April 25, 1967 T. D. GEISZLER 3,316,505

FAST SWITCHING MICROWAVE CIRCULATOR
UTILIZING REMNANT MAGNETIZATION

Filed March 1, 1965 . 2 Sheets-Sheet 1

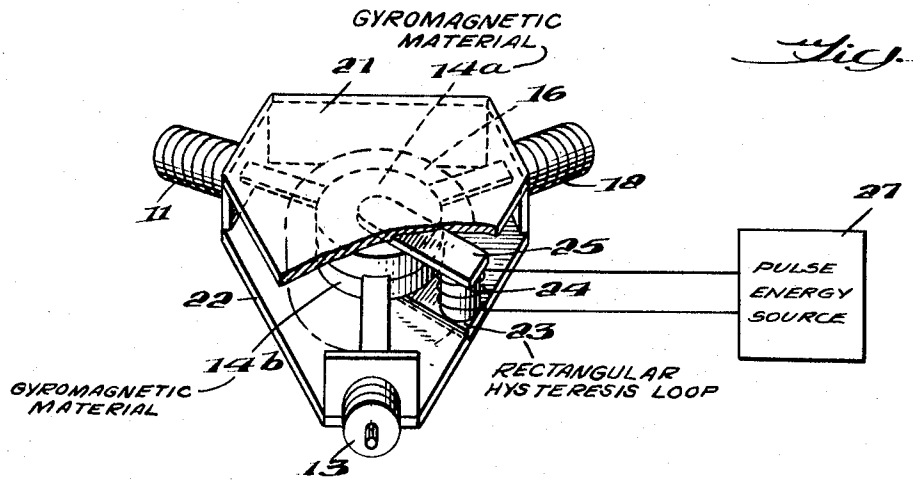


Fig. 1.

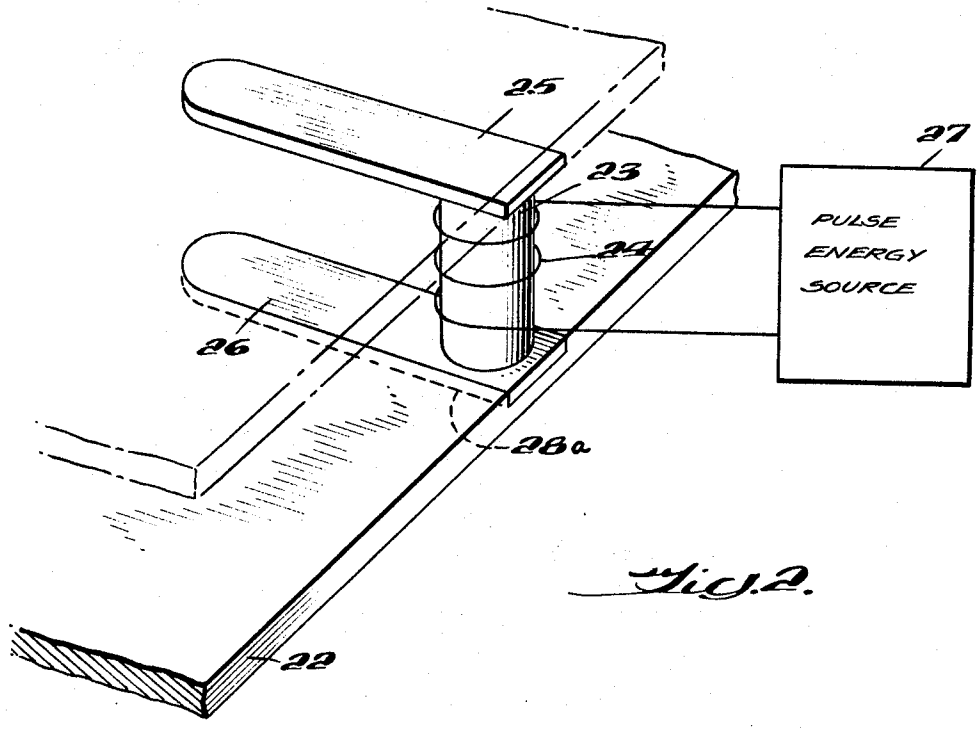


Fig. 2.

