United States Patent [19]

Tanaka et al.

[11] **3,729,692**

[45] **Apr. 24, 1973**

[54] **MICROWAVE CIRCULATOR CIRCUITS**

[75] Inventors: **Mitsuo Tanaka**, Kokubunji; **Akira Honda**, Ome, both of Japan

[73] Assignee: **Hitachi, Ltd.**, Tokyo, Japan

[22] Filed: **July 8, 1971**

[21] Appl. No.: **160,762**

[52] **U.S. Cl.** .....**333/1.1**, 333/10, 333/11, 333/84 M

[51] **Int. Cl.**.....**H01p 1/32**, H01p 5/12

[58] **Field of Search**.....333/1.1, 10, 11, 333/6

[56] **References Cited**

UNITED STATES PATENTS

2,848,714	8/1958	Ring	333/1.1 UX
3,573,651	4/1971	Engelbrecht	333/1.1 X
3,622,896	11/1971	Pircher	333/1.1 X

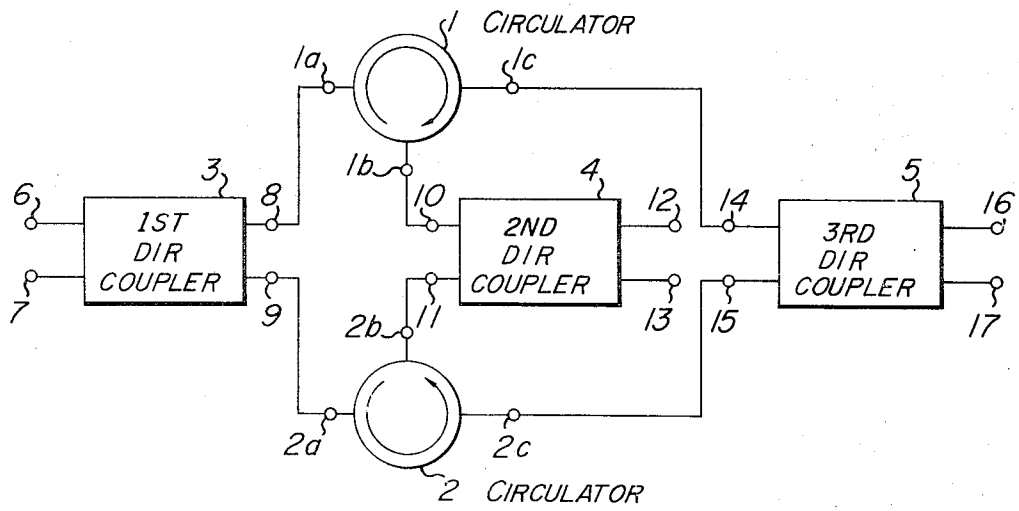
Primary Examiner—Paul L. Gensler

Attorney—Craig, Antonelli & Hill

[57] **ABSTRACT**

The microwave circulator circuit comprises two circulators of the same characteristic each having three terminals and three 3dB directional couplers each having four terminals. Three pairs of terminals, each pair consisting of corresponding ones of the terminals of the two circulators, are connected with the three pairs of terminals, each pair consisting of two terminals of particular one of the four-terminal couplers so as to form a six-terminal composite circulator.

