Moreover if the branch line (**4**) is too narrow, losses will occur. Accordingly, the size of Z is limited.

On the other hand, the sub-branch line (**5**) is a line having an opened end. Accordingly, when the length is l_2 and the characteristic impedance is Z_2 and the phase constant is B_2, then the impedance Z_c of the sub-branch line (**5**) from the junction of the main line ($1a$) and ($1b$) can be given as follows:

$$Z_c = jZ_2 \cot \beta_2 l_2 \tag{5}$$

In order to counterbalance any reflection caused by the branch line (**4**), the following condition is required.

$$(1/Z_L) + (1/Z_c) = (1/jZ_1 \tan \beta_1 l_1) - (1/jZ_2 \cot \beta_2 l_2) = 0 \tag{6}$$

$$Z_2 \cot \beta_2 l_2 = Z_1 \tan \beta_1 l_1 \tag{7}$$

From the above discussion, it is clear that the branch line (**4**) need not have a length of three-eights of a wavelength and that a unilateral attenuation of an isolator having a line shorter than one-fourth wavelength can be formed by using one end as a short circuit line. The line width of the branch line (**4**) and the sub-branch line (**5**) should be changed depending upon the selected length.

It should now be apparent that in accordance with this invention, miniaturization of the isolator can be attained in comparison with the conventional ones which require much longer lines.

From the viewpoint of improvement of Figure of merit, the unilateral attenuator can be considered as follows.

When the equations 4 and 7 alone are satisfied for the isolator, a circularly polarized radio frequency magnetic field is formed at the junction of the end short circuit branch line (**4**) and main lines ($1a$) and ($1b$). From a view of the main line ($1a$) and ($1b$), the end short circuit branch line (**4**) and the end open sub-branch line (**5**) are matched in parallel resonance.

In order to improve the frequency characteristics of the parallel resonance circuit, the length of the end short branch line l_1 is decreased and the length of the end open sub-branch line l_2 is increased, as far as possible, in the range of the equations (1) and (2) so as to decrease the inductance L of the resonance circuit and to increase capacitance C of the resonance circuit.

Incidentlly, when the frequency characteristics of the resonance circuit are improved, the impedance Z_1 and Z_2 obtained by the equations (4) and (7) are increased, so that the width of the branch Line (**4**) and the width of the sub-branch line (**5**) becomes narrow as shown in FIG. **3**(a). In the junction of the shape shown, and as confirmed by experiments, the complete circularly polarized wave in the ferrimagnetic material **6** is deteriorated, whereby the Figure of merit is deteriorated and the forward loss is increased.

In order to improve the distribution of the circularly polarized wave in the ferrimagnetic material **6** and to improve the forward loss, it is preferable to have a structure such that the juncture substantially covers the ferrimagnetic material **6** as shown in FIG. **3**(b).

However, in the structure of FIG. **3**(b), the characteristic impedances Z_1 and Z_2 of the branch line (**4**) and the sub-branch line (**5**) are respectively decreased.

Accordingly, in order to satisfy the equations (4) and (7), in said condition, l_1 should be long and l_2 should be short, so that the frequency characteristics of the parallel resonance circuit is deteriorated. A contradiction thereby results.

The present invention as now described with reference to FIG. **4**, serves to overcome the contradiction discussed above. FIG. **4** shows a schematic view of an isolator for improving the Figure of merit.

In order to counterbalance the reflection caused by the branch line (**4**) which is connected to the main line ($1a$) and ($1b$), the end open sub-branch line (**5**) is connected to the junction, and the ferrimagnetic material (**6**), whose area is not much larger than the area of the junction or is smaller than the area of the junction, is fitted around the junction and a magnetic field forming magnetic resonance absorption is externally applied to the ferrimagnetic material.

Incidentally, the end short circuit branch line (**14**) is formed by the shorted side broad conductor (**11**) and the end short circuit line (**4**), while the end open sub-branch line (**15**) is formed by the broad open side conductor (**12**) and the end open line (**5**).

In FIG. **4**, a ground plate conductor (**3**), magnet ($7a$) and ($7b$) and a composite substrate (**16**) consisting of ferrimagnetic material (**6**) filled in the dielectric substrate (**2**), are combined.

FIG. 5 is a plan view for illustrating in detail the isolator of FIG. 4. When the characteristic impedance of the main line (1*a*) and (1*b*) is Z_o; the characteristic impedance of the end short circuit line (4) is Z_A; the phase constant is β_1; the length is l_{S1}; the characteristic impedance of the shorted side broad conductor **11** is Z_B: the phase constant is β_2; the length is l_{S2}; the characteristic impedance of the end open line (5) is Z_A'; the phase constant is β_1'; the length is l_{o1}; the characteristic impedance of the open side broad conductor **12** is Z_B'; the phase constant is β_2' and the length is l_{o2}, then the following conditions will result:

$$Z_A = \frac{Z_B\left(1-\frac{Z_B}{Z_o}\tan\beta_2 l_{S2}\right)}{\left(\frac{Z_B}{Z_o}+\tan\beta_2 l_{S2}\right)\tan\beta_1 l_{S1}} \quad (8)$$

$$Z_{A'} = \frac{Z_{B'}\left(1+\frac{Z_{B'}}{Z_o}\tan\beta_{2'} l_{o2}\right)}{\left(\frac{Z_{B'}}{Z_o}-\tan\beta_{2'} l_{o2}\right)\cot\beta_{1'} l_{o'}} \quad (9)$$

