United States Patent

[11] 3,614,670

[72] Inventor **Richard G. Wilson**
San Jose, Calif.

[21] Appl. No. **874,191**
[22] Filed **Nov. 5, 1969**
[45] Patented **Oct. 19, 1971**
[73] Assignee **The United States of America as represented by the United States Atomic Energy Commission**

[54] **SWITCHABLE MICROWAVE CIRCULATOR WHEREIN GROUND PLANES ARE COMPRISED OF FOILS HAVING VERTICALLY CONDUCTIVE PARTICLES**
5 Claims, 3 Drawing Figs.

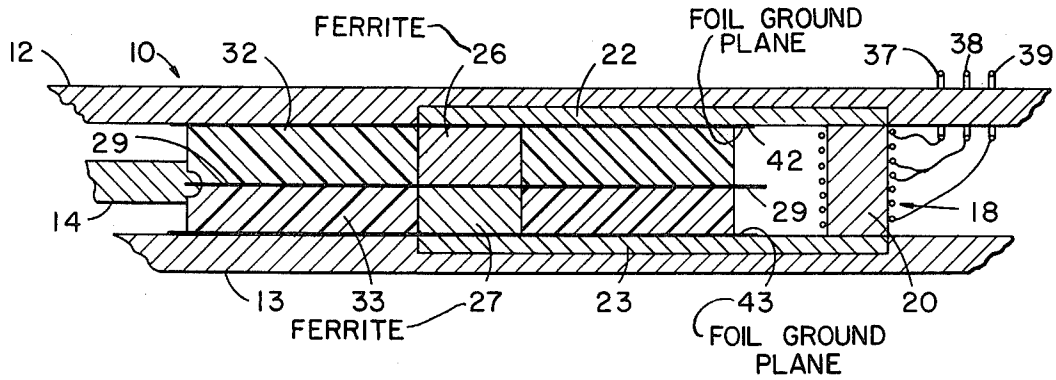
[52] **U.S. Cl.** **333/1.1,** 333/7
[51] **Int. Cl.** **H01p 1/32,** H01p 5/12
[50] **Field of Search** ..... 333/1.1, 24.1, 7, 97 S

[56] **References Cited**
UNITED STATES PATENTS

3,101,458	8/1963	Chandler, Jr. et al.	333/1.1 X
3,316,505	4/1967	Geiszler	333/1.1
3,324,418	6/1967	Caswell	333/1.1

Primary Examiner—Herman Karl Saalbach
Assistant Examiner—Paul L. Gensler
Attorney—Roland A. Anderson

ABSTRACT: A switchable microwave circulator having ground planes comprised of thin sheets of electrical insulation that have a coating of minute separate aluminum particles on one side that provides a continuous conductive path to microwaves and a resistive path to low frequency currents. The resistance of the coating eliminates induced currents that would otherwise flow around the driving members and pole pieces of the circulator during fast switching of the circulator and would slow the switching of the circulator.



