A Review Article on Design of High Power Waveguide Circulator

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***Abstract*—This paper explains the basic concept of circulator which is a ferrite device and makes use of ferrite material at high power. The specification of nonreciprocal devices such as circulator like insertion loss, power handling capacity depends on the ferrite properties like resonance linewidth, dielectric loss tangent and critical field. The applied magnetic field causes the electron to resonate about certain frequency. This field slits the rotating modes form a stationary pattern which can be rotated to isolate one of the port of circulator. The circualtor serves the basic purpose of duplexing in many communication system like RADAR.**

***Index Terms*— Ferrite circulator, Y junction, H plane.**

I. INTRODUCTION

Microwave ferrite devices permit the control of microwave propagation by a static or switchable dc magnetic field [1]. The devices can be reciprocal or nonreciprocal, linear or nonlinear, and their development requires a knowledge of magnetic materials, electromagnetic theory, and microwave circuit theory. Unlike a magnetic metal, a ferrite is a magnetic dielectric that allows an electromagnetic wave to penetrate the ferrite, thereby permitting an interaction between the wave and magnetization within the ferrite [1]. The various terms used in explaining the effect of ferrite material are discussed in [1]. *Faraday Rotation*—the rotation of the plane of polarization of a TEM wave as it propagates through a ferrite in the direction of the magnetization, *ferromagnetic resonance (fmr)*—the strong absorption that can occur when an elliptically polarized RF magnetic field is perpendicular to the direction of magnetization, *field displacement*—the displacement of the field distribution transverse to the direction of propagation resulting in more or less field in the ferrite region, *nonlinear effects*—at higher power levels amplification and frequency doubling are possible and subsidiary losses can occur, *spin waves*—short-wavelength waves of magnetization that can propagate at any angle with respect to the direction of magnetization. The spinning of electron about a static magnetic field is responsible for the functioning of ferrite in circulator.

II. PERMEABILITY TENSOR [1]

The permeability tensor is derived from the tensor susceptibility(χ), which, in turn, is derived from the equation of motion of a magnetic dipole (due to electron spin) in the presence of both a static magnetic field (H_o) and a transverse RF magnetic field (H_x). This is shown in Fig. 1.

If the RF field is present, the precession will be maintained, but there will be some absorption of the signal. Just as with a gyroscope and the direction of gravity, there is a natural direction of precession that is associated with the direction of the static field, as shown in Fig. 1. If H_o is reversed, the precession is reversed. However, an interesting phenomenon occurs if the ferrite is immersed in a rotating elliptically polarized RF magnetic field that drives the precession. If the driven precession is against the natural direction, the cone angle θ is reduced. If they are in the same sense, the cone angle will increase. Furthermore, if they are in the same sense and the driving frequency is equal to the natural frequency, resonance will occur accompanied by strong absorption of the microwave signal. This loss mechanism is called fmr and it is used in resonance isolators. To take this absorption into account, a damping coefficient α is introduced into the equation of motion and the range of static magnetic field (at a fixed frequency) over which this absorption is significant is denoted by the linewidth ΔH . The relationship between α and ΔH is given by $\alpha = \mu_o \gamma \Delta H / 2\omega$ [1].

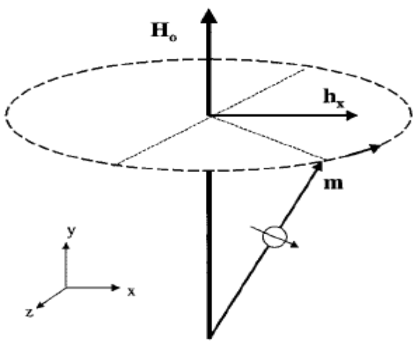

Figure 1: Magnetic dipole moment m precessing about a static magnetic field H_o [1].

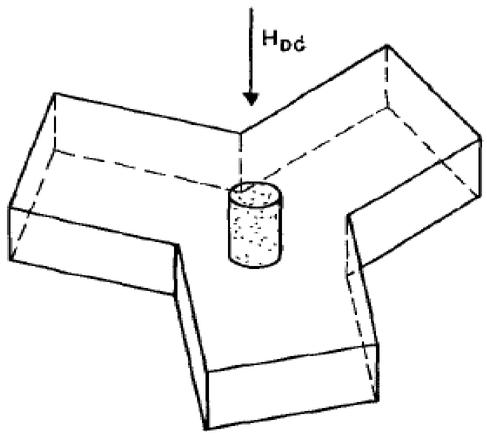

Figure 2: Three port H-plane waveguide circulator [2].

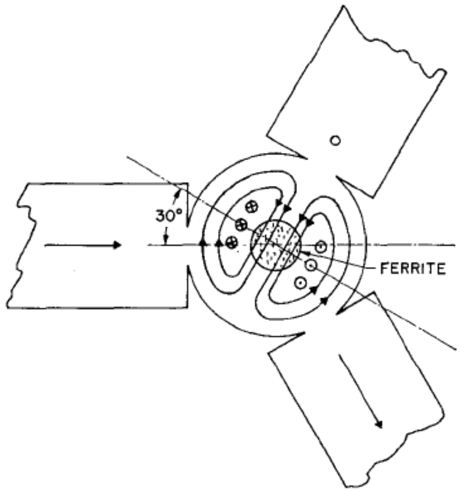

Figure 3: Mode pattern for H-plane waveguide circulator using TM_{110} mode [2].