When the following conditions are satisfied,

$$o << l_{S1} < \lambda_1/4$$

$$o < l_{S2} < \lambda_2/4$$

$$o < l_{o1} < \lambda_1'/4$$

$$o < l_{o2} < \lambda_2'/4$$

$$(Z_B/Z_A) > \tan\beta_1' l_{S1} \cdot \tan\beta_2' l_{S2},$$

wherein

$ZA' \cot\beta_1 l_{o1} > ZB' \tan\beta_2 l_{o2}$ $\beta_1 = 2\pi/\lambda_1$, $\beta_2 = 2\pi/\lambda 2$, $\beta_1 = 2\pi/\lambda_1$, and $\beta_2 = 2\pi/\lambda_2$, a uniform circularly polarized radio frequency magnetic field excited at the junction results, and the end short circuit branch line (**14**) and the end open sub-branch line (**15**) are matched and resonated in parallel from the view of the main line (1*a*) and (1*b*).

In accordance with the present embodiment, the forward loss which is dependent upon the distribution of the circularly polarized waves in the ferrimagnetic material (**6**) is decreased by the use of the broad conductors (**11**) and (**12**) on the shorted and open sides, and the frequency characteristics of the parallel resonance circuit is improved by the appropriate selection of the length and characteristic impedances of short circuit line (**4**) and the open line (**5**), whereby the fundamental contradiction of no improvements in the characteristics of the conventional isolator, can be overcome so as to result in an isolator having a compact size, a broad range and an excellent Figure of merit.

FIGS. **6** (*a*), (*b*) and (*c*) are respectively plan views of another preferred embodiment of the isolator of the present invention, wherein the broad conductor (**11**) on the short circuit side and the broad conductor (**12**) on the open side are changed in shape. This embodiment can be applied to the isolator having the end open branch line.

Although the present embodiment is shown with the ferrimagnetic material (**6**) filled in the dielectric substrate (**2**), it should be understood that it is possible to substitute the dielectric substrate and the ferrimagnetic material by one magnetic plate.

Moreover, the present embodiment can be used for a high power isolator. In order to enable high power isolator use, it is necessary to decrease the heat per volume of ferrimagnetic material. It is important to increase the volume of the ferrimagnetic material without increasing the insertion loss.

The heat per volume of the ferrimagnetic material can be decreased without substantially changing the condition of the circularly polarized wave so that an isolator suitable for high power can be obtained by increasing the area of junction size in the width direction as shown in FIG. **7.** In FIG. **7,** the structure is shown as being applied to both the end short circuit branch line and the end open branch line, however, it is possible to apply it to either of the branch lines.

In the preparation of the open type strip line formed by the dielectric substrate (**2**) in contact with the ground plate conductor (**3**) and the main line conductor (1*a*) and (1*b*), the branch line conductor (**4**), and the sub-branch line conductor (**5**), that is the microstrip line, a tight adhesiveness of the dielectric substrate (**2**), the main line (1*a*) and (1*b*) and the ground plate conductor (**3**) is quite an important factor for decreasing fluctuation of impedance of the lines and preventing undesirable modes.

In order to miniaturize or make a compact circuit, it is preferable to use a high dielectric constant material. However, in such cases tight adhesiveness of the junction is required. It has been relatively hard to insert a ferrimagnetic material (**6**) into such a structure. It has been considered to prepare it by forming a hole in the ground plate conductor (**3**) and the dielectric substrate (**2**) and then the ferrimagnetic material (**6**) is placed in the hole and the hole of the ground plate conductor (**3**) is filled with a solder. However, the adhesiveness formed in such an arrangement, is inferior, so that this type of unilateral attenuator could not be practically used, except as a shield type strip line (triplate) without using a dielectric substrate.

However, desirable results can be obtained by the following preparation using metallizing, metal plating, and etching which have been recently developed for integrated circuit (IC) processes.

A hole is formed in the dielectric substrate (**2**) and a ferrimagnetic material (**6**) is inserted and adhered to it and the surface is processed to form a composite plate or substrate (**16**). A desirable conductive pattern is formed on the composite substrate (**16**) by metallizing, metal plating, etching or printing.

It should be understood that the shape of the inserted ferrimagnetic material (**6**) can be other than disc, as shown in FIG. **2.** Thus, the ferrimagnetic material (**6**) can be of a square shape. It should be further understood that the end connection of the branch line (**4**) of FIG. **2** can be formed by metal plating, etching, and the like and also by forming a hole in the dielectric substrate and inserting a metallic screw to form a short-circuit to the ground plate conductor (**3**).