3 Claims, 8 Drawing Figures



Patented April 24, 1973 3,729,692

3 Sheets-Sheet 1

FIG. 1

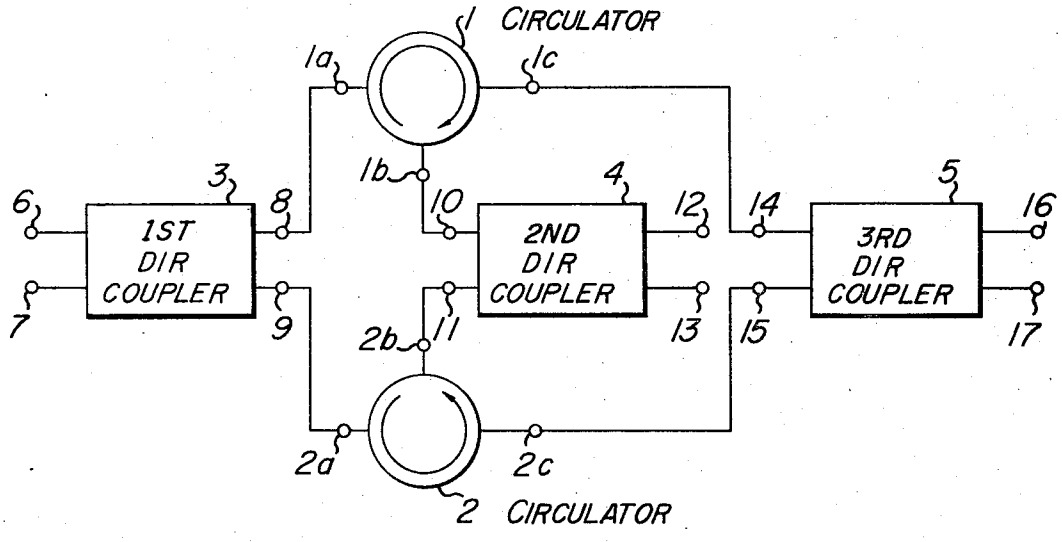


FIG. 2

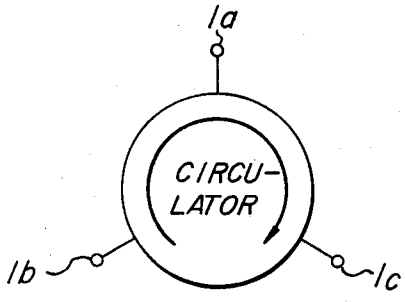
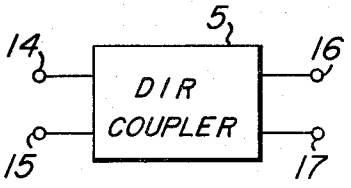


FIG. 3



INVENTORS

MITSUO TANAKA and AKIRA HONDA

BY Craig, Antonelli & Hill

ATTORNEYS

FIG. 4

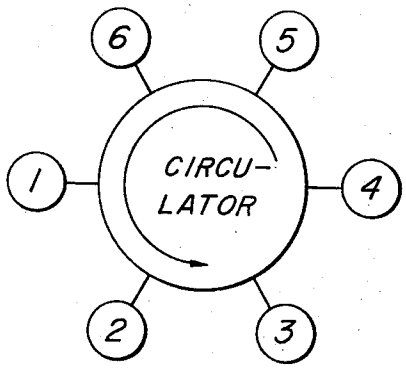


FIG. 5
PRIOR ART

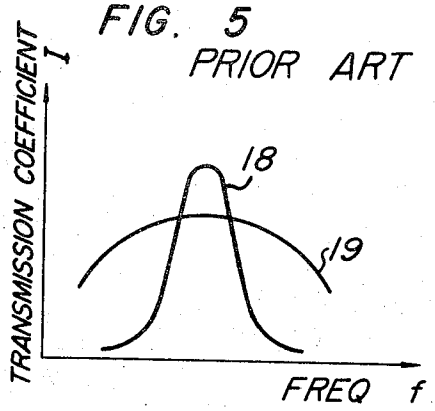
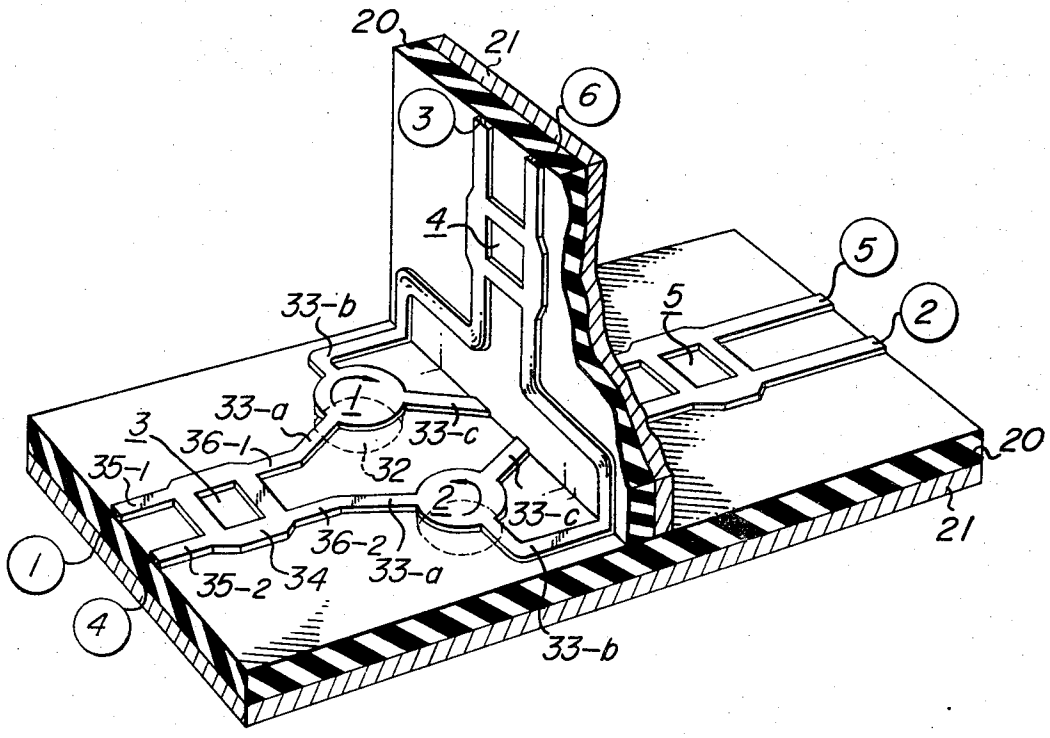