III. OPERATION OF CIRCULATOR [2]

The three-port waveguide circulator usually consists of a 120° H-plane junction having a post of ferrite at the center of the junction as shown in Fig. 2. The biasing magnetic field is applied in the direction of the cylindrical axis of the post. With rectangular waveguide operating in the dominant TE_{10} mode, and with the ferrite post being considerably smaller in diameter than the width of the waveguide, the ferrite is excited mainly by the transverse RF H-field of the wave. First let us consider a lightly coupled case in which the ferrite post is contained in a cylindrical cavity which is coupled to the branching waveguides by small irises as shown in Fig. 3. If we assume this cavity is resonant at the operating frequency in the TM_{110} mode, the field pattern will be similar to that shown in the figure. Such a standing-wave pattern can be generated by two similar counter rotating patterns. The RF magnetic field will be almost circularly polarized in the ferrite for each sense of rotation. As soon as magnetic biasing field is applied to the ferrite, the resonance splits in a manner similar to that of the stripline circulator. If the bias is adjusted so that each of the counter-rotating modes has a 30° phase angle, the resultant standing-wave pattern will have the orientation shown in Fig. 3. Here it is obvious that two ports are coupled to the standing-wave pattern and the third port lies at a null. Properties of microwave ferrite devices depend on such design parameters as shape and size of both the metallic structure and the ferrite insert and on the matching elements. However, the device properties also depend to a great extent on the choice of the ferrite and its state of magnetic polarization. In Fig. 4 a number of typical device specifications and a number of ferrite properties have been listed. To make an appropriate choice of ferrite for a given application the relations between the device specifications on the one hand and the ferrite properties on the other should be more or less known. These relations fall into the three following categories.

The dependence of insertion loss on, for instance, linewidth ΔH and dielectric loss tangent $\tan\delta_{\varepsilon}$, is similar for the three different types of nonreciprocal devices. The same holds for the dependence of high-power capability on the critical field strength h_{crict}. In recent years latching and switchable microwave ferrite devices, which are operated in the remanent state of the ferrites, have come into use. Such hysteresis-loop properties as coercive force $H_{coerc.}$ remanent flux B_{rem} squareness, etc., have therefore become important for microwave applications too. The dependence of device properties on the saturation Magnetization $4\prod M_s$ (or the average or remanent, magnetization, if the ferrite is not saturated) and on the polarizing magnetic field H_{dc} is not at all similar for the three groups of devices [3].

Purpose and Function

In microwave systems that use a single antenna aperture for both sending and receiving, the function of circulators is primarily to facilitate the routing of outgoing and incoming signals to the transmitter or receiver as appropriate. This is illustrated in Fig. 5, which shows a schematic diagram of a phased-array antenna module using a switchable circulator in addition to an ordinary (non switchable) circulator. The module also contains two T/R switches. Their function can also be satisfied by two further circulators, but switches are generally preferred in these locations because of cost and size considerations. Circulators and isolators are made possible by the nonreciprocal character of the microwave behavior of ferrites (and certain other materials) [1].

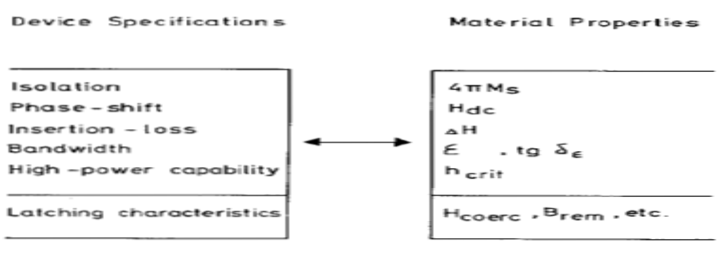

Figure 4: Device specifications strongly depend on properties of ferrite material [3].