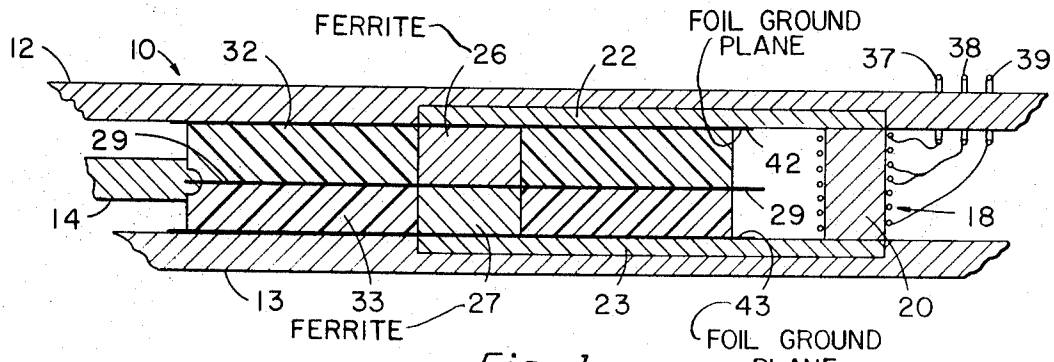


Fig. 1

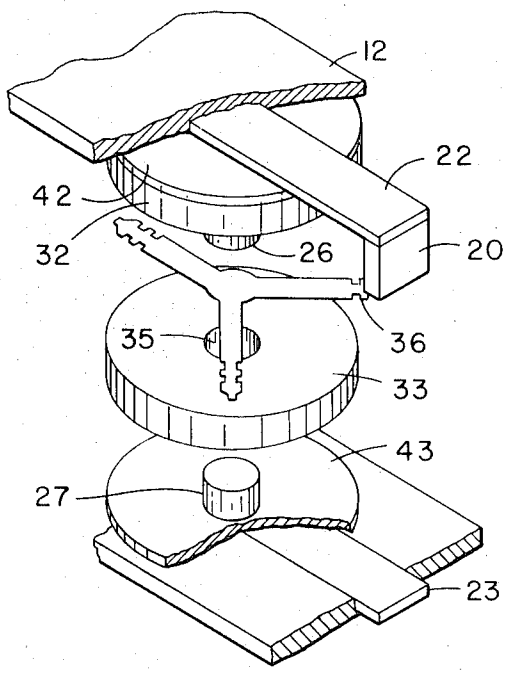


Fig. 2

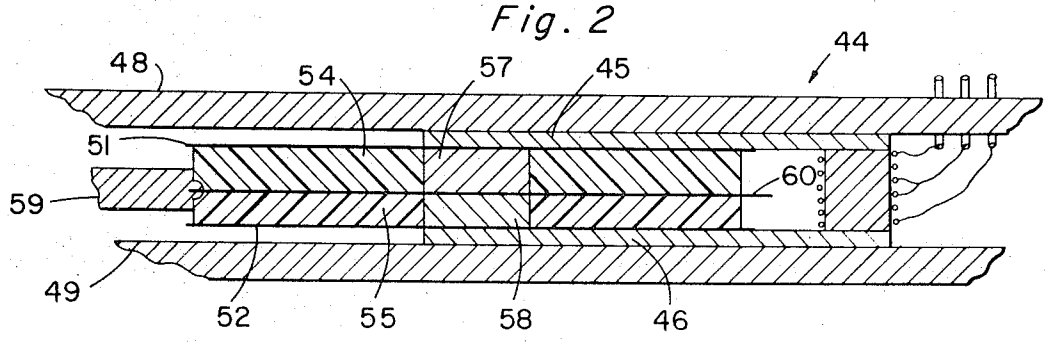


Fig. 3

INVENTOR.
RICHARD G. WILSON
BY

SWITCHABLE MICROWAVE CIRCULATOR WHEREIN GROUND PLANES ARE COMPRISED OF FOILS HAVING VERTICALLY CONDUCTIVE PARTICLES

The invention disclosed herein was made under, or in, the course of Contract No. AT (04–3)–400 with the United States Atomic Energy Commission.

BACKGROUND OF THE INVENTION

The present invention relates to switchable microwave circulators, and more particularly, it relates to a switchable circulator having a ground plane that is a thin film of particulate electrically conductive material carried on one side of a thin sheet of electrical insulation.

In some microwave systems it is desirable to provide fast-switching circulators. In such circulators it is necessary to substantially eliminate induced currents that flow around the driving members and pole pieces wherever there is a shorted path. These currents, when present, reduce the switching time of a circulator. In prior devices, the shorted paths in the ground planes are broken by providing narrow, accurately machined slits through the planes. However, such accurate machining is very expensive.

Another problem in microwave circulators is the necessity to maintain the ground planes continuous, in particular, where a pole passes through a ground plane. One solution in the prior art is to use a pole piece that is broken along planes that are even with the ground planes with at least one face at each break provided with a plating that is conductive to microwaves to maintain the ground plane continuous; a thin film of electrical insulation is provided over the plating to preserve the open circuit of the ground plane slit. However, it is expensive to plate a pole piece and then insulate it with a thin film. Moreover, a conductive plating as used in the prior art provides a limited short circuit path for eddy currents. In addition, failure of such a circulator is usually in the plating which burns out at high microwave power levels. This requires that the entire pole piece be replaced. Such replacement is costly, not only for the piece but for the necessity of maintaining a stock of circulator pieces.

