United States Patent

[11] 3,609,598

[72] Inventor **William G. Spaulding**
Huntsville, Ala.

[21] Appl. No. **20,967**
[22] Filed **Mar. 19, 1970**
[45] Patented **Sept. 28, 1971**
[73] Assignee **The United States of America as represented by the Secretary of the Army**

[54] PERIODICALLY LOADED FERRITE PHASE SHIFTER

4 Claims, 4 Drawing Figs.

[52] **U.S. Cl.** ..... **333/24.1,** 333/73 W
[51] **Int. Cl.** **H01p 1/32**
[50] **Field of Search** ..... 333/24.1, 242, 73 W

[56] **References Cited**

UNITED STATES PATENTS

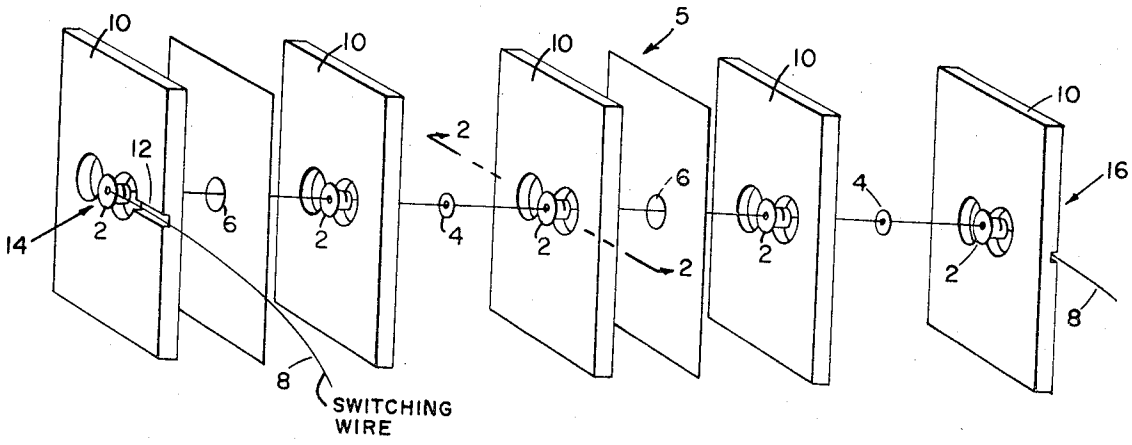
2,529,381	11/1950	Frear	333/98
3,274,521	9/1966	Nourse	333/24.1
3,277,401	10/1966	Stern	333/24.1
3,421,116	1/1969	Frank et al.	333/24.1

OTHER REFERENCES

Southworth, Principles and Applications of Waveguide Transmission, Van Nostrand Co., Princeton, N.J., 1950, Pp. 246 and 251, relied on, QC661S68

Primary Examiner—Herman Karl Saalbach
Assistant Examiner—Paul L. Gensler
Attorneys—Harry M. Saragovitz, Edward J. Kelly, Herbert Berl and Aubrey J. Dunn

ABSTRACT: An improvement over the existing art in microwave phase shifters of the nonreciprocal class. This invention employs a toroid of ferromagnetic material which can be magnetized in at least two of its remanent states. Higher interaction with microwave energy is obtained when a periodic disturbance is introduced into the transmission line which slows the propagating wave and provides a higher degree of circular polarization in the active region of the toroid. Periodic perturbation of the electromagnetic field is accomplished by spacing partitions across the waveguide which are loaded with ferrite toroids. The dimensional spacing of the partitions is on the order of a fraction of a free-space wavelength.