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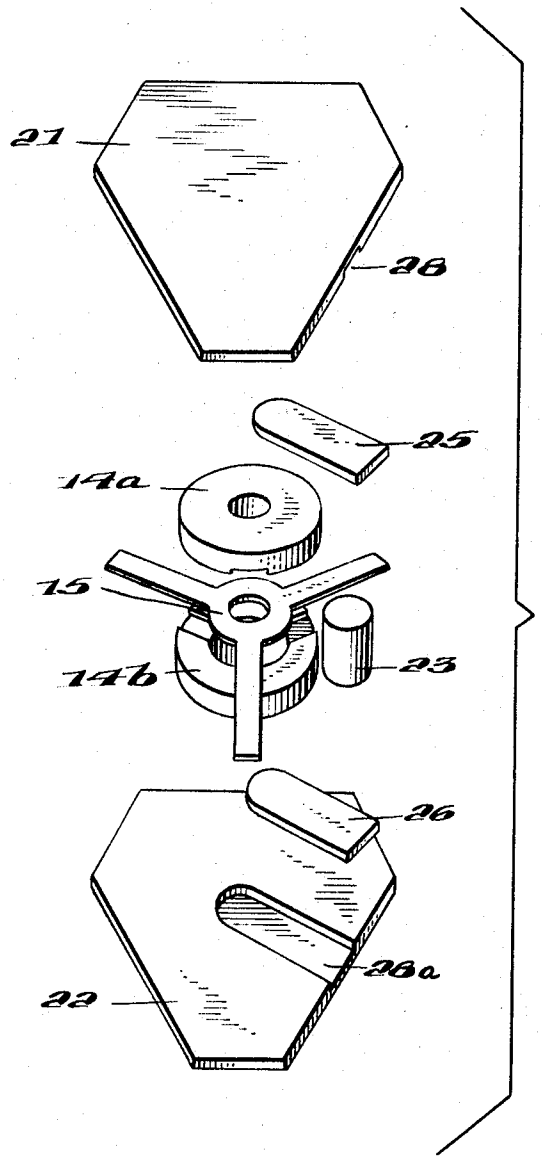
ATTORNEYS

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Filed March 1, 1965 2 Sheets-Sheet 2

Fig. 3.



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FAST SWITCHING MICROWAVE CIRCULATOR UTILIZING REMNANT MAGNETIZATION

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Filed Mar. 1, 1965, Ser. No. 435,811
8 Claims. (Cl. 333—1.1)

This invention relates in general to microwave circulator devices of the gyromagnetic material variety and in particular to latchable mircowave circulator devices.

Three-port microwave circulators have been utilized extensively in prior art microwave switching applications. Heretofore such microwave circulators have been biased by conventional magnetic control means involving bulky, relatively inefficient electromagnetic devices disposed external to the ground planes of the circulator structure. This type of magnetic control means requires a holding current during its entire operational period and consequently necessitates a substantial power source which may not be available in many applications. It is readily apparent that a switchable, latchable, compact, easily fabricated microwave circulator capable of handling relatively high peak and average power is needed and would be welcomed as a substantial advancement of the art.

Accordingly, it is an object of this invention to provide a microwave circulator which may be switched readily and maintained in a selected operational state.

It is another object of this invention to provide a relatively compact microwave circulator which does not require a continuous holding current during each selected operational state.

It is a further object of this invention to provide a latchable microwave circulator which is adaptable to relatively high power applications.

Briefly, the device of this invention is a nonreciprocal, three-port microwave network in which energy entering one port may be directed to one or the other of the two remaining ports by the application of a magnetic field of selected direction across the gyromagnetic element. In the exemplary embodiment, the magnetic control means is disposed within the circulator structure.

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of a preferred embodiment of the invention, as illustratel in the accompanying drawings in which:

FIG. 1 is a cutaway view of the device of this invention in a typical stripline embodiment;

FIG. 2 is a more detailed showing of the magnetic control means in the embodiment of FIG. 1; and

FIG. 3 is an exploded perspective view of the device of FIG. 1 showing certain essential elements.

FIG. 1 shows a three-port stripline embodiment of the device of this invention having magnetic control means disposed between ground planes **21** and **22**. In FIG. 1 the three coaxial ports **11**, **12** anl **13** of the circulator are equidisposed about a core **14***a*, **14***b* of gyromagnetic material, for example ferrite. The center conductor of each coaxial port is connected electrically to a central spider member **15** disposed in parellel relation to the ground planes **21** and **22** and separated therefrom by the core portions **14***a* and **14***b*, respectively. A conventional dielectric material **16** is shown surrounding the core portions **14***a* and **14***b*. In this embodiment the dielectric serves an impedance matching function.

The magnetic control means in the embodiment of FIG. 1 comprises a core **23** of a material having a substantially rectangular hysteresis loop characteristic, a winding **24**, and two conductive path means **25** and **26** having a low impedance to electromagnetic wave energy.

The conductive path means **25** and **26** may be made of high permeability steel, for example, and may be recessed within the ground planes **21** and **22** as indicated at **28**, **28***a* if desired. It has been found that such recess not only reduces the overall size of the device but substantially improves the operational qualities of the device by minimizing any internal field discontinuity.

The core **23** is carried to one saturation level or the other, as desired, by application of electrical pulse energy of selected polarity and duration from source **27** to the winding **24** to provide a magnetic field of selected polarity. This magnetic field energizes the ferrite core **14***a*, **14***b* by means of the conductive path means **25** and **26** such that microwave energy is directed to one port or the other.

Once a saturation level is reached, the core **23** remains saturated irrespective of the presence, or absence, of additional electrical energy of the same polarity from source **27**. Consequently the core **23** maintains its influence on the gyromagnetic core **14***a*, **14***b*, and the circulator is effectively latched in its operational mode until such time as pulse energy of opposite polarity is applied to the core **23**.

