Y-Junction Microstrip based Circulator for X-band Radar

Prof. Marai M. Abousetta, Libyan Academy for Graduate Studies, m.abousetta@academy.edu.ly

Abstract:
The proposed Y- junction, X-Band (9.6 GHz with 800 MHz bandwidth) microwave circulator is composed of a dielectric substrate in which the ferrite material disk is inserted. Because of the microwave, non-reciprocal components such as isolators or circulator are based on the gyromagnetic properties of ferrites, the Yttrium Iron Garnet (YIG) is considered as a ferrite material.. Ansoft-High Frequency Structured Simulation Software (*Ansoft-HFSS*) is used as realization software and optimized investigation work were performed using the Hewlett-Packard Advanced Design System (*HP-ADS*). Fay and Comstock [1] give the design equations used here. Isolation and return loss of more than 20 dB, and insertion loss of less than 0.2 dB are achieved in simulation results.

1-Introduction:

A device, which is finding extensive use in the microwave industry, is the ferrite circulator. A circulator is a ferrite loaded symmetrical junction of three or more transmission lines. It has the property of transferring power from the incident port to the next adjacent port and isolating all other ports. The nonreciprocal characteristics of the ferrite, under the influence of proper magnetic bias fields, make this action possible. Theoretically, a circulator can have any number of ports. However, the difficulties of realizing an n-port circulator increase as n increases. Practically 3 and 4-port circulators have been produced.

Conventionally, a Y-junction micro strip circulator consists of a dielectric substrate and a ferrite material, which is put on it. A metal ground is located below the dielectric material. Finally, the center conductor of the circulator is designed on the top of the structure Fig.1 [3]. In some cases, the ferrite disk could also be placed above the center conductor.

The Y-junction microwave circulator is typically having 3 ports (input port, output port and decoupled port). The main reason for using this junction circulator is energy supervision. Circulator allows the maximum power transfer from one port to another port in a way that the power flows from input port to output port and 3rd port will be isolated. It is like the power enters at port 1 is fully transmitted to port 2, power enters at port 2 is completely transmitted to port 3 and power enters at port 3 is completely transmitted to port 1. At the same time the circulation can take place in reverse direction too, Fig.2.

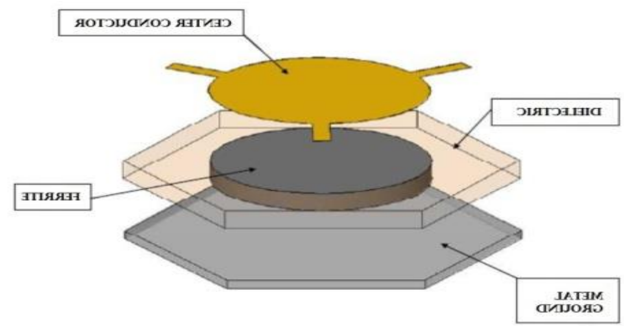

Figure 1: Principal construction of
a microstrip junction circulator [3]

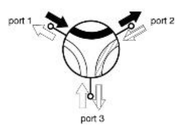

Figure 2: Energy flow in a 3-port-circulator [4

2-Design and Construction:

Many techniques are adopted for designing of circulator - with stripline and waveguide transmission medium. One uses green function and scattering matrix analysis for three-port stripline circulator. Others have given phenomenological description in terms of rotating modes and analysis of stripline with new set of equations [5]. In this work an X-band microstrip realized circulator is simulated using *Ansoft-HFSS,* design equations as in [6] are followed and optimization is achieved using *HP-ADS.*

3- Circulator Structure and Magnetic Material

The proposed circulator is composed of a dielectric substrate in which the ferrite material cylinder is inserting. The substrate is placed on a lower ground plane; finally, the plane of the central circular conductor will be the upper layer of the structure where the radii of the upper conductor and ferrite material disk kept the same; like that of (Fig.3).

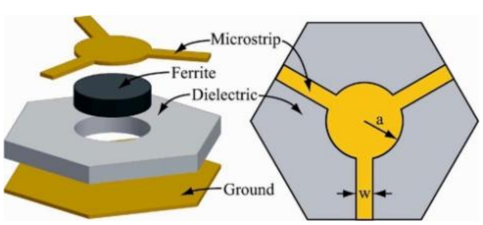

Figure 3: The proposed Y-junction Circulator geometry [7].

The chosen specifications of the X band frequency circulator are given in table I:

Table I. Specification of X band circulator [8]

Center Frequency		9.6 GHz
Bandwidth		800 MHz
Insertion loss		< 0.4 dB
Isolation		> 20 dB
Return loss		> 20 dB

As mentioned in [6] and [8], the frequency of operation, bandwidth, and RF power level and insertion loss are primary parameters effected by the chosen ferrite material. Therefore, the important properties of such material to be considered are saturation magnetization, resonance linewidth, and magnetization temperature coefficient. High saturation magnetization results in wider bandwidth, but it also lowers power-handling capability; so there always is a tradeoff between bandwidth and power handling capability. Here, the bandwidth is more concerned with, so the saturation magnetization requirement will be high. Insertion loss will depend on resonance linewidth of ferrite material. To lower the insertion loss, the ferrite whose linewidth is minimum is chosen. Temperature stability of ferrite material is considered when the device is to be operated over wider temperature range.

Based on the same tradeoffs and properties of various ferrite materials [9] - yttrium iron garnet Y220 selected as the ferrite material. Here resonance linewidth of Y220 is lowest and saturation magnetization is highest. Though temperature stability of Y220 is slightly lesser than other materials, here low insertion loss is more important; so Y220 is chosen among available ferrites. Material properties of yttrium iron garnet Y220 is given in Table II.

Table II. Properties of Ferrite Material Y220 [8,9]

Saturation Magnetization (4πMs)	**1950 G**
Curie Temperature (Tc)	**205°C**
Resonance line width (ΔH)	**10 Oe**
Effective linewidth (ΔH eff)	**2 Oe**
Spin wave linewidth (ΔHk)	**1 Oe**
Dielectric Constant (ε_r)	**15.4**
Magnetization Temperature coefficient (α)	**3.1 x 10^{-3}/°C**

For purpose of calculation, the ferrite radius is determined from the equations given in [6]. The solutions of the field theory equations involve the Bessel function of the N^{th} order. For practical circulators, n =1 and the resonance occurs when,

$$J_n' \ (ka) = 0 \qquad (1)$$

Where J is the Bessel function, k is the wave number and a is the ferrite radius. Evaluating the first root of (1), we get,

$$ka = 1.84 \quad (2)$$

From (1) and (2), we found that the initial radius of ferrite a = 2.1 mm; and electrical design of microstrip circulator is prepared as shown in Fig. 3.

The proposed circulator is considered to be operating in below resonance region, where the value of saturation magnetization is low which increases the peak power handling capacity of the circulator. On the other hand, the lower saturation magnetization decreases the bandwidth of the circulator. Also, for high frequency operation, the high magnetic bias is required in above resonance region. So, to achieve this objective condition, the ferrite must be operated in below resonance region so that the required magnetic bias is decreased.

However, if the saturation magnetization is decreased in above resonance region, then the needed higher magnetic bias field also decreases as will. Thus, for all the above points and based on the priority of the desired parameter the below resonance is the region of operation has been selected for our device.

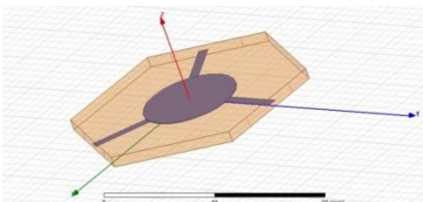

Figure 4: Electrical design of basic circulator

4- Design procedure:

For sake-of synthesizing the circulator design, the procedures start with desired circulator *VSWR*, from which admittance phase angle can be calculated using the equation;

$$VSWR \approx sec^{2}\theta \quad (3)$$

Where θ is the admittance phase angle and its value is used to find the loaded quality factor of the disk resonator as given in following equation.

$$Q_L = \frac{\tan\theta}{\left(\frac{\Delta f}{f_o}\right)} \quad (4)$$

Where Q_L is loaded quality factor (Q).

Δf is required circulator bandwidth

f_o is the band-center = $\frac{1}{2}$ bandwidth.

Ones the Q_L is calculated, the frequency splitting factor ($\frac{k}{\mu}$) can determined as following,

$$\frac{k}{\mu} = \frac{0.71}{Q_L} \quad (5)$$

As we assumed above that the circulator is operated in below resonance region, and ferrite is considered as just saturated and by putting μ = 1; the ferrite effective permeability (μ_{eff}) can be given as following

$$\mu_{eff} = 1 - \left(\frac{k}{u}\right)^2 = 1 - \left(\frac{\gamma\, M_o}{\omega}\right)^2 \qquad (6)$$

Where γ is gyromagnetic factor, M_o Is saturation magnetization, ω is resonant frequency. More details about these designing roles are elaborated in [6] and [10].

5-Simulation and Optimization

The ferrite disk is inserted in the dielectric as shown in both exploded 3-D and top views, as well as proposed *Ansoft-HFSS* circulator model in Figs. (3) and (4) respectively, where the radius of conducting disk and the ferrite as well are kept the same. Each of the three microstrip input ports are 120° apart and extend over a coupling angle of the center-conducting disk. Simulation is carried out from 9.2 GHz to 10 GHz.For comparison, the investigation work was performed using *HP-ADS* model as shown in fig.5

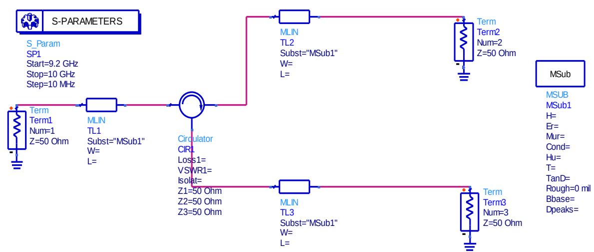

Figure 5: Simulation setup for the proposed model

The optimized *S* parameters achieved are shown in Fig. 6, and 7. Return loss is > 25dB, insertion loss is < 0.2dB and isolation is > 25dB which are better than the industrial standards, i.e. return loss and isolation > 20 dB and insertion loss < 0.4 dB. Our results as shown in table III are better than the referenced industry product.

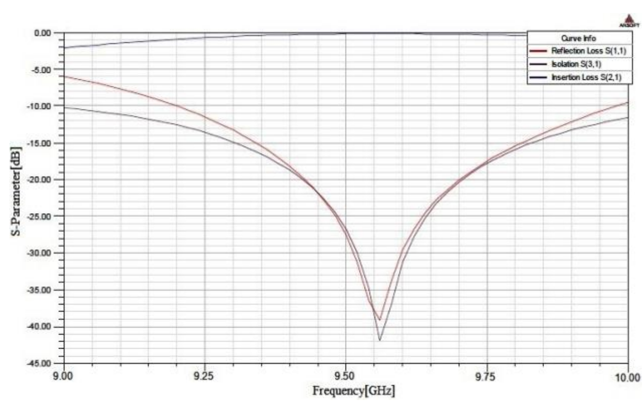

Figure 6: *HFSS* Optimized S-Parameters
Of The Simulation Model

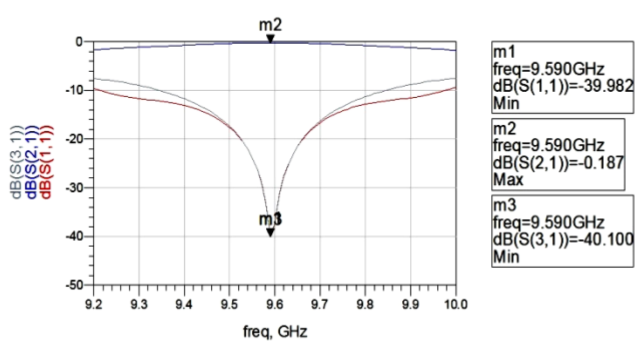

Figure 7: *ADS* Optimized S-Parameters Of The Simulation Model

According to the above S-parameters plots, it is very clear that the transmission has occurred from port 1 to port 2 i.e. (S_{21}) and the isolation has occurred between port 1 and port 3 i.e. (S_{31}). Here the blue curve represents the insertion loss (S_{21}), red curve represents the return loss (S_{11}) and the gray curve represents the isolation (S_{31}).

According to the Fig. 8, it is very clear that the propagation of the electric field is minimum at the isolated port 3 and is maximum at the transmitted port 2

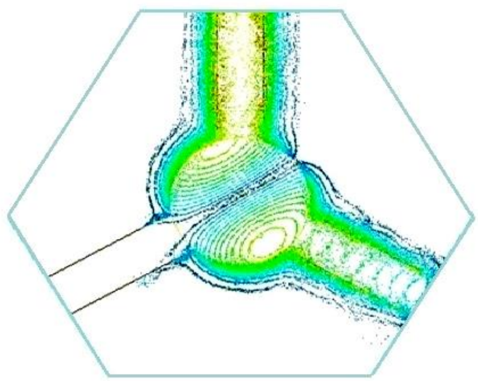

Figure 8: Power transfer occurs from port 1to 2 and decoupled at port 3

The best design parameters are selected and good S-parameters are achieved by the optimization and good bandwidth (25%) coverage is obtained according to the tuned design parameters. According to Figure 7, the minimum insertion loss -0.187dB is obtained at the operating frequency, the return loss is minimized to -39.982dB and the isolation is greatly improved to -40.1dB.

Table III. Comparison of our design with industry product

Parameters	Insertion Loss, dB	Return Loss, dB	Isolation, dB
Our Design	< 0.2	> 25	> 25
Trak Microwave Corporation	0.3	21	21

All these optimized S-parameters covered 25% bandwidth of the system, which is generally a good coverage in wideband communication systems but here the circulator has been designed by assuming zero electric and magnetic losses. In reality, the insertion loss could be even more than what has been achieved. Therefore, all these parameters and ferrite properties set a bandwidth limit.

6-Conclusions:

Based on the standard microstrip circulator design roles, X band microstrip circulator has been designed using magnetic material films in order to increase the electronic integration with other microwave elements in a radar system.

better performance than the industrial product is thought of if a prototype of designed circulator actually realized.

7- References:

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