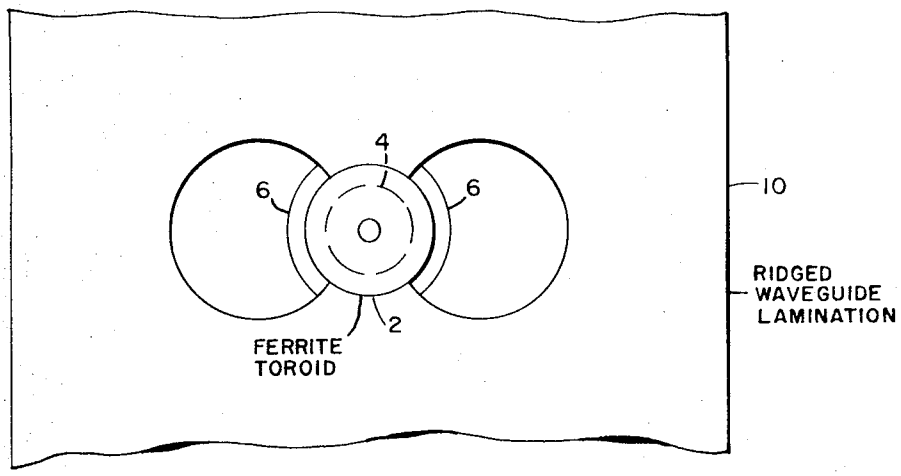


FIG. 2

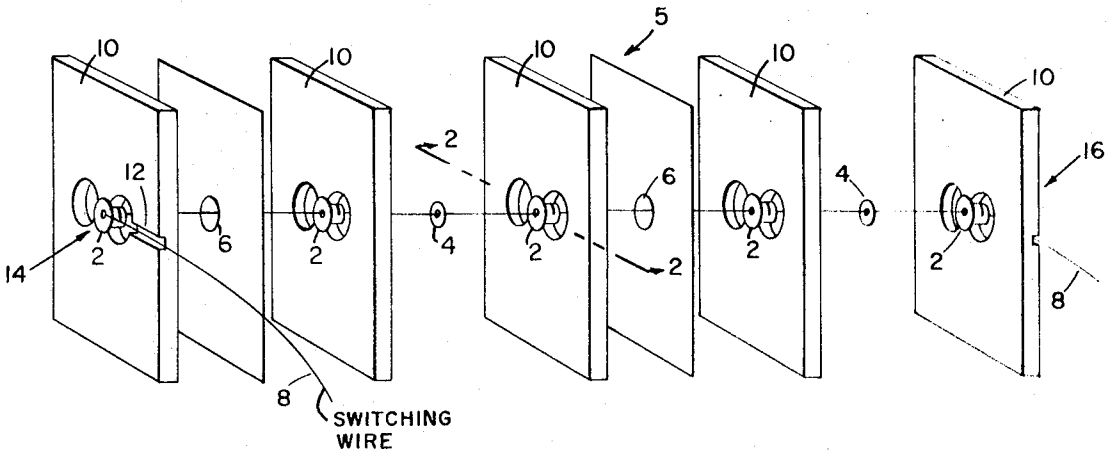


FIG. 1

William G. Spaulding,
INVENTOR
BY Harry M. Saragovitz
Edward J. Kelly
Herbert Berl
Aubrey J. Dunn

