© 2016 IJEDR | Volume 4, Issue 2 | ISSN: 2321-9939

An Overview of Design of Microstrip Junction Circulator

[1]Najama Momin, [2]Brijesh Shah
[1]Student, [2]Associate Professor
Electronics and Communication Department,
Chandubhai S. Patel Institute of Technology, Charotar University of Science and Technology, Anand, India

***Abstract* - this paper explains the basic concept of microstrip junction circulator which is a nonreciprocal ferrite device. The properties of nonreciprocal ferrite device depend strongly on the properties of ferrite material used. The selection of ferrite materials depends on the frequency and bandwidth of the circulator as well as RF power level, ambient temperature and insertion loss required. The junction circulator is based on two counter-rotating modes. The applied magnetic field used to saturate ferrite material causes the electrons to resonate about certain frequency. The circulator serves the basic purpose of duplexing in many communication systems like RADAR.**

***Index Terms* – Junction Circulator, Ferrite, Microstrip.**

I. INTRODUCTION

In communication systems as well as in antennas' T/R modules, circulator is an important part. The minimal size; weight and cost for the design of circulators are the requirements of development of integrated circuits. As microstrip circulators are more compact and easy to integrate with other devices, it has been widely used.

In microwave ferrite devices, the propagation of microwave can be controlled by a static or switchable dc magnetic field [1]. The ferrite devices can be linear or nonlinear, reciprocal or nonreciprocal. A ferrite is a magnetic dielectric which allows the penetration of electromagnetic wave in it, which permits an interaction between the wave and magnetization within the ferrite [1]. The various properties used in explaining the effect of ferrite material discussed in [1]. Faraday rotation – When a TEM wave propagates through the ferrite in the direction of the magnetization, the rotation of the plane of polarization of the TEM wave is called Faraday rotation. Ferromagnetic resonance – The strong absorption that can occur when an elliptically polarized RF magnetic field is perpendicular to the direction of magnetization is called ferromagnetic resonance (fmr). Field Displacement – The displacement of the field distribution transverse to the direction of propagation resulting in about field in the ferrite region is called field displacement. Nonlinear effects - At higher power levels, frequency doubling and amplification are possible and subsidiary losses can occur which are called nonlinear effects. Spin – Short-wavelength waves of magnetization that can propagate at any angle with respect to the direction of magnetization.

II. PERMEABILITY TENSOR [1]

The interaction between the RF magnetic field and the magnetization of the ferrite can be described by Polder tensor permeability. We can derive the permeability tensor from the tensor susceptibility (χ) which is derived from the equation of motion of a magnetic dipole in the presence of both a transverse RF magnetic field (H_x) and a static magnetic field (H_0). This is shown in Figure 1 and it is assumed that $\|H_x\| \ll \|H_0\|$.

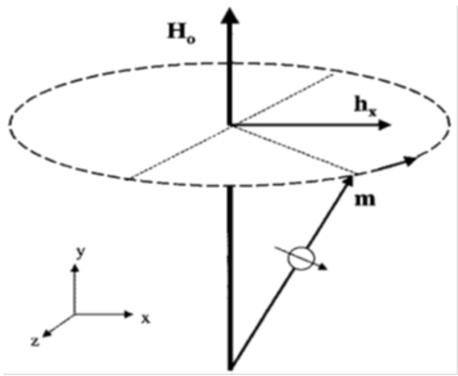

Fig. 1 Magnetic dipole moment **m** precessing about a static magnetic field

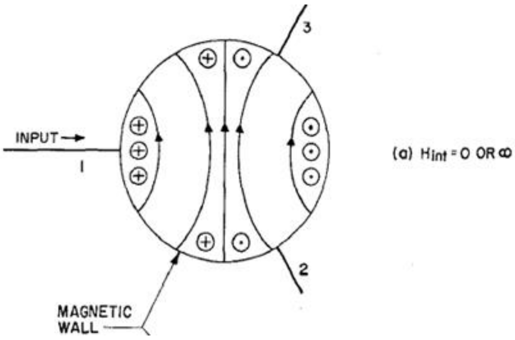

Fig.2 Standing wave pattern of Unmagnetized disk $H_{int} = 0$

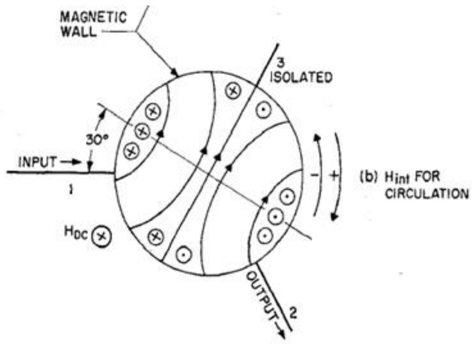

Fig.3 Standing wave pattern of Magnetized disk $H_{int} \neq 0$

When a magnetic dipole (**m**) is immersed in a static magnetic field due to the electron spin, it precesses about the field axis with an angular frequency. The precession will be maintained, if the RF field is present. But there will be some absorption of the signal. There is a natural direction of precession which is associated with the direction of the static field, as shown in Figure 1. If H_0 is reversed, the precession is reversed. An interesting event occurs, if the ferrite is immersed in a rotating elliptically polarized RF magnetic field which drives the precession. The cone angle θ is reduced, if the driven precession is against the natural direction. The cone angle will increase when they are in the same sense. Resonance will occur accompanied by strong absorption of the microwave signal when they are in the same sense and the natural frequency is equal to the driving frequency. This loss mechanism is called fmr and it is used in resonance isolators. To take this absorption into account, a damping coefficient 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 by the linewidth. The relationship between and is given by $\alpha = \mu_0 \gamma \Delta / 2\omega$.

III. OPERATION OF CIRCULATOR [2]

The operation of Y junction stripline circulator is described in terms of counter rotating modes. The operations of stripline and microstrip junction circulator are same in nature. Basic structure of microstrip junction circulator consists ground plane, dielectric slab and ferrite material. Three conducting strips are attached to the center disk at 120° apart from each other. In microstrip circulators a hole is drilled in the dielectric slab and ferromagnetic material placed in the hole. The conductors are then formed over the ferrite and dielectric material to form a circulator junction. The ends of the conductors are adapted to be connected to associated transmission lines. At the resonant frequency, the Y junction microstrip circulator is under coupled and standing wave existed in the structure. The maximum isolation occurs at the frequency at which the insertion loss is minimum. The resonance of a center disk is an essential feature for the operation of circulator.

When the disk is unmagnetized, the standing wave pattern will appear as shown in the Figure 2 where input voltage at port 1 results in 180° out of phase voltages at port 2 and port 3 with respect to input voltage and it will be half in the magnitude compared to input voltage. So, basically in unmagnetized case circulator behaves as coupler. When the disk is magnetized properly by applying external bias field, the standing wave pattern will appear as shown in Figure 3. Here it can be seen that given input voltage at port 1, the same voltage with phase and magnitude appears at port 2 and port 3 is isolated.

Regions of Circulator operation

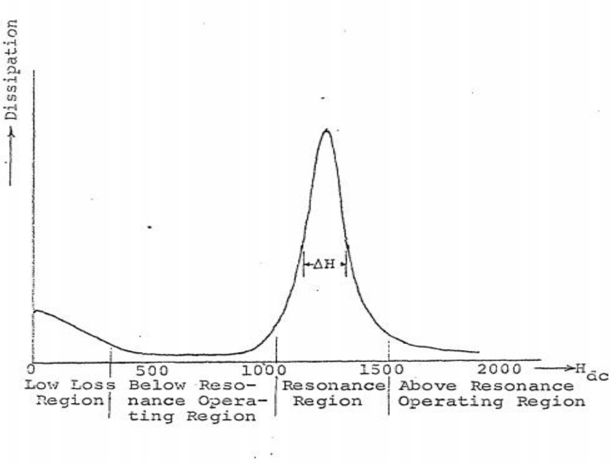

Fig.4 Resonance Curve Shows basic Regions of Circulator operation [6]

The operating region of circulator in terms of applied magnetic field is divided among three parts. They are below resonance, above resonance and at resonance. For three regions there are different conditions that must be followed. If value of $\omega_o/\omega=1$ then the ferrite is operating in resonance region. But in this region the imaginary part of permeability tensor becomes infinite which leads ferrite to become lossy and absorbs all power applied to it. To avoid this situation the ferrite must be operated in either above resonance ($\omega_o/\omega<1$) or in below resonance ($\omega_o/\omega>1$).

In the below resonance region, the value of saturation magnetization is low which increases the peak power handling capacity of the circulator. But on the other hand the lower saturation magnetization decreases the bandwidth of the circulator. But in above resonance region, high magnetic bias is required for high frequency operation. So to have high frequency the ferrite must be operated in below resonance region so that the required magnetic bias is decreased. But if the saturation magnetization is decreased in above resonance region then the need of higher magnetic bias field also decreases. So keeping all the above points in mind and based on the priority of the desired parameter the region of operation must be selected. So the below resonance region is selected for microstrip junction circulator. In general, junction circulators below 2 GHz are developed in above resonance mode; for circulators above 2-3 GHz, below resonance operation is utilized.

IV. Design Methodology

The properties of nonreciprocal ferrite devices depend strongly on the ferrite properties [3]. For the three different groups of nonreciprocal devices, the dependence of different device specifications, such as power capability, insertion loss etc. on line width, critical field, dielectric loss tangent etc. is similar and the dependence of bandwidth and insertion loss on polarization field and ferrite magnetization is specific for a special group.

Device Specifications	Material Properties
Isolation	$4\pi M_s$
Phase-shift	H_{dc}
Insertion-loss	ΔH
Bandwidth	ε, $t_g \delta_\varepsilon$
High-power capability	h_{crict}
Latching characteristics	H_{coerc}, B_{rem} etc.

Table 1 Relation between device specifications and material properties [3]

Passive nonreciprocal microwave ferrite devices belong to one of three groups. One group makes use of Faraday rotation in circular waveguides, the second group is based on nonreciprocal field effects in rectangular waveguides and the last one is the group of junction circulators. Junction circulators are popular due to their compact and simple design.

If low insertion loss is to be maintained; the ferrite material should have a very low dielectric tangent. The line width of the material must be narrow (approximately 50 to 100 Oe) to avoid the resonance losses [4]. The magnetic biasing field should be approximately equal to $4\pi M_s$of the material, but it can be adjusted in the test for the best result. For a circulator housing, the selected metal should be easily machinable, highly conductive, inexpensive, light weight and nonmagnetic. If insertion loss is an important specification then the center conductor may be silver-plated. Cold rolled steel is used for magnet pole pieces [5].

V. Conclusion

From the above references an overview of basics of ferrite material and microstrip junction circulator is presented. It conveys that the ferrite material is the most important part of microstrip junction circulator and is responsible for the operation of circulator. It may also be concluded that circulator is used in many communication system as a duplexer or as an isolator.

References

[1] J. Douglas Adam, Fellow, IEEE, Lionel E. Davis, Gerald F. Dionne ,Ernst F. Schloemann and Steven N. Stitzer, “Ferrite Devices and Materials” IEEE Transaction on microwave and techniques, vol.no.50, issue:3, ISSN: 0018-9480, DOI: 10.1109/22.989957, pages 721-737, March 2002.

[2] C.E.Fay and R.L.Comstock, “Operation of the ferrite Junction Circulator” IEEE Transaction on microwave and techniques, vol.no.13, issue: 1, ISSN: 0018-9480, DOI: 10.1109/TMTT.1965.1125923, pages 15-17, January 1965.

[3] Henk Bosma, “A General Model for Junction Circulators; Choice of Magnetization and bias field”, IEEE Transaction on magnetics, vol.no.4, issue: 3, ISSN: 0018-9464, DOI: 10.1109/TMAG.1968.1066335, pages 587-596 September 1968.

[4] J.W.Simon, “Broadband strip-transmission line Y-junction Circulator”, IEEE Transaction on microwave theory and techniques, 1965.

[5] Douglas K Linkhart, “Microwave Circulator Design”, Artech House, 1989.

[6] Vilas Vernon Risser Jr., “Design and construction of microstrip circulators”, Iowa State University, 1969.

[7] Sándor Hosszú, László Jakab, Tibor Berceli, “Computer Aided Microstrip Circulator Design”, Microwave Radar and Wireless Communications (MIKON), 2010, 18th International Conference.

[8] Y.S.WU, Fred J. Rosenbaum, “Wide-band Operation Of Microstrip Circulator”, IEEE Transaction on Microwave Theory and Techniques, Vol MTT-22,No.10,October 1974.