Another problem is that the prior art circulators generally require housing that is separate from the ground plane; and, because of the number of pieces between the housing surfaces there is a tolerance buildup that is impractical to eliminate by using closer tolerances. Since all parts of a circulator must be accurately spaced for the circulator to be predictably in tune, this tolerance buildup requires that during the manufacture of circulators of the prior art type that each circulator be individually and empirically tuned. Also, after any replacement of parts of such a circulator, the circulator must be tuned again because of spacing variations introduced during the replacement.

The disadvantages of prior art switchable microwave circulators results in a very high initial cost for the circulators and a very high cost of repair of the circulators. These high costs become prohibitive where it is desirable to use a large number of circulators, such as in a microwave system of a long linear accelerator.

SUMMARY OF THE INVENTION

In brief, the invention pertains to a switchable microwave circulator ground plane that is a foil comprised of a thin film of electrically conductive material in particulate form on thin sheet of electrical insulation. Sheets of such foil are commonly available, low in cost and have a total thickness that is less than the tolerances to which the other pieces of a circulator can reasonably be held. The thin film of conductive material is comprised of minute and separate electrically conductive particles that provide, because of their minuteness and separateness, a substantial-resistance to low-frequency currents. However, the film presents substantially no resistance to currents at microwave frequencies. The foil therefore may be used to simultaneously provide a path for microwave frequencies and to break low-frequency eddy current paths. Moreover, the foil is easily cut to any desired shape, it may be simply adhered to other pieces of the circulator by means of silicone grease or any of various types of glue or cement. Because of the ease of placement of the foil, its inherent inhibition of eddy currents, its thinness and its microwave conductivity, there is a wide design choice as to its location as a ground plane, and it is no longer necessary to provide a slit in the ground plane or to maintain the ground plane at a level that is even with the circulator housing. Thus, the foil may be used with a high degree of freedom to bridge a slit or pole face to conduct microwaves thereacross and may be arranged to provide a ground plane out of the plane of the housing. This freedom to locate the ground plane away from the housing permits the use of standard slab line, readily available at relatively low cost and very accurately spaced, to be used as the housing without being machined. By using slab line as housing, as ground plane leading to the circulator and as a reference surface at the circulator, the number of circulator pieces is reduced and tolerance buildup thereby minimized. With tolerance buildup minimized, microwave circulators can be mass produced and be predictably in tune without the presently required individual empirical tuning. Furthermore, since the invention leads to the use of standard slab line as housing for a circulator, such a circulator may be conveniently integrated with other microwave circuitry by etching the circuitry directly on the slab line adjacent to the circulator.

It is an object of the invention to simplify the construction of a switchable microwave circulator.

Another object is to minimize the cost of producing and repairing a switchable microwave circulator.

Another object is to eliminate the need to empirically tune a switchable microwave circulator.

Another object is to eliminate machining operations in the production of a switchable microwave circulator.

Another object is to provide foil that is conductive for microwaves and resistive for low frequencies as a ground plane in a switchable microwave circulator.

Another object is to simplify integration of a switchable microwave circulator with other microwave circuitry into a single integrated circuit device.

Other objects and advantageous features of the invention will be apparent in a description of a specific embodiment thereof, given by way of example only, to enable one skilled in the art to readily practice the invention, and described hereinafter with reference to the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a cross-sectional view of a switchable microwave circulator having ground planes comprised of foil that is conductive to microwaves and resistive to low frequencies and located substantially in the plane of the housing, according to the invention.

FIG. 2 is an exploded perspective view of the circulator of FIG. 1, showing the relationship between essential elements of the circulator.

FIG. 3 is a cross-sectional view of a switchable microwave circulator having ground planes comprised of foil that is conductive to microwaves and resistive to low frequencies and located in planes that are displaced from the planes of the housing.