In still another preferred embodiment as shown in FIG. **8,** a metal plate (**8**) is inserted between the upper magnetic pole (7*a*) and the surface of the dielectric substrate (**2**) adhering the main line (1*a*) and (1*b*) and the branch line (**4**), the sub-branch line (**5**), etc., by departing from the surface of the dielectric substrate in a direction substantially parallel to it, whereby certain disturbances which may be caused by the outside are prevented, certain affects of wave leakage to the outside are prevented and certain structural advantages are provided.

When the frequency of operation is decreased to the VHF band, a satisfactory size of miniaturization cannot be attained by the present embodiment. Accordingly, an embodiment to result in miniaturization can be provided by using a lumped constant alternative device for the branch line and the sub-branch line.

FIGS. **1** (*a*) and (*b*) can be shown as by equilavent circuit in FIG. **9.** Accordingly, the same operation can be obtained by using lumped constant elements without using a distribution constant line to provide a miniaturized and compact unit particularly for low frequency use.

An embodiment will now be illustrated with reference to FIG. **10** and FIG. **11** wherein lump constant elements are used.

FIG. **10** is a schematic view of an isolator similar to that of FIG. **1** except that the branch line (**4**) is substituted with an inductance (**4***a*), such as a coil, and the sub-branch line (**5**) is substituted with a condenser (**5***a*).

FIG. **11** shows a preferred embodiment of an isolator wherein a ferrimagnetic material (**6**) is placed in the dielectric substrate (**2**) and the main line (**1***a*) and (**1***b*), the inductance (**4***a*) and the condenser (**5***a*) are formed on the surface in a conductive pattern by employing metallization, metal plating, etching or printing technology.

When the isolator is prepared by employing printing technology, the same shaped conductive pattern can be accurately formed, so that effective stabilization of the characteristics of the isolator can be obtained relatively inexpensively. While in the embodiments of FIGS. **10** and **11** the ferrimagnetic material is placed in the dielectric substrate (**2**), it is to be understood that it is possible to substitute the dielectric substrate and the ferrimagnetic material by a single sheet of a ferrimagnetic substrate. Also the embodiments of FIGS. **10** and **11** can be applied to not only the microstrip type line but also to the triplate type strip line. Various types of inductances and condensers can be used and it is preferable to select them so as to be convenient for the particular use desired.

FIG. **12** is a schematic view of another preferred embodiment of the isolator of the present invention wherein two unilateral attenuators are connected in series so that it is unnecessary to have as great an inverse loss for each one. Accordingly, the forward loss for each attenuator can be overly small, and it is possible to use the part having superior frequency characteristics of forward loss. Accordingly, as a whole, it is possible to obtain an isolator having a miniaturized compact size and high frequency characteristics of forward loss and a broad band zone of inverse loss.

FIG. **13** is a schematic view of yet another preferred embodiment of the isolator of the present invention wherein different lengths of the end short-circuit branch line (**8***a*) and (**8***b*) or different lengths of the end open sub-branch line are formed so as to deviate the frequency causing the circularly polarized radio frequency magnetic field. In accordance with this embodiment, the frequency band of the inverse loss becomes a broader band then that of FIG. **12,** though the forward loss and VSWR frequency characteristics are relatively lower than those of FIG. **12.**

Obviously, numerous modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that within the scope of the teachings herein and the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed as new and desired to be secured by letters patent of the United States is:

1. An isolator which comprises:
- a dielectric substrate;
- a ferrimagnetic material inserted in a hole of said dielectric substrate in the direction of thickness of said dielectric substrate;
- a single ground plate conductor placed on one surface of said dielectric substrate;
- a main line conductor placed on the other surface of said dielectric substrate and over said ferrimagnetic material; and
- a branch line conductor and a sub-branch line conductor placed on said other surface and connected to and branching from said main line conductor at approximately the location of said ferrimagnetic material;

wherein one end of said sub-branch line conductor is opened and one end of said branch line conductor is connected to said single ground plate conductor.

2. The isolator according to claim **1**, wherein the width of said conductors at the junction of said main line and both of said branch lines is broader than the width of at least one of said lines.

3. The isolator according to claim **1,** wherein the conductive material comprising said conductors which is placed on both of said surfaces of said substrate is formed by a conductive pattern.

4. The isolator according to claim **1,** wherein at least one of both of said branch line conductors is formed by a lumped constant element.

5. The isolator according to claim **1,** wherein a circularly, polarized wave is formed at the junction of the main line, the branch line and the sub-branch line.

6. The isolator according to claim **1,** further comprising a plurality of pairs of branch lines and sub-branch lines which are connected in series to said main line conductor.

7. The isolator according to claim **5,** wherein different lengths of said plurality of branch lines are provided.

8. The isolator according to claim **6,** wherein different lengths of said plurality of sub-branch lines are provided.

* * * * *