FIG. 6



INVENTORS

MITSUO TANAKA and AKIRA HONDA

BY Craig, Antonelli & Hill

ATTORNEYS

FIG. 7

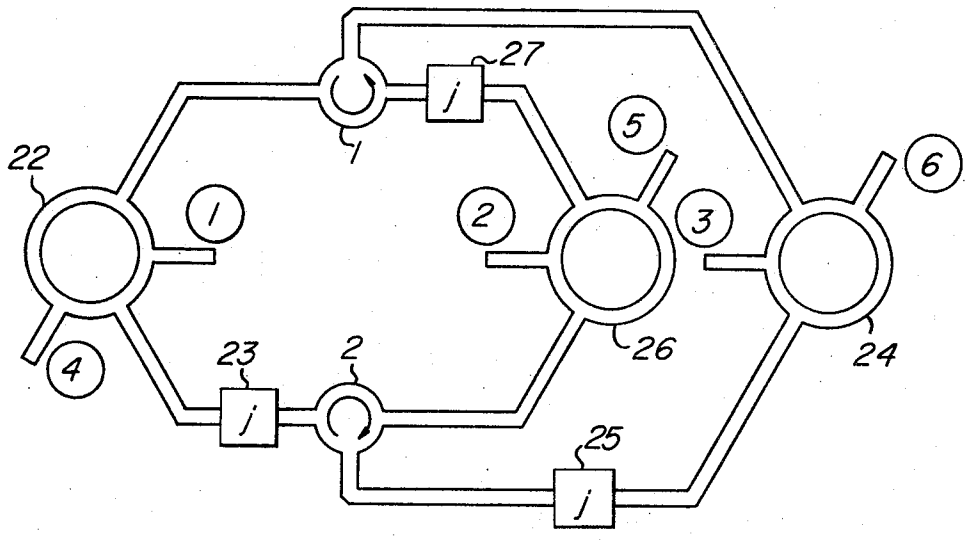
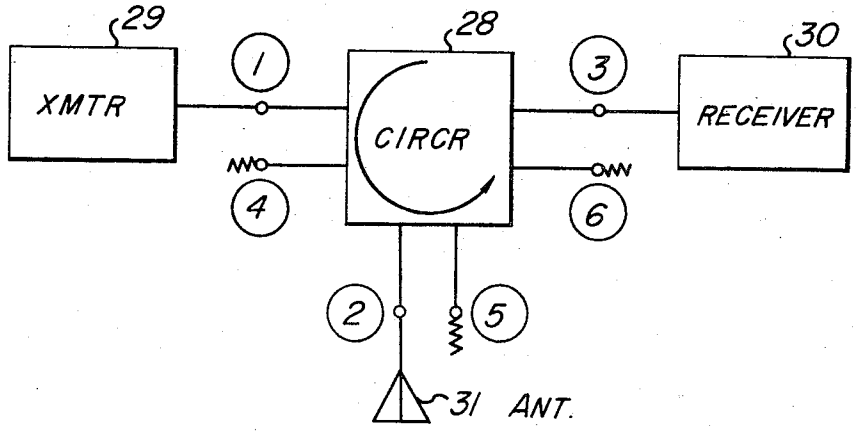