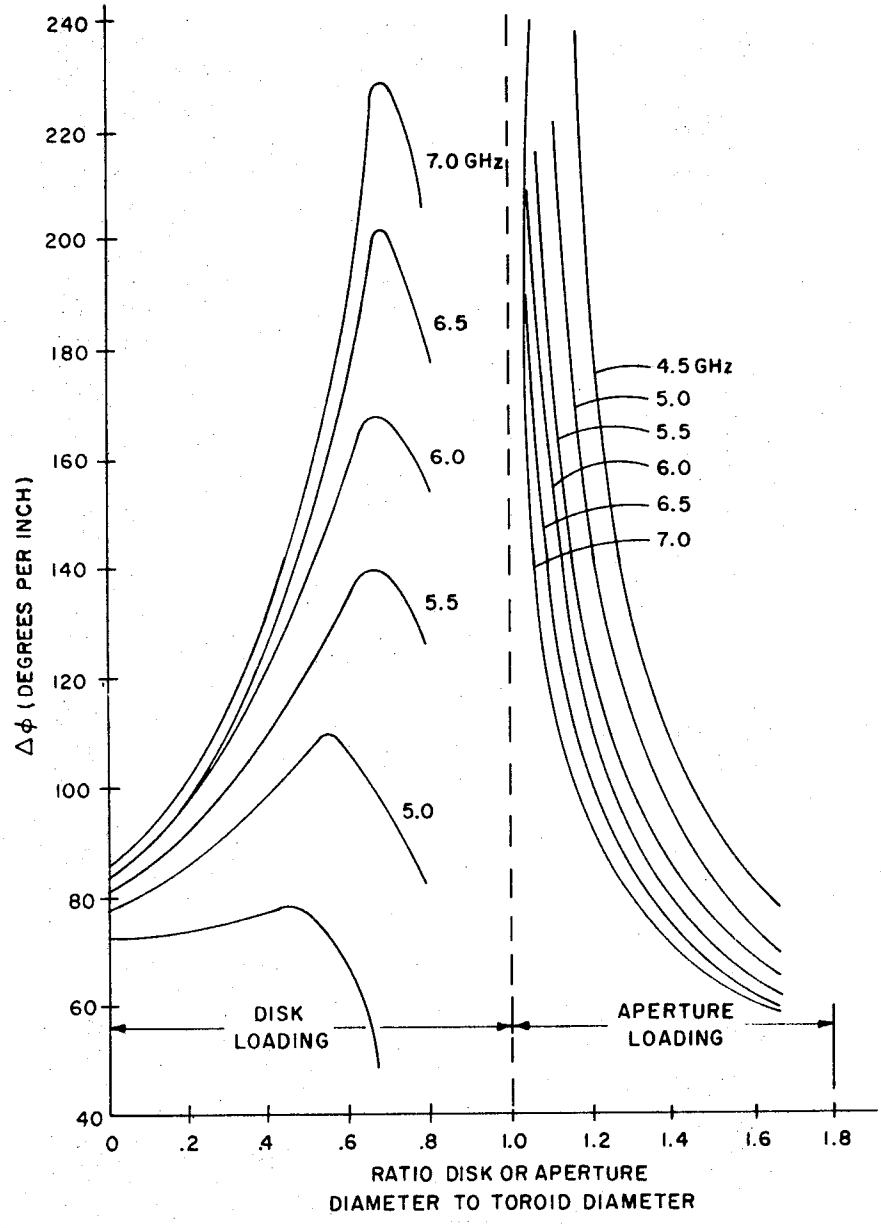


FIG. 3

William G. Spaulding,
INVENTOR
BY Harry M. Saragovitz
Edward J. Kelly
Herbert Berl
Aubrey J. Dunn

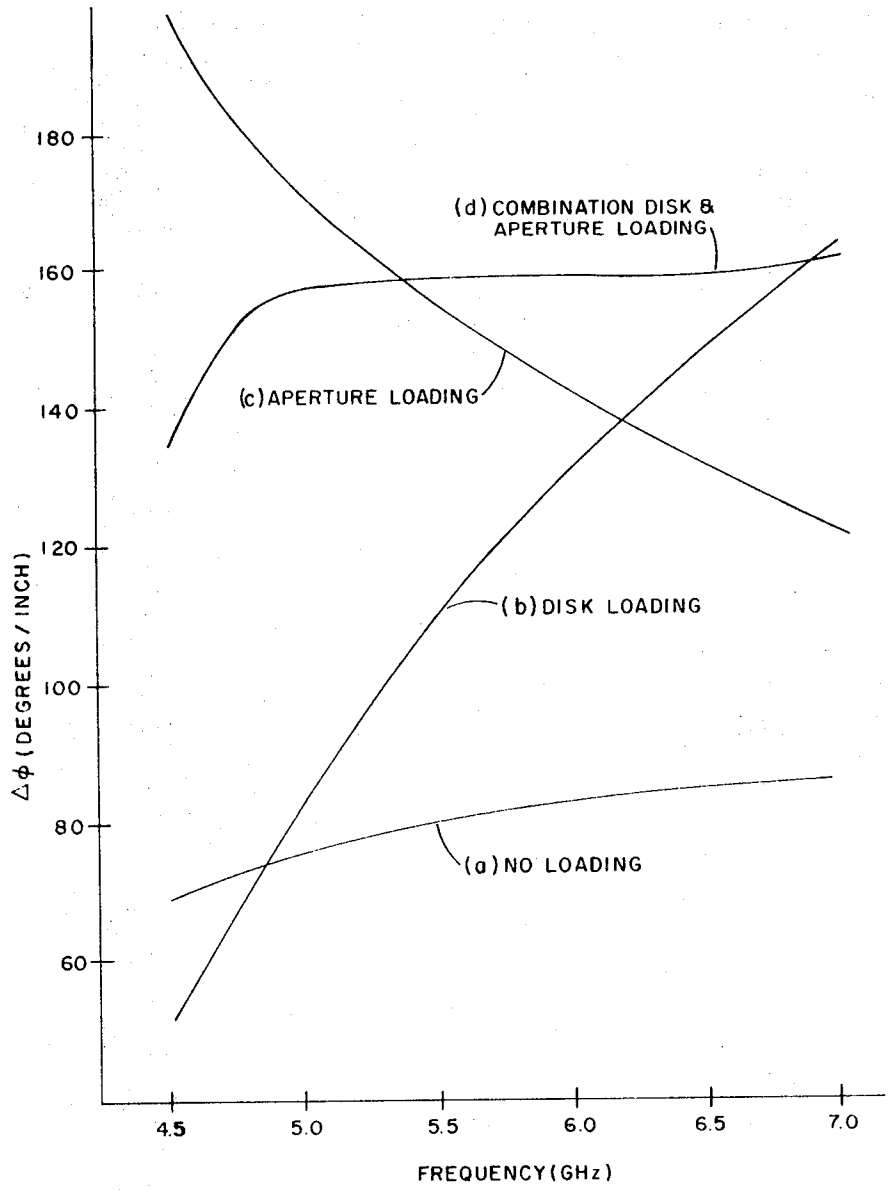


FIG. 4

William G. Spaulding,
INVENTOR
BY Harry M. Saragovitz
Edward J. Kelly
Herbert Berl
Aubrey L. Dunn

PERIODICALLY LOADED FERRITE PHASE SHIFTER

BACKGROUND OF THE INVENTION

This invention relates to ferrite phase shifters and in particular to an improvement over the existing art referred to in the current technology as latching, nonreciprocal, ferrite phase shifters. The existing designs of this type of phase shifter utilize a microwave transmission line loaded with a ferrite or garnet toroid disposed within the waveguide to interact with the electromagnetic field of the microwave energy. A switching wire is threaded through the toroid and is provided with terminals outside the transmission line in a manner that does not permit coupling of the waveguide energy out of the line. A pulsed current on the switching wire provides a magnetic field which "latches" or magnetizes the low reluctance toroid into a state of remanent magnetization. The two polarities of current possible permit at least two states of remanent magnetization. Generally, the two remanent maximums on the major hysteresis loop are used, however, other remanent states on any minor hysteresis loop can be used to provide additional states.

The effect of a remanent magnetization is to change the effective permeability of the ferrite media to an elliptically polarized electromagnetic wave which has its magnetic field in a plane orthogonal to the remanent magnetization. The elliptical polarization found in the magnetic field of a guided wave in a smooth transmission line is used for this interaction in some of the existing art devices. In other devices a smooth transmission line is wrapped or folded back on itself to provide an elliptical polarization between adjacent turns of the transmission line. The length of these turns is adjusted to optimize their interactions on a continuous basis in case of a helix, or at given areas in the case of the meander line type of device.

SUMMARY OF THE INVENTION

In the present invention the interaction within the waveguide is increased by purposely perturbing the electromagnetic fields to increase the elliptical polarization in the ferrite vicinity, on a periodic basis, down the length of the transmission line, in the direction of propagation. The differential phase shift, e.g., the difference in phase lengths of the device between the two opposite latched states of the ferrite, is enhanced considerably by this technique. In addition the wave is slowed providing an increased number of electrical cycles per unit length of transmission line which also increases the interaction. The periodic perturbation of the electromagnetic field is accomplished by spacing a partition across the smooth transmission line which is loaded with a ferrite toroid. The dimensional spacing of the partitions is on the order of a fraction of a free spaced wavelength.

Two types of partitions are used for the periodic circuit of this invention. One type, an aperture, has a negative dispersion of the differential phase shift versus frequency. The other type, a disk, has positive dispersion of the differential phase shift versus frequency. An inductive susceptance is created by the presence of an aperture in the transmission line while a capacitive susceptance is introduced by the presence of a disk in the transmission line. A combination of these two general types of partitions is used which result in little or no dispersion of the differential phase shift versus frequency over a given frequency band. This is a second improvement of the device over other types of "slow-wave" circuit phase shifters. By appropriate choice of periodic structural partitions, this device can be frequency compensated over bandwidths larger than previous art "slow-wave" phase shifters.

Accordingly, it is an object of this invention to provide a phase shifter which has increased phase shift per unit length of device, reduced volume of toroid material, and reduced switching energy.

Another object of this invention is to provide a method of frequency compensating the differential phase shift of a periodic structure.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is an exploded perspective view of the present invention; and

FIG. 2 is a cross-sectional view taken about line 2—2 of FIG. 1,

FIG. 3 is a graph showing the change in phase shift per inch of waveguide versus the ratio of disk or aperture diameter to toroid diameter; and

FIG. 4 is a graph showing the change in phase shift per inch of waveguide for various types of loading (disk, aperture, combination, none) versus frequency.

Referring now to the drawings, FIGS. 1 and 2 disclose a preferred embodiment of the invention, FIG. 2 being a cross section of the structure of FIG. 1. In FIG. 1 a ferrite phase shifter 5 is shown in exploded perspective to disclose the waferlike construction thereof. The body of phase shifter 5 consists of laminations 10 machined from sheet metal. The basic structure of the phase shifter is that of a ridge waveguide dielectrically loaded with circular ferrite or garnet toroids 2. The present phase shifter is a section of waveguide and is composed of a variable plurality of laminations, which can easily be loaded with thin periodic obstacles 4 and 6. Three dimensions are used to describe the geometry of the guide as is disclosed in the figures. This geometry was chosen because of the ease with which it can be fabricated in sheet metal laminations. It has the inherent advantages of providing a cradle to hold the ferrite toroid in a well-defined position without resorting to bonding. The ferrite toroid is an ideal one to minimize switching energy. Periodic partitions 4 and 6 are interspersed between laminations 10 which form the waveguide body. Disk 4 and iris, or aperture 6, are made of beryllium copper and are placed as additional laminates to form the periodically loaded phase shifter. Switching wire 8 is threaded through a hole in the center of toroids 2 and disk 4. It is then brought out of the waveguide 5 via feed-through slots 12 cut in the surface of the metal serving as the endmost laminations 10. Appropriate transition structures are required at input 14 and output 16 of the phase shifter in order to match its characteristic impedance to the transmission lines used for interconnection in a particular application.

