

Miniature Triangular Circulator with Coplanar Waveguide Structure

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Abstract—A different form of coplanar triangular circulator structures is proposed in this work. The HFSS is used to simulate the circulator and to check the non-reciprocal characteristics at operating frequency. In this analysis, an insertion loss of -0.21 dB and a non-reciprocity of -33 dB appeared at around 13.5 GHz; these results show good circulation performances of the device. The miniaturization of device need to have a small size which it is a principal advantage of a coplanar triangular circulator.

Index Terms—circulator, S-parameters, ferrite, non reciprocity, triangular structure

I. INTRODUCTION

In recent years, the Democratization of telecommunications systems, for reasons of compactness and cost, has led a race for miniaturization of nonreciprocal devices using a magnetic materials subjected to a static magnetic field such as circulators. These passive components include the ability to differentiate and select the waves transmitted and received by the telecommunications systems. A many different topologies can be designed of circulators, all different from each other, but their common property is the nonreciprocity of the device.

The stripline Y-junction circulator has been studied by Bosma in 1962 [1]. This study is allowed to establish the circulation conditions and from there on, to deduce the essential physical parameters in the design of stripline circulators.

Many researchers have improved the circulator performances using the microstrip structure [2]. The CPW line was introduced in 1969 by Wen [3]. In 1971; Ogasawara [4] has showed and has confirmed that the Y-junction circulators with CPW successfully operated at certain frequencies. This work is devoted to the study of the three port ferrite circulator using CPW technology. In particular cases we will study a different type of circulator that uses a triangular central pattern. The triangular structure has been proposed and studied by J. Helszajn [5], [6] using a microstrip topology. Certain

advantages in terms of performance relative to the circular structure have been demonstrated. Recently, Zahwe was suggested this triangular structure in topology coplanar [7]. In this work, the main approach will be developed in order to improve the performance of the coplanar triangulaire circulator and compare our results with that of Zahwe [7].

II. THEORY

The conception of a coplanar triangular circulator is based on the parametric study presented in [1], [5]. The Y-junction stripline circulator proposed by Bosma [1] is the most used of such passive microwave components.

From the theoretical results obtained by J. Helszajn [6]:

$$r = \frac{A}{2\sqrt{3}} \quad (1)$$

r either represents the inscribed radius defined by the triangular resonator, and A is the length of the side of the inner triangular conductor, shown in Fig. 1.

Or the actual radius of the ferrite disk:

$$r = R \quad (2)$$

We can calculate the value of the triangle side A from this equation [6]:

$$kA = 4\pi/3 \quad (3)$$

k is the wave number in the medium and is defined by:

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

where ϵ_f is the relative dielectric constant, μ_{eff} is the effective permeability of the ferrite calculated from the model of Polder. K and μ are the elements of the tensor Polder ferrite.

From measurements of the resonant frequency for the first mode, authors in [6] 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.

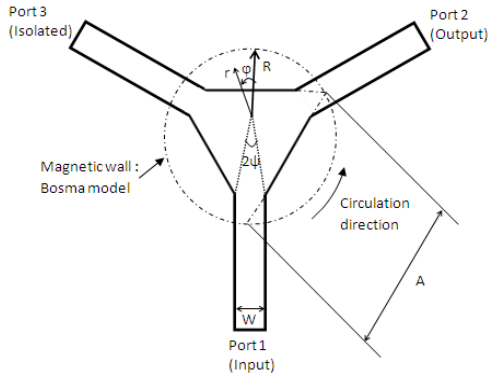


Figure 1. Configuration of the central conductor.

It is possible to determine the stripline conductor's width W depending on the stripline width angle ψ and the radius of the ferrite disks lines R as follows [1]:

$$W = 2R \sin \psi, \quad \psi = \frac{1}{\sqrt{3}} \frac{\pi(K/\mu)}{1.84 \sqrt{\mu_{eff} f / \epsilon}} \quad (6)$$

The magnetic material used in [1] is the ferrite which it is placed in the center for device. This magnetic material gives the circulator its non-reciprocity. The ferrite is polarized along the axis of the cylinder and saturated. The ferrite is polarized along the axis of the cylinder and saturated using an internal static magnetic field given by the following expressions:

$$H_i = \sqrt{\frac{\lambda}{\sqrt{3}w} H_0 - 4\pi M_s - 4\pi M_s} \quad (7)$$

where λ is the free space 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:

$$H_0 = \frac{\omega}{\gamma} \quad (8)$$

With γ , ω respectively represent the gyromagnetic factor, the angular frequency.