DESCRIPTION OF AN EMBODIMENT

Referring to the drawing there is shown in FIGS. 1 and 2 a prototype ferrite switchable microwave circulator 10 to which microwaves are conducted by means of a slab line that includes flat parallel members 12 and 13 with a center conductor 14. The slab line plates are also used as a housing for the circulator. The circulator also includes a coil 18 wound on a driving core 20 which is part of a magnetic circuit including a pair of ferrite driving members 22 and 23. The core 20 is connected across on end of the driving members 22 and 23 while a pair of elements in the form of ferrite discs 26 and 27 are

connected across the opposite end of the driving members. A groove is formed in each of the slab line members **12** and **13** for receiving a driving member. The grooves are at a depth that holds the inner surface of the driving members parallel with the inner surface of its associated slab line member. A center conductor junction **29** having three arms spaced 120° apart is positioned in the circulator with its center portion sandwiched between the ferrite discs **26** and **27**. One arm of the circulator is axially aligned with the slab line and connected to the center conductor **14** for bringing microwaves into the circulator. Each of the other arms may be used to conduct microwaves to other parts of a microwave system. A pair of dielectric discs **32** and **33** are mounted on each side of the center conductor junction **29**. The dielectric discs **32** and **33** are concentric with the ferrite discs **26** and **27** and are provided with holes **35** for receiving the ferrite discs. The discs **26** and **27**, and **32** and **33** are of equal width and therefor sandwich the center conductor junction **29** therebetween along a centerline between members **12** and **13** in a stripline configuration. The dielectric discs **32** and **33** and the center conductor junction **29** which is provided with tuning stubs **36** constitute a transformer for a transition from the slab line configuration of the members **12** and **13** and center conductor **14** to the stripline configuration of the members **12** and **13** and center conductor junction **29**.

In operation switching pulses are applied across selected ones of three switching terminals **37**, **38** and **39** for application to the coil **18**. Application of a pulse across the terminals **37** and **38** drives the coil **18** in a first direction while application of a switching pulse across the terminals **38** and **39** drives the coil in the opposite direction. With the coil **18** driven in the first direction a magnetic circuit including the driving members **22** and **23** and ferrite discs **26** and **27** conduct flux through the center of the center conductor junction in a first direction causing microwaves applied between center conductor **14** and the members **12** and **13** to be conducted only through one of the arms of the center conductor junction **29**; and when the coil **18** is driven in the opposite direction, magnetic flux is conducted through the center portion of the center conductor junction **29** in the opposite direction causing the microwaves to be conducted from the center conductor **14** to other one of the arms **29**.

In order to avoid distortion of the microwave field at the center of the center conductor junction by the ferrite discs **26** and **27** and the driving members **22** and **23**, it is necessary to provide a pair of ground planes parallel to the center conductor junction **29** and symmetrically spaced therefrom. The ground planes should completely overlie the center conductor junction and provide a continuous surface for conduction of microwaves. To inhibit eddy currents in the ground planes and still provide a continuous conductive surface for the microwaves, the ground planes may be foils comprised of thin sheets of electrical insulation having a coating of minute separate electrically conductive particles on one side. The conductivity of the particles provide a continuous path for the microwaves while the separateness and minuteness of the particles present a resistive path to low frequency eddy currents, thereby breaking the eddy current paths and preventing the occurrence of eddy currents. A foil that has been found suitable for the ground planes is a commonly available super insulation comprised of thin (0.001 inches thick) sheets of polyethylene terephthalate resin which are vapor coated with a very thin film of aluminum particles resulting in a coating having a DC resistance of 5 ohms per unit square. This foil may be cut into circular pieces **42** and **43** which are slightly larger or have substantially the same diameter as the dielectric discs **32** and **33**. The foil may be secured to the discs by gluing the aluminum-coated side of the foil to the discs **32** and **33**. It has been found that the diameter of the foil is not critical and that by extending the foil slightly beyond the edges of the discs **32** and **33** that there is no detectable distortion of the microwave field. This is due to the resin sheets being so thin, less than the tolerances to which the plates **12** and **13** are manufactured, that the sheets present no discontinuity to microwaves. By using such foil, eddy current paths which would otherwise exist around the driving members **22** and **23**, and the discs **26** and **27** are eliminated by the resistance of the coating to microwaves, while a continuous conductive path is presented to microwaves.