FIG. 8



INVENTORS

MITSUO TANAKA and AKIRA HONDA

BY Craig, Antonelli & Hill

ATTORNEYS

MICROWAVE CIRCULATOR CIRCUITS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a microwave circulator circuit and more particularly to a circuit device which can separate input signals from output ones, or received signals from signals to be transmitted, in wave guide circuits or integrated microwave circuits.

2. Description of the Prior Art

The conventional transmitter-receiver circuit for use in a radio communication system has employed the combination of circulators and filters to separate received signals from signals to be transmitted. Such circulators are of multi-terminal type, each having a plurality of terminals.

The terminals have their directional input and output characteristics for proper signal circulation in the circulator and yet they are to exhibit infinite attenuation characteristics for reverse circulation under an ideal condition. However, in practical application, the attenuation is nearly 20 to 40 dB. Therefore, when such a circulator is used in a transmitter-receiver circuit where the frequency interval between the transmitting frequencies and the receiving ones is narrower than the band width of intermediate frequencies, signals to be transmitted leak directly into the receiver circuit. This causes the receiver to be saturated and moreover the leak signals are superposed upon received signals so that the interference between both the signals will make the communication impossible. Especially, the conventional circulators cannot be used for a radar transmitter-receiver, specifically a continuous wave radar system, since the radar system uses transmitted and received waves whose frequencies are nearly equal to each other so that one of the waves cannot be effectively separated from the other through the circulators. Consequently, it is difficult to design a superior receiver means of heterodyne mode with the aid of such conventional circulators. Conventionally, a homodyne detection system has been employed, but the reception sensitivity in the homodyne system is poorer than in the heterodyne system. There has been also proposed an arrangement in which two circulators of the same characteristic are in cascade connection in order to equivalently increase the amount of attenuation for reverse circulation through the circulator as mentioned above. However, in this arrangement, the leakage of spurious signals during reverse circulation is considerably great so that the characteristic of the circulator circuit cannot be substantially improved.

SUMMARY OF THE INVENTION

An object of the present invention is to provide an improved microwave circulator circuit almost free from the influence of leakage signals during reverse circulation.

Another object of the invention is to provide a circulator circuit which experiences no influence thereupon by spurious signals such as reflected waves created in the circulators incorporated in the circuit.

A further object of the invention is to provide a circulator circuit having a simple structure and yet an excellent characteristic.

Therefore, the present invention devised so as to attain the above said objects is characterized by the following construction.

Namely, according to the present invention, two circulators of the same characteristic are combined together in a balanced type configuration. Corresponding terminals of the two circulators each having three terminals are grouped in two's to provide three pairs of terminals, each pair being connected with a four terminal coupler. Thus, a six-terminal circulator circuit is provided of which the attenuation of the circulating current in the reverse direction is equivalently rendered infinite.

It is apparent that the further objects, features and advantages of the present invention will be better understood when the following descriptions of the embodiments of the invention is read in conjunction with the accompanying drawings. Moreover, it is apparent that the described embodiments are only some of the examples of this invention and that the present invention is in no way limited to these embodiments above.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram illustrating the fundamental constitution of a circulator circuit of the present invention.

FIGS. **2** and **3** are schematic diagrams respectively of the circulator and directional coupler used in the constitution in FIG. **1**.

FIG. **4** shows an equivalent circuit of the circulator circuit of the present invention.

FIG. **5** is a graphic representation of the relation between the frequency and the transmission coefficient of the conventional circulator circuit.

FIG. **6** is a perspective view showing an embodiment of a circulator circuit made according to the present invention, using microstrip lines, with its principal portion magnified for clarity.

FIG. **7** is a plan view showing a pattern of constitution of another embodiment of the present invention, also using microstrip lines.