III. COPLANAR TRIANGULAR CIRCULATOR

The simply structure on study is shown in Fig. 1, which has dimensions of $3 \times 3 \times 1 \text{ mm}^3$. The central part of our device has a triangular configuration. The metallization (ground plane (GND)) of $1 \mu\text{m}$ thickness is made of copper. A ground plane (GND) in the form of a triangular thin film is placed at the center of the junction on the ferrite (see Fig. 1.b). it provides the signal transition from access lines to central conductive portion triangular lines (horizontal) [8].

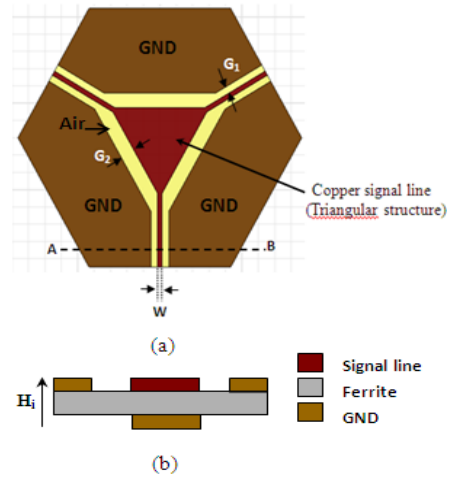


Figure 2. Structure of a CPW triangular circulator. (a) top view, (b) cross-section of the CPW structure.

The integration of magnetic material is essential for producing the non-reciprocal properties of the circulator. The thickness of the ferrite layer is $h=1 \text{ mm}$. It is defined by the following features: a relative permittivity $\epsilon_r=15.3$, a saturation magnetization $4\pi M_s=1780 \text{ Gauss}$, a dielectric loss tangent $\tan\delta_E=10^{-4}$ (measured value in about 9.4 GHz), and a ferromagnetic resonance (FMR) linewidth $\Delta H = 100 \text{ Oe}$ and . An internal magnetic field polarization $H_i=350.57 \text{ KA/m}$ was applied in a direction perpendicular to the ferrite layer (see (7)). The conductor line and GND planes was made of copper with a relative permeability $\mu=0.999991$ and a conductivity $\sigma = 58.10^6 \text{ S / m}$.

Table I above shows a comparison of the performance of the circulator having conductors with thicknesses of 1 and 4 μm of copper or gold. These results obtained did not show a remarkable difference in performance of coplanar circulator. It was found that the conductive material either gold or copper with very little influence on circulator performance when the thickness of ferrite is important.

TABLE I. PERFORMANCE OF THE CIRCULATOR ACCORDING TO THE CONDUCTIVE MATERIAL (COPPER / GOLD) AND ITS THICKNESS

		Transmission (dB)	Isolation (dB)	Reflexion (dB)
Copper	1 μm	-0.22	-50.17	-29.27
	4 μm	-0.21	-26.32	-28.80
Gold	1 μm	-0.20	-32.21	-26.97
	4 μm	-0.20	-25.11	-28.43

IV. PARAMETRIC STUDIES OF THE BEHAVIOR OF A COPLANAR TRIANGULAR CIRCULATOR

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: $A = 3 \text{ mm}$ (the side of the inner central triangle), $W = 0,14 \text{ mm}$ (the width of signal line), $G_1 = 0,08 \text{ mm}$ (a signal Line-to-GND spacing), $G_2 = 0,90 \text{ mm}$ (spacing between GND plane and the signal line). The resulting characteristic impedance is equal to 48Ω .

In addition, the electromagnetic configuration shows the electric field distribution of the coplanar triangular circulator (the field displacement phenomenon) (see Fig. 3). The electromagnetic configuration of Fig. 3 shows the circulation phenomenon of the device. The electromagnetic field has a coplanar configuration on access lines level.