While the core **23** of the rectangular hysteresis loop material may be disposed other than as shown in FIG. 1, it has been found that by construction of the magnetic return paths integral with the ground planes **21** and **22**, the shorted turn effect and the total reluctance are reduced. Moreover, it has been found that by utilizing a core **23** having a high coercive force and a spider member **15** of high permeability steel, or of plated ferrite material, the efficiency of the magnetic control circuit is greatly enhanced. This efficiency can be further increased by silver plating and/or annealing the spider member **15**. The necessity of such efficiencies may be dependent upon the loss and switching time requirements of the particular application.

To guarantee the proper boundary conditions for the microwave fields at the junction, it is desirable to silver plate the portion of the control magnetic field conductive elements directly adjacent the core **14***a*, **14***b*. For high power applications it is especially desirable to utilize high permeability fast switching steel for the conductive path means **25** and **26**. It has been found that this type of steel not only performs well in the magnetic sense but affords an excellent heat sink, as well. It may also be desirable to incorporate impedance matching means such as disclosed in my copending application, Serial No. 389,580, entitled Improved Microwave Strip Transmission Line Circulator, which was filed August 14, 1964.

It has been found that the switching time characteristic may be improved, and the energy required to switch decreased, by the utilization of rectangular hysteresis loop material for the core **14***a*, **14***b*, as well as for the core **23**. It is recognized that the operational characteristics of the latchable microwave circulator of this invention may be optimized by selective disposition of the rectangular hysteresis loop material and associated magnetic field conductive elements. Furthermore, it is understood that the rectangular hysteresis loop material may be carried to saturation by any conventional means and that the portion of the magnetic control means in the embodiment of FIG. 1 which is contained between the ground planes **21** and **22** may be potted in dielectric material or ortherwise.

Operational characteristics for C Band and X Band embodiments of the structure of FIG. 1 have clearly demonstrated the practical utility of the device of this invention in fast acting switching applications. In a C Band embodiment minimum and maximum isolation was 20 db and 25 db respectively; insertion loss was 0.15 db; and switching time was 50 μsec. In an embodiment

designed for X Band, minimum and maximum isolation was 20 db and 25 db, respectively; insertion loss was 0.20 db; and switching time was less than 10 μsec.

While the invention has been shown and described with particular reference to a preferred embodiment, it will be understood by those skilled in the art that various changes in form and details may be made without departing from the spirit and scope of the invention.

What is claimed is:

1. In a microwave circulator device of the variety incorporating an element of gyromagnetic material having an axis, a magnetic body of rectangular hysteresis loop material having an axis spaced from but parallel to said element axis and adapted to energize said element of gyromagnetic material when said body reaches a saturation level condition and means for reversing the saturation level of said body.

2. In a microwave circulator device of the stripline variety incorporating spaced ground planes and an element of gyromagnetic material having an axis, said gyromagnetic material being disposed between said ground planes, a magnetic body of rectangular hysteresis loop material having an axis spaced from but parallel to said element axis and disposed between said ground planes and adapted to energize said element of gyromagnetic material when said body reaches a saturation level condition, and means for reversing the saturation level of said body.

3. In a microwave circulator device of the stripline variety incorporating spaced ground planes and an element of gyromagnetic material, disposed therebetween, a magnetic body of rectangular hysteresis loop material disposed between said ground planes and adapted to energize said element of gyromagnetic material when said body reaches a saturation level condition, and means for reversing the saturation level of said body, said first and second magnetic field conductive means being disposed in spaced relation between said ground planes such that said first magnetic field conductive means, said element of gyromagnetic material, said second magnetic field conductive means and said body of rectangular hysteresis loop material form a complete magnetic circuit.

4. An assembly as defined in claim 3 wherein said first and second magnetic field conductive means are planar means disposed in juxtaposition with respective ground planes of said circulator device.

5. An assembly as defined in claim 4 wherein said first and second magnetic field conductive means are of high permeability steel material.

6. An assembly as defined in claim 5 wherein said first and second magnetic field conductive means are recessed within said respective ground planes.

7. An assembly as defined in claim 6 wherein said means for reversing the saturation level of said body comprises an inductive loop encompassing said body and a pulse energy source adapted to energize said inductive loop in reverse directions.

8. An assembly as defined in claim 7 wherein there is only one ferromagnetic body and a single inductive loop surrounding said body.

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HERMAN KARL SAALBACH, *Primary Examiner.*

P. L. GENSLER, *Assistant Examiner.*

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,316,505 April 25, 1967

Theodore D. Geiszler

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

In the heading to the printed specification, line 3, and in the sheets of drawings, line 3, for "REMNANT", each occurrence, read -- REMANENT --; column 3, line 36, strike out "said", second occurrence.

Signed and sealed this 21st day of November 1967.

(SEAL)
Attest:

Edward M. Fletcher, Jr.
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents