REVIEW OF FERRITE PHASE SHIFTER TECHNOLOGY

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Abstract

Ferrite phase shifter technology is reviewed. Particular emphasis is placed on discussion of nonreciprocal, toroidal waveguide phasers and dual mode reciprocal phasers for use in phased array antennas.

Introduction

Three important classes of ferrite phase shifters were introduced in the early to mid 1950's. The simplest and perhaps the earliest reported nonreciprocal ferrite phaser is the Faraday rotator or gyrator. The gyrator described by Hogan[1] in 1952 is shown in Figure 1. In this device 180° of nonreciprocal phase shift is obtained. The other two types of phasers, the nonreciprocal twin slab phaser[2] and the Bush-Reggia-Spencer reciprocal phaser were introduced later.

Variations of the basic twin slab phaser are shown in Figure 2. The operation of such phasers are well known and are described in the book by Lax and Button. Although the Faraday rotator was used in the earliest microwave circulators, the twin slab design has found wide application in circulators and switches. During the past, considerable effort has been expended in developing such phasers to meet particular systems requirements. A novel implementation of the twin slab phaser using closed ferrite toroids was described by Treuhaft and Silber in 1958.[3] This development was largely overlooked for several years but subsequently has proven to be of considerable importance.

A reciprocal phase shifter in which changes in phase are obtained by the variation of biasing longitudinal magnetic field was first reported by Bush.[4] In this phaser, a ferrite rod or slab is centered within a rectangular waveguide. A solenoid is then wound about the waveguide. Reggia and Spencer[5] and other investigators have extensively investigated this geometry. For several years, this phaser was the only available reciprocal phaser and has found application in various systems.

Phase Shifters for Phased Arrays

During the recent past, most phase shifter research and development effort has been extended to the realization of small cross section (cross section less than $\lambda/2 \times \lambda/2$), fast switching phase shifters for use in phased array antennas. Two types of phase shifters have evolved for such use. They are the nonreciprocal toroidal, waveguide phaser following the work of Treuhaft and Silber, and a reciprocal phaser which utilizes the Faraday rotation effect. These important phasers will be described below.

Toroidal Nonreciprocal Phaser

Since 1963, several types of ferrite phasers have been investigated using a variety of shapes of ferrite toroids. Some of these include the waveguide nonreciprocal phaser,[6] helical phase shifters,[7] reciprocal[8] and nonreciprocal[9] strip transmission line phase shifters, meander line phase shifters in microstrip[10] and latching Reggia-Spencer phase shifters.[11,12] Although expensive to fabricate, the waveguide, nonreciprocal toroidal phaser has proven electrically superior to the other types. Specifically, it offers the lowest insertion loss or the largest figure of merit (maximum differential phase shift/loss (measured in degrees/dB)). In most cases, the figure of merit for the toroidal waveguide type is twice that of the others.

The basic operating mechanism of the waveguide ferrite toroidal phaser is shown in Figure 3. A ferrimagnetic toroid is centered in either a standard or reduced width waveguide as shown. Varying amounts of differential phase shift are obtained by reversing the remanent magnetization of toroid bits of varying length. Switching is accomplished also by partially switching the internal fields in a single long toroid (Figure 3(c)). Good electrical performance is obtained presently for toroidal, waveguide phasers operating at center frequencies from about 3 to 35 GHz.

The unit cost of toroidal phasers is high and much present effort is addressing this problem. Some of the areas receiving attention include:

- pressing toroids to shape or other techniques such as arc plasma deposition of toroids,
- reduction of magnetostriction in yttrium-iron garnet materials by materials modification,
- depositing or otherwise forming the waveguide housing about the toroid,
- materials research on lithium-titanium ferrites for garnet replacement,
- simplification and integration of driver circuits.

The Dual Mode Phaser

Within the past four years, a new Faraday rotation phaser has been developed which is both performance and cost competitive with the toroidal type.[12,13,14] The dual-mode reciprocal phaser converts linear polarized energy in rectangular waveguide to either left or right circular polarized energy as shown in Figure 4. This occurs in quadrantally symmetric, fully loaded waveguide. The energy is phase shifted and then reconverted to linear polarization in rectangular waveguide. In this construction, a circular or square ferrimagnetic rod is metallized to form the fully loaded waveguide. All biasing circuits and cooling is external to the rf circuitry.

Some of the desirable features of the dual-mode phaser include:

- the geometry of the phaser is such that parts for many phasers may be macchined at the same time,
- all non-rf circuits are external to the fully loaded waveguide,
- the phase shift element is accessible for heat sinking,
- the phaser may be characterized accurately and computer computational techniques may be utilized.

Switching speeds for the reciprocal, dual mode phaser are considerably slower than for a corresponding non-reciprocal, toroidal phaser. Thus the toroidal phaser is better suited for fast switching applications.

Future Trends in Phasers

For the foreseeable future, phased array systems requirements will emphasize cost reduction in ferrite phasers. Many systems presently under development are committed to the use of toroidal nonreciprocal phasers. Thus, improved low cost fabrication techniques for toroids and waveguide housings will receive continued attention. Tradeoff studies are required to determine if dual mode phasers may be produced at lower cost than toroidal types. Preliminary studies have indicated that at frequencies above 4 GHz, the dual mode phaser may be cheaper. As emerging systems utilize the dual mode phaser, further cost reduction studies will be required. Work on cost reduction and integration of drivers for both type of phasers will continue.

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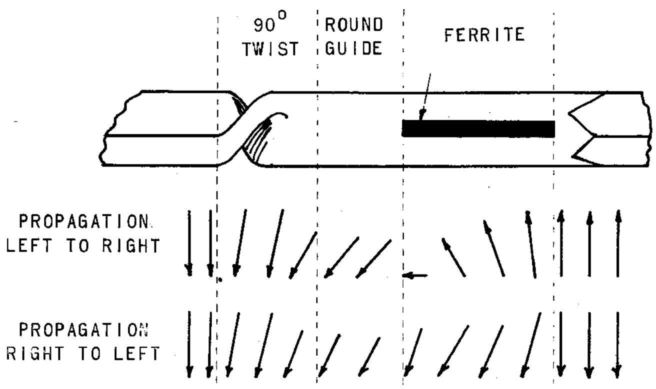


FIG. 1
The gyrator rotates the direction of polarization 180° for left to right propagation, no rotation for right to left propagation (After C.L.Hogan, Bell System Tech.J., Vol.31, p.1, 1952.)

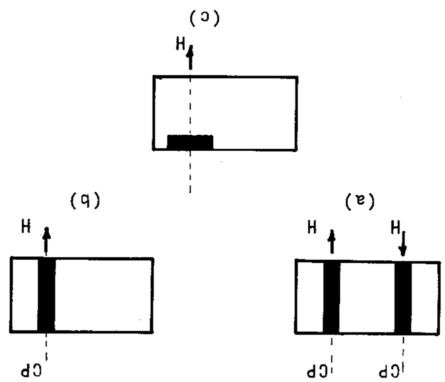
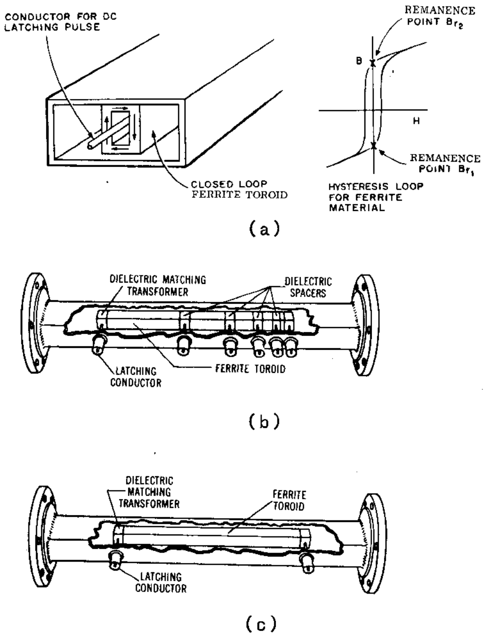


FIG. 2
Variations of basic twin slab phase shifter (a) Basic configuration, (b) Single slab phase shifter, (c) Phase shifter configuration suitable for high power applications.



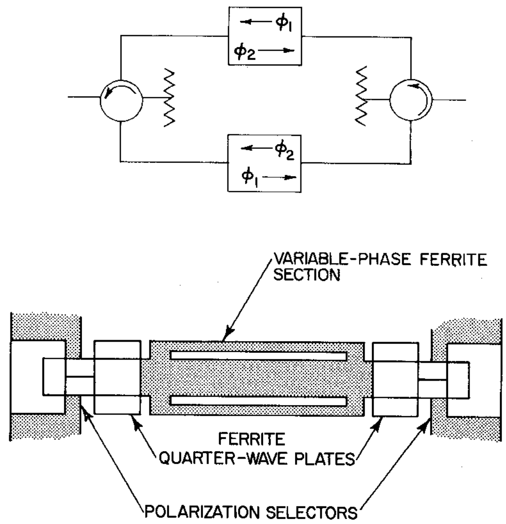


FIG. 3
Nonreciprocal toroidal phaser (a) Switching of ferrite toroid, (b) Five-bit nonreciprocal phaser, (c) Single toroid phaser to be switched by flux transfer techniques.

FIG. 4
Dual mode reciprocal phaser, basic mechanisms and physical realization.