Aug. 20, 1963 J. CHANDLER, JR., ETAL 3,101,458

FERRITE PHASE SHIFTER HAVING CASING-SUPPORTED THIN-FOIL WAVEGUIDE, WITH MAGNETISING POLE PIECES PENETRATING THE CASING

Filed Aug. 4, 1958 2 Sheets-Sheet 1

Fig. 1.

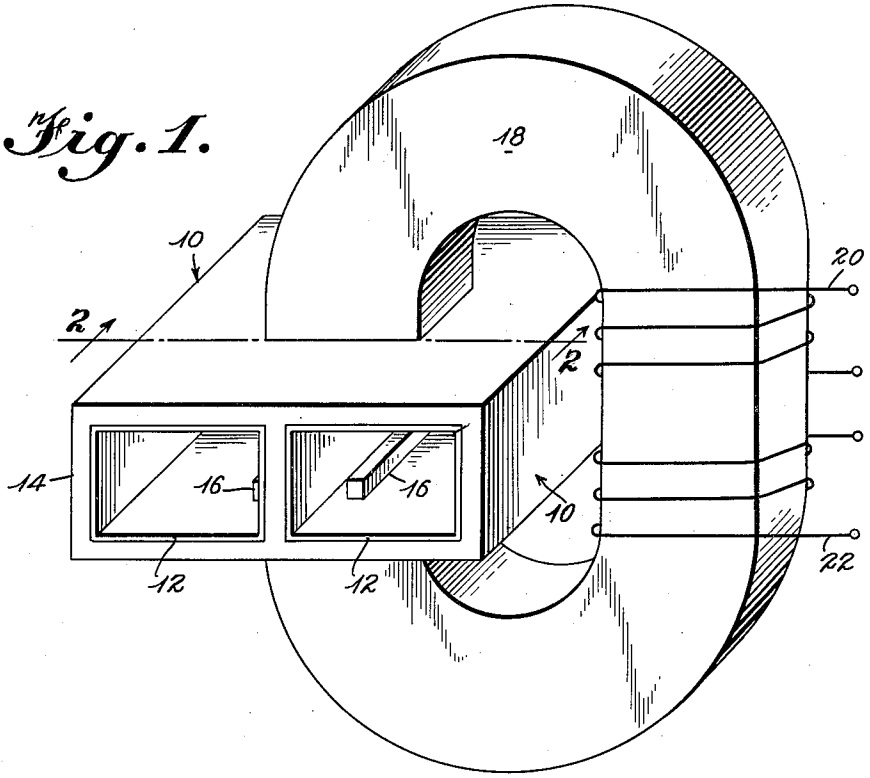
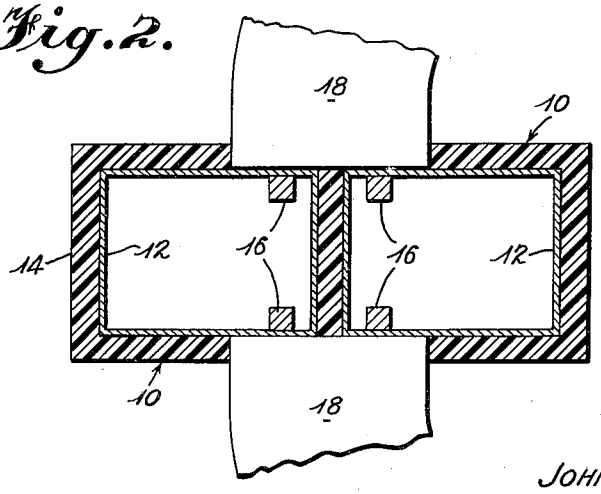


Fig. 2.



INVENTORS
JOHN CHANDLER, JR.,
LESTER C. HOLLY AND
JOHN LEE VILBIG, JR.

BY Stevens, Davis, Miller & Mosher
ATTORNEYS

Aug. 20, 1963 J. CHANDLER, JR., ETAL 3,101,458

FERRITE PHASE SHIFTER HAVING CASING-SUPPORTED THIN-FOIL WAVEGUIDE, WITH MAGNETISING POLE PIECES PENETRATING THE CASING

Filed Aug. 4, 1958 2 Sheets-Sheet 2

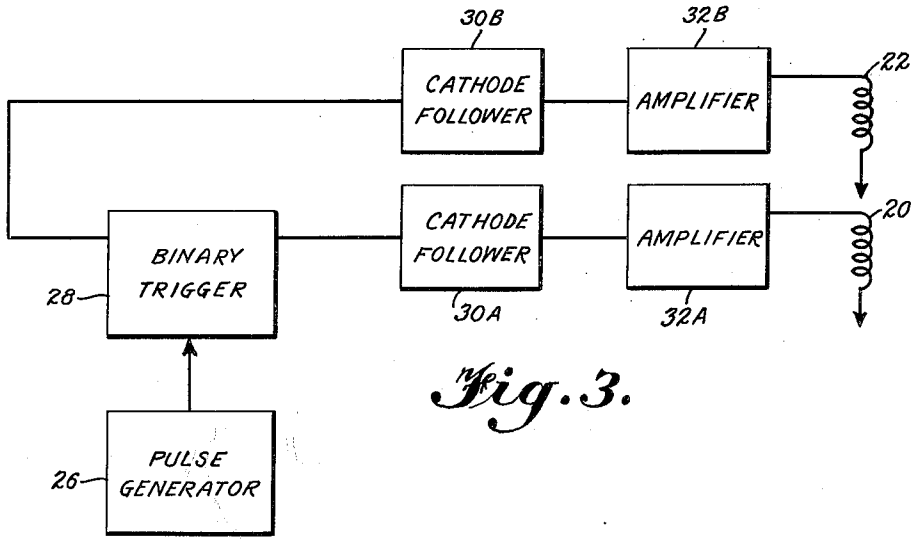
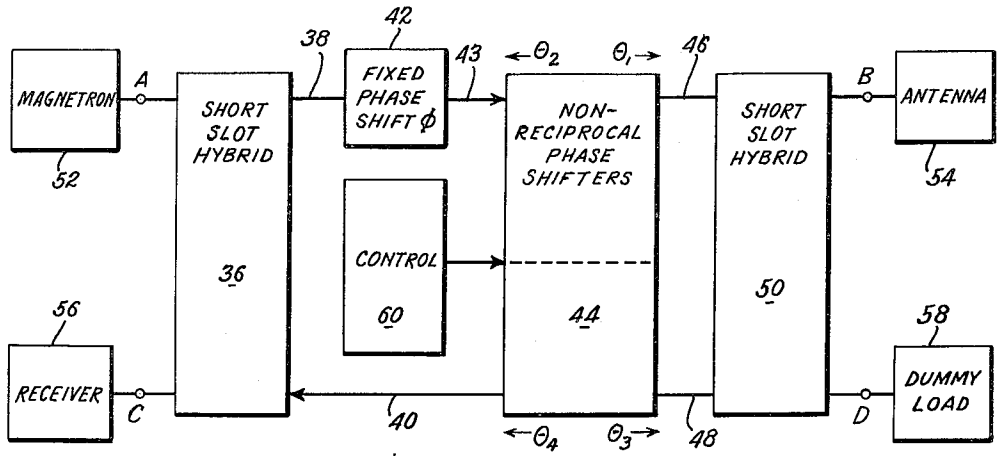


Fig. 3.

Fig. 4.



INVENTORS
JOHN CHANDLER, JR.,
LESTER C. HOLLY AND
JOHN LEE VILBIG, JR.

BY Stevens, Davis, Miller & Mosher
ATTORNEYS

United States Patent Office 3,101,458 Patented Aug. 20, 1963

3,101,458

FERRITE PHASE SHIFTER HAVING CASING-SUPPORTED THIN-FOIL WAVEGUIDE, WITH MAGNETISING POLE PIECES PENETRATING THE CASING

John Chandler, Jr., Dallas, Lester C. Holly, Irving, and John Lee Vilbig, Jr., Dallas, Tex., assignors to Texas Instruments Incorporated, Dallas, Tex., a corporation of Delaware

Filed Aug. 4, 1958, Ser. No. 752,933
4 Claims. (Cl. 333—24.2)

This invention relates to a novel microwave apparatus of the type wherein at least one element of ferrite or similar material is mounted in a waveguide and is impressed with a magnetomotive force. More specifically, this invention concerns microwave apparatus of substantially improved design which is capable of efficient switching at high frequencies.

There are essentially three general types of microwave ferrite devices in present use. They are the nonreciprocal phase shifter, the resonance isolator and the field displacement devices. Each incorporates a waveguide containing at least one ferrite element and depends upon an externally applied magnetic field for its nonreciprocal behavior. The size, shape and location of the ferrite element and the magnitude of the applied magnetic field depend on the particular application and critically affect the propagation in each direction.

The nonreciprocal phase shifter either advances or retards the phase of the microwave signal depending upon the direction of propagation and the polarity of the externally applied magnetic field. The resonance isolator transmits energy in one direction and attenuates it in the other, while the field displacement device is used to couple energy to another waveguide in one direction of propagation but not in the other. The latter may be used as an isolator in combination with a resistive material located where the field is large for one direction of propagation but small for the other direction.

The nonreciprocal phase shifter may be one of two types. The first uses the Faraday rotation principle in a circular waveguide with a ferrite rod placed along its longitudinal axis. The magnetic field is applied longitudinally in this type. The second type utilizes the transverse field effect in a rectangular waveguide having one or more ferrite elements placed in contact with one or more of its walls. It is this second type to which the preferred embodiment of the present invention is directed although the principles of the invention are applicable to the entire class of magnetic microwave devices wherein the materials behave essentially like isotropic dielectrics in the absence of a magnetic field and become anisotropic in the presence of a magnetic field.

Briefly, a major application of a nonreciprocal phase shifter is in a four port circulator. For example, a magnetron, antena, dummy load and receiver are connected via the nonreciprocal phase shifter so that reflections or received signals at the antenna are presented to the receiver input, but very nearly all of the magnetron power is radiated at the antenna due to elimination of substantially all of the so-called "long-line" effect of the isolation and impedance matching provided.

Pertinent prior art has a prime disadvantage in that

the conductive waveguide walls contain openings to receive the pole faces of the magnet which engages the ferrite material and supplies the magnetic field. This produces a discontinuity in the waveguide walls thereby causing excessive heating since the high frequency current must flow through the high resistance discontinuity. When alternate schemes are employed, the reluctance of the magnetic path is too great and hence, are not practical.

These problems which have not been solved by the prior art are now overcome by the present invention which, for the first time, provides a magnetic microwave apparatus that is capable of high frequency operation such as in the K or V bands and that is capable of switching waveguide energy at an exceptionally fast rate, such as 4000 times a second.

The present invention accomplishes the above by an apparatus including two rectangular waveguides, each having a pair of ferrite elements mounted on opposing pairs of walls of the waveguide. The conducting portion of the waveguide is formed of very thin conductive foil of material such as aluminum for decreasing the eddy currents and for presenting a very low reluctance to the applied magnetic field which acts upon the ferrite elements. The pole pieces of an electromagnet are placed in engagement with the waveguide material adjacent the ferrite elements. An outer case of non-conducting material, such as plastic, is supplied to support the foil and give rigidity to the waveguide structure. One or more coils can be used on the electromagnet to effect switching.

Accordingly, it is a principal object of this invention to provide an improved microwave apparatus wherein one or more ferrite elements are mounted within a waveguide and are coupled to an external source of magnetic flux through a very low reluctance path, which enables operation at substantially higher frequencies and a fast switching time.

It is a further object of this invention to provide microwave apparatus wherein a magnetic field is selectively impressed upon one or more ferrite elements mounted within a waveguide having a continuous unbroken surface.

Other and further objects of the present invention will be obvious from a detailed description of the accompanying drawings.

In the drawings:

FIGURE 1 is an isometric view of the microwave apparatus of the present invention;

FIGURE 2 is a section of the apparatus of FIGURE 1 taken along the lines 2—2;

FIGURE 3 is a functional block diagram of the electrical apparatus for exciting the magnetic circuits of FIGURES 1 and 2; and

FIGURE 4 is a functional block diagram of the apparatus for utilizing the device of the present invention.

Referring now to the drawings, there is shown in FIGURE 1 a pair of integrally connected waveguides **10** of essentially identical construction. The location of ferrite elements and magnetic circuit may differ, however, if desired. Although the apparatus of FIGURE 1 is shown as a double waveguide, it will be understood that a single waveguide may be used according to the principles of the present invention.

As shown in FIGURES 1 and 2, the conductive portion of the waveguides **10** comprises aluminum foil **12** defining a pair of rectangular guides. The minimum thickness

of the foil is determined by the current penetration of the signal energy in the waveguide at the transmission frequency. The thickness of the waveguide walls must be greater than the depth of this penetration. Plastic, such as Bakelite, constitutes a backing or supporting structure **14**. Ferrite elements **16** are mounted on the foil **12** on the pair of opposing walls which are perpendicular to the E vector of the propagated wave. As illustrated more clearly in FIGURE 2, a laminated pole piece of magnetic material **18** is received in a slot provided in opposite sides of the plastic structure **14** and the pole faces of the pole piece engage the foil **12** in the proximity of the ferrite elements **16**. First and second coils **20** and **22** are wound in a reverse relationship about the pole piece for providing opposing magnetic flux. It will be understood, however, that reversing of the magnetic field may be accomplished by using only one coil and reversing the current therein.

An arrangement for switching the apparatus is illustrated in FIGURE 3. As shown, a pulse source **26** drives a binary trigger **28**, the latter changing state upon each successive application of an input pulse. Alternately, the right-hand and left-hand sides of the trigger **28** present a more positive voltage to cathode followers **30A** and **30B**, respectively, for driving their associated amplifiers **32A** and **32B**. Corresponding coils **20** and **22** are energized upon the operation of the amplifiers **32A** and **32B**.

A circulator embodying the principles of the present invention is shown in block form in FIGURE 4. A short slot hybrid **36** provides an equal power split and a 90 degree phase shift difference between a pair of outputs **38** and **40**. A fixed phase shift device **42** is interposed between the waveguide **38** and a waveguide **43** to insure that the proper phase relationship exists between the divided transmission paths **40** and **43**. The waveguides **40** and **43** are coupled to one side of a nonreciprocal ferrite phase shifter **44**, such as the one shown in FIGURES 1 and 2, and output waveguides **46** and **48** are coupled to the other side of the nonreciprocal phase shifter **44** and to a second short slot hybrid **50**.

For purposes of analysis it may be assumed that ϕ represents the difference in phase shifts between the two paths of the circulator when the ferrite devices have no external fields applied to them. With a magnetic field applied, the phase shift through the ferrite devices are as indicated in FIGURE 4 where the arrows show the direction of propagation. Three equations must be satisfied for this circulator:

$$(\theta-\theta_2)-(\theta_3-\theta_4)=\pm 180° \quad \text{Equation (1)}$$
$$\phi+\theta_1-\theta_3=180° \text{ or } 0° \quad \text{Equation (2)}$$
$$\phi+\theta_2-\theta_4=0° \text{ or } 180° \quad \text{Equation (3)}$$

These equations are satisfied if

$$\theta_1=-\theta_2=-\theta_3=\theta_4=\pm 45° \text{ and } \phi=90°$$

For the power to flow from A to B, B to C, C to D, and D to A, then $\theta_1=-\theta_2=-\theta_3=\theta_4=+45°$. This will be considered as condition I. For power to flow from A to D, D to C, C to B and B to A, $\theta_1=-\theta_2=-\theta_3=\theta_4=-45°$. This will be considered as condition II.

As a practical application of this circulator, a magnetron **52** can be connected at A, an antenna **54** can be connected at B, a receiver **56** can be connected to C and a dummy load **58** can be connected to D. Under condition I, power into A will emerge at B and be directed to the antenna. Reflected or received signals at the antenna are directed to C and the receiver **56**. Thus, the circulator serves as a load isolator and duplexer.

To further demonstrate the versatility of the invention an antenna can be connected to each of B and D instead of the antenna **54** and dummy load **58**. With this arrangement, the signal into A from the magnetron **52** will emerge at B under condition I and at D under condition II. Signals received by the antenna connected at B will be provided at C under condition II and signals received by the antenna connected at D will be provided at C under condition I. Thus, a combination load isolator, duplexer and microwave switch is provided.

To switch from condition I to condition II require reversing the externally applied magnetic field to the nonreciprocal phase shifter **44** and this can be accomplished by use of an electromagnet having two coils or a single coil is explained previously.

In one form of the present invention, a circulator similar to that shown in FIGURE 4 but having an antenna connected at each of B and D was designed to operate specifically at 34,860 plus or minus 300 megacycles per second with a switching time from one antenna to another at a rate of 4000 operations per second. Only 80 ampere-turns were required to achieve a switching time of 80 microseconds.

The structure of this invention lends itself well to miniaturization as required by the present trend toward operation at higher and higher frequencies. Such waveguides as the one of the present invention have been constructed having inside dimensions of the order of 0.140 by 0.280 inch.

Although the specific nonreciprocal phase shifter illustrated includes two ferrite elements per waveguide, it will be recognized from the foregoing description that the invention is equally applicable to apparatus employing a single waveguide or a single ferrite element.

Substances affecting microwave energy to a considerable extent include polyirons, ferrites and powdered magnetic metal mixed with a suitable dielectric and are so well known in the art that it is unnecessary to describe the especific materials employed in the practice of this invention other than to say that any suitable materials can be used. Ferrite susbtances have been referred to for the purposes of illustration and description.

It will be expressly understood that the illustrations and description are employed to teach the basic concepts of the invention and that modifications and other embodiments will be obvious to those skilled in the art from the teachings herein. Such modifications and further embodiments are within the contemplation, spirit and scope of the invention.

What is claimed is:

1. Microwave apparatus comprising a section of waveguide consisting of thin conductive foil supported on the interior of a hollow casing of nonconductive material, ferrite-type phase-shifting means mounted within said waveguide, and selectively-reversible magnetic flux producing means coupled to said phase-shifting means, said flux-producing means including a magnetic core having a pair of pole pieces, said pole pieces extending through said casing and contacting said foil.

2. Microwave apparatus comprising a section of waveguide consisting of thin conductive foil supported by a casing of nonconductive material, a flux-responsive phase-shifting device mounted within said waveguide, and magnetic core means having a pair of pole pieces engaging said thin conductive foil adjacent said device for providing selectively reversible magnetic flux, said pole pieces being positioned in relieved portions of said casing.

3. Microwave apparatus comprising a section of rectangular waveguide consisting of thin continuous conductive foil supported on the interior of a hollow casing of nonconductive material, said casing being apertured at areas along transversely opposed faces of said waveguide to expose portions of said foil, magnetic means for providing a selectively reversible transverse magnetic field through said waveguide, said magnetic means including a magnetic core having a pair of pole pieces positioned in said apertured areas of said casing and engaging said exposed portions of said foil, and phase-shifting means positioned in said waveguide between said pole pieces and responsive to said magnetic field.

4. Microwave switching apparatus comprising:

(*a*) a section of waveguide composed of thin conduc-

tive foil means supported on the interior surface of a hollow casing of nonconductive and nonmagnetic material,

(*b*) the casing having transversely-opposed relieved areas,

(*c*) flux-responsive phase-shifting material positioned within the waveguide between the relieved areas,

(*d*) and selectively-reversible magnet flux producing means having pole pieces extending into the relieved areas of the casing and engaging the foil means adjacent the phase-shifting material.

References Cited in the file of this patent

UNITED STATES PATENTS

2,574,790	King	Nov. 13, 1951
2,776,412	Sparling	Jan. 1, 1957
2,849,685	Weiss	Aug. 26, 1958

OTHER REFERENCES

IRE Convention Record, vol. 5, part I, July 15, 1957, pages 227–234.

IRE Transactions on Microwave Theory and Techniques, vol. MTT–6, No. 3, pages 300–303, July 1958.