FIG. **8** is a schematic block diagram of a transmitter-receiver circuit of a continuous wave radar system using a circulator circuit according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In FIG. **1**, reference numerals **1** and **2** indicate circulators of the same characteristic, respectively having terminals **1***a* to **1***c* and **2***a* to **2***c*. The terminals **1***a* and **2***a* are connected respectively with the terminals **8** and **9** of a first 3dB directional coupler **3**. The terminals **1***b* and **2***b* are connected respectively with the terminals **10** and **11** of a second 3dB directional coupler **4**. Finally, the terminals **1***c* and **2***c* are connected respectively with the terminals **14** and **15** of a third 3dB directional coupler **5**. Thus, the three directional couplers and two circulators in all constitute a circulator circuit or composite circulator having six terminals, i.e., two terminals **6** and **7** of the coupler **3**, two terminals **12** and **13** of the coupler **4**, and two terminals **16** and **17** of the coupler **5**.

In this figure, the circulators **1** and **2** and/or the directional couplers **3**, **4** and **5** may be conventional circulators and directional couplers. Moreover, the constitutions of such circuit elements are well known to those skilled in the field of microwave technology (see, for example, "Microwave Filters, Impedance Matching

Networks and Coupling Structures"; Matthaei, Young, Jones; McGrawnHill Book Co.). These elements can be constructed not only by solid circuits but also by plane circuits as used in the embodiments of this invention described below. Thus, there are a variety of possible modifications of such circuits as constitute the circuit elements and therefore their constitutions are not described in this specification. However, in order to provide a fuller understanding of the embodiments of this invention, the functions of the circuit elements are briefly explained.

FIG. 2 schematically shows a circulator having three terminals, in which the terminals are indicated for convenience sake by the same reference characters 1a, 1b and 1c as used to denote the terminals of the circulator 1 in FIG. 1.

Now, explanation will be given of the function of the circulator as shown in FIG. 2. If an input E is applied to the terminal 1a, it circulates in a direction indicated by arrow and an output E is derived at the terminal 1*c*. In like manner, an input applied to the terminal 1*c* gives an output at the terminal 1*b*. Similarly, an input applied to the terminal 1*b* results in an output at the terminal 1*a*.

FIG. 3 schematically shows a 3dB four-terminal directional coupler, in which the four terminals are designated for convenience sake by the same numerals 14, 15, 16 and 17 as used to denote the terminals of the directional coupler 5 as shown in FIG. 1.

The function of the directional coupler is as follows. If an input $\sqrt{2E}$ is applied to the terminal 14, then signals 0 (zero), E and jE (*j* denotes 90° lead in phase) appear respectively at the terminals 15, 16 and 17. In like manner, if an input $\sqrt{2E}$ is applied to the terminal 15, then signals 0 (zero), E and jE appear respectively at the terminals 14, 17 and 16. A similar result will be obtained when an input signal is applied to the terminal 16 or 17.

With these functions kept in mind, the description of the operation of the circulator circuit of FIG. 1 given below will be readily appreciated.

An input signal wave applied to the terminal 6 of the first directional coupler 3 is split into two signal waves which have the same amplitude but are different relatively by 90° in phase and the two waves are delivered at the terminals 8 and 9 and consequently applied to the terminals 1*a* and 2*a* of the circulators 1 and 2, respectively. The components of the two waves travelling along the proper directions, that is, in the directions indicated by arrows in the circulators 1 and 2, are fed to the 3dB directional coupler 5 respectively through the terminals 14 and 15 to be synthesized. Now, if the magnitude of the input voltage applied to the terminal 6 is $\sqrt{2E}$, the output at the terminal 8 and therefore the input at the terminal 14 will be of a magnitude E, while the output at the terminal 9 and therefore the input at the terminal 15 will be jE. Accordingly, no output will appear at the terminal 16 of the directional coupler 5 since $E/\sqrt{2}+j\,x\,j\,E/\sqrt{2}=0$, while an output $j\sqrt{2E}$ will appear at the terminal 17 since $jE/\sqrt{2}+jE/\sqrt{2}=j\sqrt{2E}$. In like manner, if an input $\sqrt{2E}$ is applied to the terminal 17 of the coupler 5, an output $j\sqrt{2E}$ will appear at the terminal 12 of the directional coupler 4.