To establish a reference phase of the microwave signal transmitted by the phase shifter, toroids 2 are magnetized by means of a current pulse, of an appropriate magnitude and duration, through switching wire 8. To change the phase length of the device, another current pulse is passed through switching wire 8 of different polarity, or magnitude, or duration, or any combination thereof. The current passed through switching wire 8 is used to magnetize toroids 2 in different states of remanent magnetization. This provides an effective permeability change between these states which alters the propagation constant of the guided wave. Thus, the electrical length, or insertion phase length, of the device is altered and the phase of the microwave signal at its output 16 is shifted.

When the smooth transmission line of FIG. 1 is periodically loaded with an aperture or disk a slow wave structure is formed having a passband of frequencies where the structure acts very much like a conventional "loss-less" transmission line with a reduced velocity of propagation. In addition, the differential phase shift is altered considerably. This is illustrated for varying disk diameter, on the left, and aperture diameters, on the right, of FIG. 3. Frequency is shown as the parameter. It is noted that the addition of either type of periodic obstacle increases the phase shift and produces a severe dispersion; however, the dispersions are in opposite directions. By combining disk and aperture loading, it is possible to increase the differential phase shift and simultaneously eliminate the dispersion over an appreciable band width.

The sequence of frequency compensation by this technique is shown in FIG. 4. The coordinates here are differential phase shift per total length of device versus frequency. Curve A: a smooth line containing ferrite may have a slight frequency

dispersion, either positive or negative, yet it can also be dispersionless over a limited band if steps are taken to compensate it by the usual methods of adjusting the cutoff frequency. Curve B: the same line periodically loaded with disk yields a positive dispersion slope. Curve C: loading with periodic apertures yields a negative dispersion. Curve D: by appropriate adjustment of the aperture diameter to disk diameter, and alternating the two in the direction of propagation, the structure can be frequency compensated fairly well. The added advantage shown by these data is the obvious 2:1 improvement in the differential phase per unit length.

The present invention may also be utilized as a band-pass filter. An effect of periodic loading is that it limits the frequency passband of the transmission line. As the inductive and capacitive susceptance is increased the passband is narrowed. Thus, the capacitive and inductive susceptance may be adjusted to achieve a desired passband. It should be noted, however, that the differential phase shift is increased as the passband is narrowed.

I claim:

1. A periodically loaded ferrite phase shifter comprising: a plurality of laminae coaxially aligned and having symmetrical openings therethrough forming a waveguide section, a plurality of ferrite toroids positioned in respective laminae openings along the longitudinal axis of said waveguide section, a plurality of thin metallic disks periodically positioned along the longitudinal axis of said waveguide section and coaxially aligned with said toroids for providing a capacitive susceptance in said waveguide section, and means for magnetizing said toroids into at least two states of remanent magnetization.

2. A periodically loaded ferrite phase shifter as set forth in claim 1 and further comprising a plurality of thin metal sheets partially obstructing said symmetrical laminae openings and having symmetrically spaced apertures therethrough, said apertures being periodically positioned along the longitudinal axis of said waveguide and coaxially aligned with said toroids for providing an inductive susceptance in said waveguide section, and wherein said disks and said apertures are positioned alternately between said toroids.

3. A periodically loaded ferrite phase shifter as set forth in claim 2 wherein said apertures have a diameter greater than and said disks have a diameter less than the diameter of said toroids.

4. A periodically loaded ferrite phase shifter comprising: a plurality of coaxially aligned laminations having symmetrical, aligned openings therethrough forming a waveguide section, a ferrite toroid positioned in each of said lamination openings in coaxial alignment, a plurality of thin metal sheets, each having an aperture therein, periodically inserted between said laminations, said sheets partially obstructing said laminate openings and said apertures being coaxially aligned with said ferrite toroids for introducing an inductive susceptance in said waveguide section, and means for magnetizing said ferrite toroids into at least two states of remanent magnetization.