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Passive Coplanar Circulator with the Yig Thin Films

Rahmouna El-Bouslemti [1,1], Faouzi Salah-Belkhodja [1],

[1] LTTNS Laboratory, Department of Electronic, University of Djillali Liabès, Sidi Bel Abbés, Algeria
rahma_bouslemti@yahoo.fr, fouzi_belkhodja@hotmail.com

Abstract. This paper presents the design and analysis of a new triangular structure of a coplanar circulator using a coplanar topology (CPWG) in the X band frequency. Design and simulation were performed by the ANSOFT HFSS simulator based on the finite element methods. The design is a topology with its planar conductors in the same plane. As a result, a miniature ciculator at 11 GHz with insertion loss of 0.85 dB and isolation of 20.06 dB has been designed.

Keywords: circulator, coplanar waveguides (CPWG), S-parameters, microwave.

1 Introduction

The circulator belongs to a large family of non-reciprocal devices widely used in microwave components based on magnetic materials.

Because the requirements for communication devices, miniaturization of microwave components is required. The objective of our work is to model a miniature circulator with a magnetic massive layer of YIG.

Many researchers have studied the transmission characteristics of the stripline Y-junction circulator whose work of Bosma [1], [2], Fay and Comstock [3], and other authors who have given a general baseline for all models of stripline circulators shape microstrip [4], [5], and coplanar circulators [6], [7].

In this paper, a coplanar circulator having a central conductor of triangular shape has been studied on the basis of design studies made by J. Helszain [8] where the classic strip triangular structure is implemented in coplanar technology.

The optimization component is accomplished through a parametric study in HFSS simulator that provides a satisfactory structure.

[1] Rahmouna El-Bouslemti.

2 Theoretical Study

In this work we have studied the particular case of coplanar circulators having a central conductor triangular in shape and based on the studies of J. Helszajin [8].

This study helps to understand the operation and the good working of the circulator. The design parameters are the characteristics of the magnetic material, the polarization and the circulation frequency of the device.

The internal bias field layer of Yig is defined by the relation:

$$H_i = \sqrt{\frac{\lambda}{\sqrt{3}w} H_0 - 4\pi M_s} - 4\pi M_s \ . \quad \textbf{(1)}$$

Where λ is the wavelength, w is the radius of the central conductor, M_s is the saturation magnetisation and H_0 is the external static field is defined by:

$$H_0 = \frac{\omega}{\gamma \mu_0} \ . \quad \textbf{(2)}$$

With γ, ω and μ_0 respectively represent the gyromagnetic factor, the angular frequency and the permeability of vacuum.

We have used the results presented in the study referenced in [8] to obtain the size of the triangular conductor principal (A).

$$kA = {}^{4\pi}/_{3} \ . \quad \textbf{(3)}$$

A is the length of the side of the inner triangle and k is the wave number in the medium and is defined by:

$$k = \frac{2\pi}{\lambda_0}\sqrt{\epsilon_f \mu_{eff}} \ . \quad \text{and} \quad \mu_{eff} = \frac{\mu^2 - k^2}{\mu} \ . \quad \textbf{(4)}$$

Where ϵ_f is the relative dielectric constant, μ_{eff} is the effective permeability of the ferrite calculated from the model of Polder [10]. k et μ are the elements of the tensor Polder ferrite; λ_0 (meters) is the wavelength in vacuum. It is measured by the meter.

From measurements of the resonant frequency for the first mode, authors in [3] found that the edges of the resonator are not really perfect magnetic walls. They defined the effective value of the triangle side A_{eff} as follows [7]:

$$A_{eff} = A + \frac{h}{4} \quad (5)$$

Where h *is* the thickness of the ferrite layer.

3 Circulator Structure

Figure 1 shows the circulator designed [8], [9], which has a hexagonal structure coplanar (CPW: coplanar waveguide) [11]. The central part of our device (Fig. 1) has a triangular configuration. This Y-junction circulator has three accesses oriented at 120^0 relative to each other.

The metallization (ground plane (GND) and lower mass) of 1 μm thickness is gold.

A ground plane (GND) in the form of a thin film is placed at the center of the junction on the Yig (CPWG topology (Coplanar Waveguide with Lower Ground Plane). This lower ground plane provides the signal transition from access lines (horizontally) to central conductive portion triangular lines lines (horizontal) [10] (see Fig. 2). To ensure proper operation of the device, a magnetic bias field (H_i) must be applied in a direction perpendicular to the solid layer of Yig.

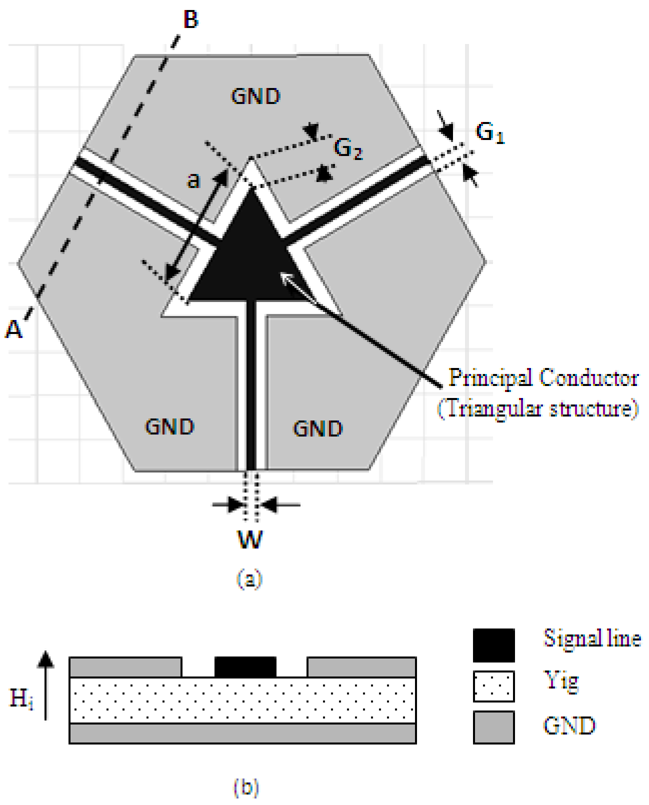

Fig. 1. Structure of a triangular circulator with CPWG structure.

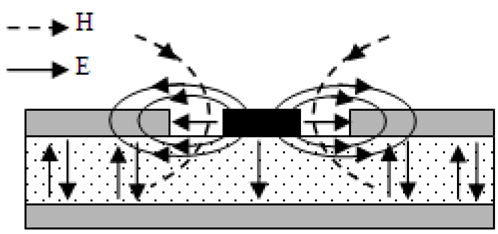

Fig. 2. Electromagnetic configuration of the CPWG coplanar line.

The thickness of the YIG layer is 100 microns. The magnetic material (the Yig) is defined by the following features: a relative permittivity εr = 15.3, a dielectric loss tangent $\tan\delta = 10^{-2}$, a saturation magnetization M_s=178 mT and the damping factor α = 0.0175. An internal magnetic field polarization Hi = 90KA/m was applied in a direction perpendicular to the ferrite layer. The metallization with the gold has a relative permeability μ =0 .99996 and a conductivity $\sigma = 41.10^6$ S / m.

4 Simulation and discussion

The commercial software ANSOFT-HFSS was employed. We studied the effects of several parameters on the performance of the circulator. From the parameter studies, the dimensions of our circulator are obtained as follows: a = 2.4 mm (the side of the inner central triangle), W = 0.16mm (the width of signal line), G_1 = 0.12mm (a signal Line-to-GND spacing), G_2 = 0.30mm (spacing between GND plane and the signal line). The resulting characteristic impedance is equal to 45Ω.

To start the simulation, it is necessary to excite the two structures. We use Wave-Ports that are specified for the excitation signal is not fully enclosed in the slot and extend into the air above the Yig. CPW is the HFSS under simulated surrounded by a sufficient distance to air box of the line.

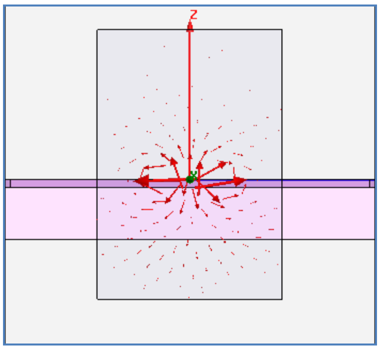

Fig. 3. Wave-Port: Configuration of the electrical signal.

The results of the simulation parameters of the circulator are illustrated in Fig. 2.

The non-reciprocal transmission characteristics represented by $|S_{12}| = 22.36\ dB$, is observed at 11.40GHz. The signal propagates from port 1 to port 2 with insertion losses $|S_{21}|$ is 0.89dB, in the direction of the port 3, the signal is blocked with an isolation rate $|S_{31}|$ of the order of 28.44dB and the return loss at the port 1 is $|S_{11}| = 22.28$ dB.

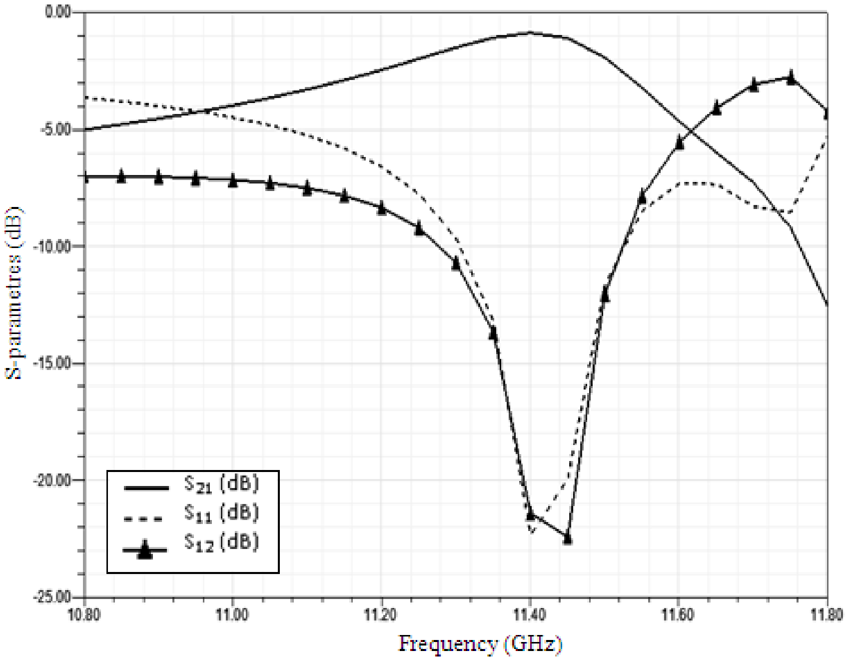

Fig. 4. Evolution of *S*-parameters of a triangular coplanar circulator.

4.1 Effect of the G_1 and G_2 on the S-Parameters

The influence of the G_1 (a signal Line-to-GND spacing) and the G_2 (spacing between GND plane and the signal line) on the transmission characteristics are analyzed and studied to estimate their influence on the S-parameters and assess their impact on device performance. We are executed at several simulations to study the behavior of the circulator by Ansoft HFSS.

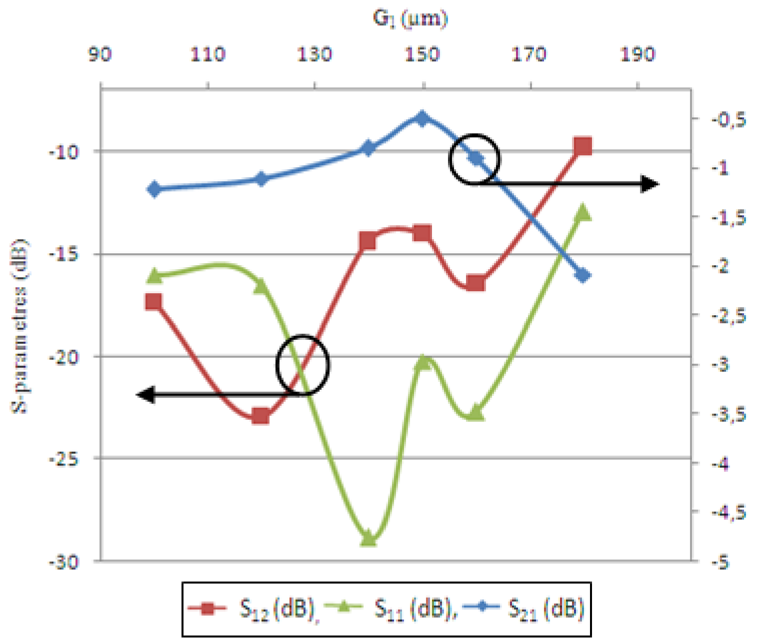

Fig. 5. Variation of S-Parameters (S_{21}, S_{12}, S_{11}) with G_1 (a signal Line-to-GND spacing) of the CPWG.

The parameters G_1 varies from 100 to 180 µm which shown in Fig. 3 keeping a W/G_1 report as the resulting impedance of access remains close to 50 Ω. The *S*-parameters fluctuate with the parameter G_1, it appears that it vary irregularly with the parameter G. the best performance is obtained at the G_1 = 150mm with the insertion loss of 0.70 dB and isolation of 20.25dB. Through a very comprehensive comparison with the transmission characteristics, we have selected a G_1 parameter of 150µm of our circulator.

Another simulation is done to quantify the effect of G_2 (spacing between GND plane and the signal line) on the S-parameters (Fig. 7). The G_2 parameter varies from 100 and 700µm. The *S*-parameters fluctuate with the parameter G_2. The isolation gets the best performance at G_2 = 300mm for a$|S_{12}| = 26.78\ dB$, the best return losses are obtained for G_2 = 600 m for a$|S_{11}| = 37.14\ dB$. We have selected a G_2 parameter of 300µm of our circulator after a very exhaustive comparison of simulation results in isolation losses

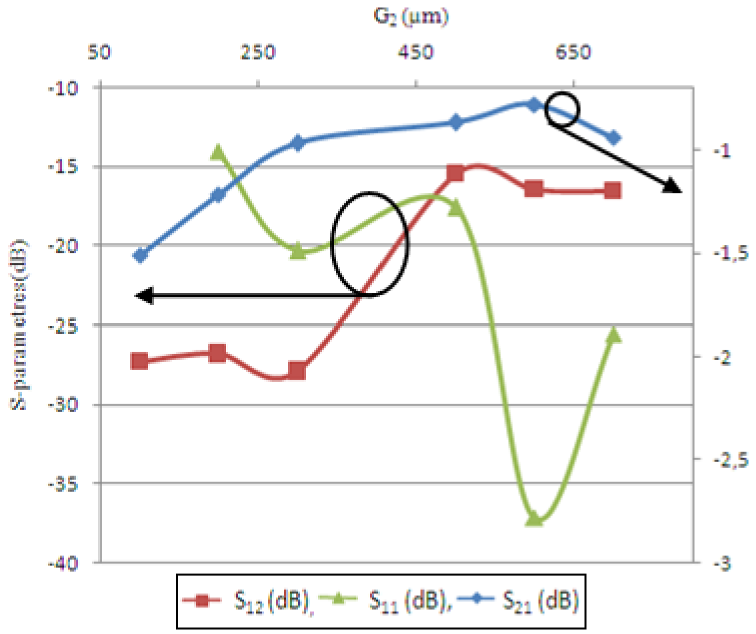

Fig. 6. Variation of S-Parameters (S_{21}, S_{12}, S_{11}) with G_2 (the spacing between signal line and GND) of the CPWG.

4.2 Effect of the Non-connected Ground plane

The simulation results are shown in Fig 6. We have removed the non-connected GND plan that is presented in the figure to show its effect.

We can see that the circulation phenomenon disappeared and transmission is reciprocal which ensures that the lower ground plane allows a better transition wave that propagated access lines (horizontal) to the circular portion of the center conductor (vertical) [12].

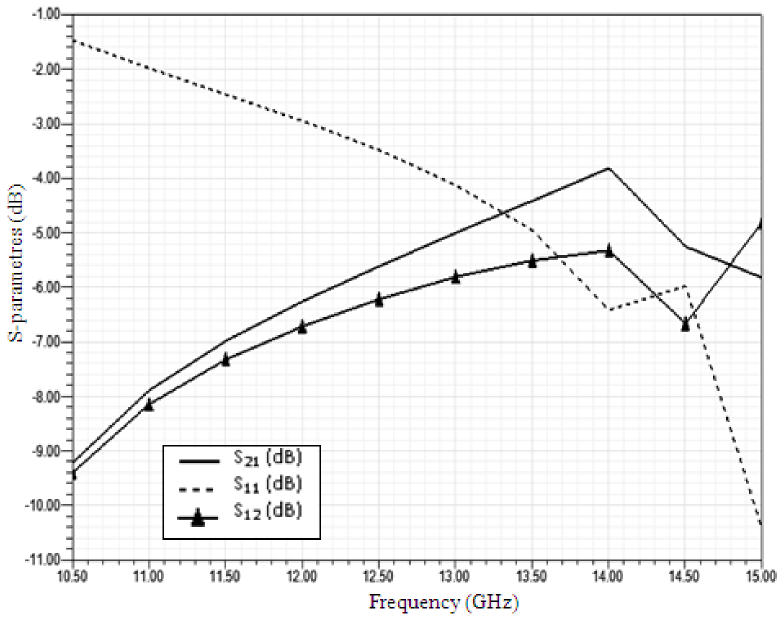

Fig. 7. Evolution of *S*-parameters for a circulatorin which GND plane under the Yig is removed.

5 Conclusion

In this work, we have presented a numerical study of a coplanar circulator in the band 10-20 GHz with a triangular shape of its principal conductor, based on Yig, a magnetic material 1000 microns. The structure, the geometric dimensions and the different magnetic characteristics were presented. The results obtained from the simulation in HFSS show the functioning of the circulator.

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