On the other hand, as to the spurious components of the aforementioned two waves travelling in the reverse directions opposite to the proper directions, if an input signal wave is applied to the terminal 6 of the directional coupler 3, one of them passes through the terminal 8, circulates counterclockwise in the circulator 1 and appears at the terminal 16, while the other passes through the terminal 9, circulates clockwise in the circulator 2 and appears at the terminal 2*b*. The two outputs at the terminals 1*b* and 2*b* are synthesized through the directional coupler 4 according to its splitting and phase-shifting property so that combined spurious signal is produced at the terminal 13 while no output appears at the terminal 12 because of offset effect. In the same manner, if an input signal is applied to the terminal 17 of the coupler 5 or to the terminal 12 of the coupler 4, the corresponding spurious components result in a combined output only at the terminal 9 or the terminal 16 of the coupler 5, respectively. Therefore, if a three-terminal circulator circuit is defined by using the terminals 6, 17 and 12 respectively as a transmitter input terminal, a transmitter output terminal (= a receiver input terminal) and a receiver output terminal, then no spurious signal components will appear at those terminals. With this configuration of circuit which the present invention proposes, the influence of signal leakage on the circuit as a whole can be completely eliminated even if there are substantial leakage of signal in the circulators 1 and 2 for reverse circulation of signals. Moreover, no special design is needed for the circulators themselves and their degree of attenuation of the signal in the reverse direction need not be higher than that attainable with the conventional circulator. And therefore, the circulator circuit of the present invention may be very easily and economically produced since it employs none other than such conventional circuit elements as circulators and directional couplers. In the explanation given above, particular terminals are concerned, but the same explanation will be applied to the case where the roles of the terminals are exchanged among themselves in a circulating order because of the symmetrical structure of the circulator circuit fabricated according to the present invention. Namely, the circulator circuit as shown in FIG. 1 may be equivalently reduced to a single block circulator as seen in FIG. 4 by representing the terminals 6, 17, 12, 7, 16 and 13 especially mentioned in the above explanation as equivalent terminals 1, 2, 3, 4, 5 and 6. Thus, if it is desired to have a three-terminal circulator, any three neighboring terminals of the six equivalent ones are to be chosen.

Moreover, according to the present invention, in addition to the elimination of signal leakage, spurious signals due to reflected signal waves generated in the circuit and transmission lines constituting the circulator circuit are also eliminated on the basis of the same principle as described concerning the offsetting of the leak signals. Namely, the geometrical configuration of the circulator circuit of the invention is of a balanced type providing a structural symmetry so that reflected signals generated due to the physical discontinuity of the circuit cancel one another when appearing at desired output terminals and therefore they are substantially eliminated.

Further, the circulator circuit or a composite circulator made according to the invention has a broad band characteristic. In general, the frequency characteristic of the conventional circulator is represented by the curves as shown in FIG. 5. In the figure it is known that the relation between the frequency f and the transmission coefficient I is such that the greater is the transmission coefficient the narrower the available frequency band while the broader is the frequency band the more degraded the transmission coefficient, thus resulting in the greater signal leakage in the reverse direction. On the other hand, the circulator circuit of the present invention produces no spurious signals at desired terminals thereof, though such a signal leakage is substantially caused indeed. Hence, the circulator circuit of the invention can provide an effective broad band characteristic.

In FIGS. 6 and 7, the embodiments of the present invention are shown as constructed with microstrip lines (by microwave integrated circuit technique). The circuit as shown in FIG. 6 is almost the same as that as shown in FIG. 1 so like reference numerals indicate like elements. The terminals 1 through 6 as shown in FIG. 6 correspond to those of the model circulator as shown in FIG. 4.

As seen in FIG. 6, the circulators 1, 2 and the directional couplers 3, 4, 5 are constructed with transmission lines (referred to as microstrips) providing a transmission mode of asymmetric TEM (transverse electric and magnetic) wave. The thin conductors or transmission lines having specific shapes are parallel extended over a broad conductive surface region or ground plane 21 with a dielectric substance 20 having a great dielectric constant interposed between them.