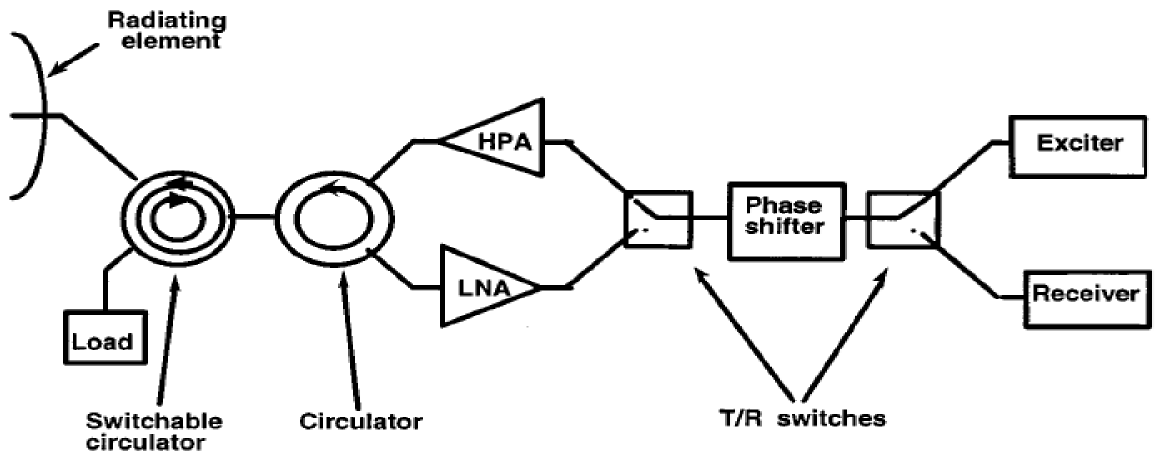

Figure 5: Schematic diagram of phased-array antenna module [1].

IV. Design Approach

The circulator with partial height ferrite posts has a wider bandwidth as compared to its full-height counterpart. There are basically three geometry configurations, a half wavelength long ferrite cylinder open-circuited at both ends, two quarter waveguide ferrite cylinder coupled in the middle of the waveguide junction, and a single quarter-wavelength ferrite resonator. Analysis and performance of the three geometry configurations are very similar. As illustrated in Fig. 6, two ferrite disks are in a circular cavity connected to three rectangular waveguide and a dielectric cylinder is located between two pieces of the ferrite disks. The ferrite disks with relative dielectric constant of ε_r and relative permeability of μ_f (μ_f =1) and waveguide junction together constitute a resonator. Without static magnetic field bias, the center frequency of the waveguide circulator is determined by the resonant frequency of the dielectric resonator [4].

A design approach is mentioned in [4] which has required bandwidth of 400 MHz and center frequency 9.375 GHz. VSWR and insertion loss is less than 1.2 and 1 dB respectively and pulsed power is 30 KW with average power of 10W.The simulated and tested results are shown in Fig. 7 and Fig. 8 respectively.

V. Conclusion

From the above references an overview of basics of ferrite material and circulator is presented. It conveys that the ferrite material is the heart of waveguide circulator and is responsible for the functioning of circulator. It may also be concluded that circulator is used in many communication system for duplexing purpose.

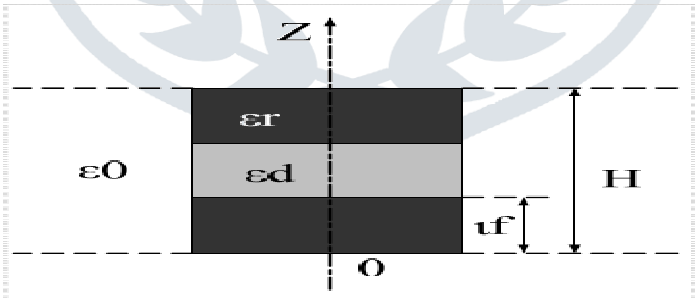

Figure 6: Junction geometry configuration (edge view) [4].

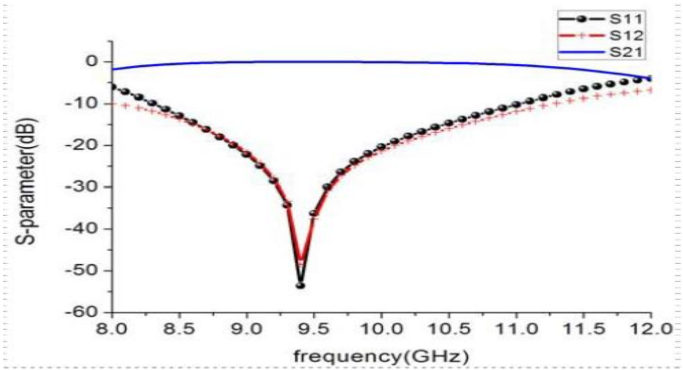

Figure 7: Simulated result [4].

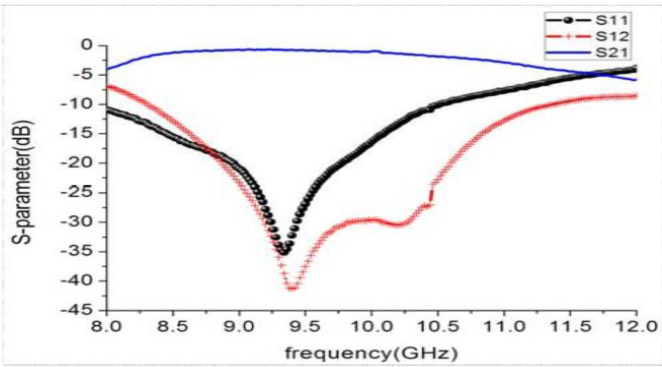

Figure 8: Tested result [4].

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