Since the foils **42** and **43** are easily secured to the dielectric discs **32** and **33** with various types of adhesives and have been found to be highly effective in inhibiting eddy currents as well as conducting microwaves, there is a high degree of freedom as to their location in a circulator. Specifically, the foil ground planes may be located out of the plane of the slab line housing. Such an arrangement is shown in FIG. **3** which illustrates a circulator **44** comprised of driving members **45** and **46** mounted directly against the inner surface of slab line housing members **48** and **49**. Ground plane foils **51** and **52** are secured to the outer surface of dielectric discs **54** and **55** as well as ferrite discs **57** and **58** which are mounted concentric to the dielectric discs **54** and **55** respectively. The diameter of the foils **51** and **52** has been found not to be critical and may be conveniently made to extend slightly over the dielectric discs **54** and **55**. With the ground planes established by the foils **51** and **52** displaced from the plane of the slab line housing members, it has been discovered that there is no distortion in the microwave field in the transition from the slab line configuration of members **48** and **49** and a center conductor **59** to the stripline configuration of the ground plane foils **51** and **52** and a center conductor junction **60**. Advantages of the arrangement of circulator **44** are that the circulator components may be uncritically mounted in the space between the slab line housing members **48** and **49**; no machining whatsoever of the members **48** and **49** is required; and tolerance buildup is minimized by mounting the circulator components directly between the members **48** and **49** with the inner surface of these members acting as reference surfaces such as are accurately located in standard slab line housing. As discussed with respect to the circulator of FIG. **1**, the foils **51** and **52** of the circulator **44** act as a continuous ground plane throughout the space of the circulator and also inhibit the flow of eddy currents which tend to flow in circular paths concentric with the ferrite discs **57** and **58**.

A prototype switchable microwave circulator exemplifying the invention was constructed and successfully operated. It was fully switched in one microsecond when operating in a power range of 43 to 48 kw. and was found to have a voltage standing wave ratio of 1.03 with losses less than 0.5 db. The cost of this circulator was on the order of one-fourth that of conventional mass-produced circulators.

While an embodiment of the invention has been shown and described, further embodiments or combinations of those described herein will be apparent to those skilled in the art without departing from the spirit of the invention.

I claim:

1. In a switchable microwave stripline junction circulator the combination of:

a first driving member for conducting magnetic flux;

a first ferrite element adjacent said driving member;

a first foil comprised of a thin sheet of electrical insulation with a thin film coating of minute separate electrically conductive particles on one side of said thin sheet facing said first ferrite element said separate particles constituting a low-resistance conductive path for microwaves and further constituting a substantial-resistance path to low-frequency currents, said foil being mounted between said driving member and said ferrite element and constituting a microwave ground plane for said circulator;

a second ferrite element;

first and second dielectric discs each having a central hole for receiving said first and second ferrite elements respectively;

a center conductor junction sandwiched between said first disc and said first ferrite element and said second disc and said second ferrite element;

a second driving member for conducting magnetic flux, said ferrite elements, dielectric discs and junction being disposed between said first and second driving members;

a second foil comprised of a thin sheet of electrical insulation with a thin film coating of minute separate electrically conductive particles on one side thereof facing said second ferrite element said particles constituting a low resistance conductive path for microwaves and further constituting a substantial resistance path to low frequency currents, said second foil being mounted between said second driving member and said second ferrite element and constituting a microwave ground plane for said circulator, said first foil overlying said first ferrite element and said first dielectric disc between said first ferrite element and said first driving member, said second foil overlying said second ferrite element and said second dielectric disc between said second ferrite element and said second driving member; and

a source of magnetic flux connected between said first and second driving members for supplying magnetic flux for conduction through said first and second driving members to said first and second ferrite elements, said source being operable to supply magnetic flux to said elements in a first direction, said source being further operable to supply magnetic flux to said elements in a second direction.

2. The combination of claim 1 wherein said foil is a sheet of polyethylene terephthalate resin having a particulate coating of aluminum on one side, said sheet being on the order of 0.001 inches thick, said coating presenting substantially zero resistance to microwaves, said coating presenting a resistance of approximately 5 ohms per unit square to direct current.

3. The combination of claim 1 further including a housing having first and second flat parallel members for mounting said circulator, said members having opposing flat parallel surfaces, said members each having a groove formed in said opposing surfaces for receiving said first and second driving members respectively, said first and second foils being entirely flat and positioned against the parallel surfaces of respective first and second housing members and overlying said first and second driving members respectively.

4. The combination of claim 1,

further including a housing having first and second members for mounting said circulator, said members having opposing flat parallel surfaces; and

wherein said first foil is positioned between said first driving member and said first element in a plane displaced from said parallel surface of said first housing member.

5. The combination of claim 4 wherein said first driving member is mounted against said parallel surface of said first housing member.