The thin conductors constitute two spider members 1, 2 serving as circulators and three lattice members 3, 4, 5 serving as directional couplers and as a whole constitute a circulator circuit or a composite circulator. Each of the spider members consists of an orbicular common portion and three strips 33-*a*, 33-*b* and 33-*c* extending radially symmetrically from the common portion. In portions of the dielectric substance 20 between the orbicular common portions of the two spider members and the ground plane 21 are embedded circular discs of aeolotropic magnetic material 32 which has nearly the same diameter as the orbicular portion and a thickness slightly larger than the dielectric substance 20.

Each of the lattice members (for example, only the directional coupler 3 is explained but similar explanation will be applied to the other couplers 4, 5) consists of a lattice portion 34 and two pairs of strips 35 and 36. The strips 36-1 and 36-2 constituting one of the pairs are connected respectively with the strips 33*a* of the aforementioned spider members 1 and 2. The strips 35-1 and 35-2 constituting the other pair forms the terminals 1 and 4 of the composite circulator and may be connected in well known manner with other strip lines, coaxial lines or any suitable load (not shown).

FIG. 7 shows a composite six terminal circulator identical in principle with that shown in FIG. 1, in which directional couplers are composed of rat races and quadrature-phase shifters. This circuit pattern of integrated microwave circuit in FIG. 7 is also designed with microstrip lines as used in the circuit pattern shown in FIG. 6.

Namely, a rat race 22 and a phase shifter 23 form the directional coupler 3 in FIG. 1 circuit, a rat race 24 and a phase shifter 25 the directional coupler 4, and a rat race 26 and a phase shifter 27 the directional coupler 5. The pattern of this embodiment can be advantageously developed on a plane.

FIG. 8 shows an embodiment of this invention in which the composite circulator according to the present invention is used in a transmitter-receiver circuit for continuous wave radar system. In this figure, numeral 28 designates the composite circulator whose terminals 1 through 6 correspond to the respective terminals of the six terminal composite circulator or circulator circuit as described in the foregoing explanation of embodiments. Numerals 29, 30 and 31 indicates respectively a transmitter, a receiver and an antenna for use in both transmission and reception. A continuous wave transmission signal is fed to the antenna 31 via the terminal 1, the composite circulator 28 and the terminal 2 and radiated from the antenna to the ambient medium. Some of the radiated wave is reflected from the object to be searched, and again reaches the antenna. Then, the received wave is sent to the receiver 30 via the terminal 2, the composite circulator 28 and the terminal 3. Suppose that the composite circulator 28 is replaced by a conventional circulator having its terminals 1, 2 and 3 connected respectively with the transmitter 29, the receiver 30 and antenna 31 just as in FIG. 8. In this case transmission signals to be fed via terminals 1 and 2 to the antenna 31 will considerably leak into the receiver 30 through the terminal 3. For example, if the level of the transmission signal is zero dB.m, there will be a leakage of −20 to −30 dB.m. The received signal is only a part of the reflected signal which is already a part of the total transmitted signal. Moreover, the signal transmitted from the antenna will experience attenuation due to transmission through medium, and therefore its level will often be lowered to about −100 dB.m when it has reached the antenna again. Thus, the level of the leakage signal is by far higher that of the received signal so that the receiver cannot perform its proper operation.

On the other hand, according to the present invention, such signal leakage or spurious signals due to reflection of signal waves in the transmitter-receiver circuit will appear exclusively at the terminals 4, 5 and 6 which are unused for transmission and reception operation. Therefore, the undesirable components of signals can be completely removed if suitable load impedances to provide non-reflecting termination are connected with the terminals 4, 5 and 6.

The present invention has heretofore been described through a few embodiments, but it is apparent that the present invention is not limited to those embodiments but permits further alternations and modifications made without departing from the scope and spirit of the invention.

What we claim is:

1. A microwave circulator circuit comprising two circulators of the same characteristic each having three terminals, the corresponding ones of said terminals of respective said circulators forming three pairs of terminals, three 3dB directional couplers each having four terminals, the two terminals of each pair of said three pairs of terminals being connected respectively with two terminals of relevant ones of said directional

couplers, the remaining six terminals of said directional couplers being input and output terminals.

2. A microwave circulator circuit as claimed in claim 1, wherein each of said directional couplers consists of a rat race having four terminals and a quadrature-phase shifter connected with one of the four terminals of said rat race.

3. A microwave circulator circuit as claimed in claim 1, wherein both said circulators and said directional couplers are constructed with microstrip lines.

* * * * *