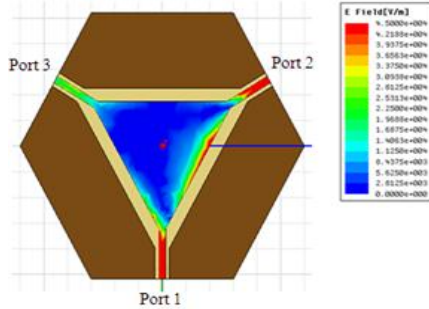


Figure 3. Circulation phenomenon: Signal transmitted from port 1 to port 2, port 3 is isolated.

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

The non-reciprocal transmission characteristics represented by $|s_{12}| = 50.17 \text{ dB}$, is observed at 13.55 GHz . The signal propagates from port 1 to port 2 with insertion losses $|s_{21}| = 0.21 \text{ dB}$, in the direction of the port 3, the signal is blocked with an isolation rate $|s_{31}|$ of the order of 32.53 dB and the return loss at the port 1 is $|s_{11}| = 29.27 \text{ dB}$.

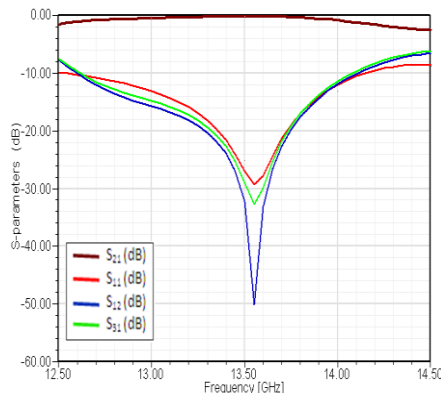


Figure 4. Evolution of S-parameters of a triangular coplanar circulator.

A. Effect of Radius of Triangular GND (RG) on the S-parameters

The effect of the RG parameter (radius of triangular GND) on transmission characteristic, such as insertion loss S_{21} and non-reciprocity S_{12} is investigated. This parameter was calculated from (5) that shows the geometric relationship between the side and the radius of the circumcircle of a triangle (see Fig. 1).

The results presented in the figure below shows that the gap RG varies from 1.73 mm to 2.13 mm . The Insertion losses have the same level lower at 0.5 dB . The variation of this parameter directly affects the non-reciprocity loss. The circulator achieves the best non-reciprocity loss value when $RG=1.73 \text{ mm}$.

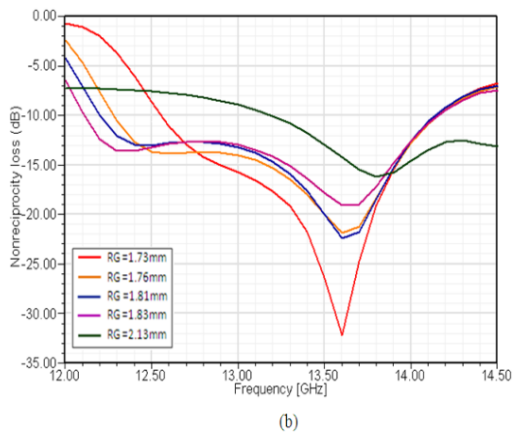
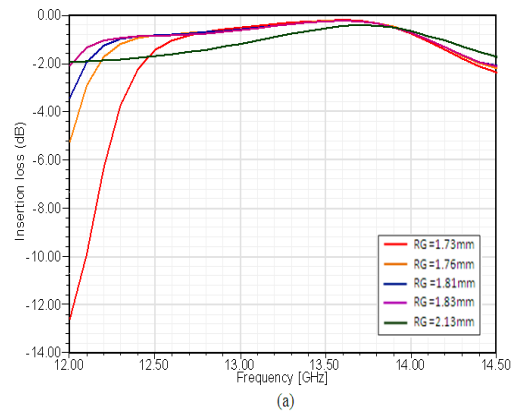


Figure 5. Effect of the RG on the transmission characteristics, (a) Insertion loss, (b) Nonreciprocity loss.

B. Effect of the G_1 and G_2

The influence of the G_1 (a signal Line-to-GND spacing) and the S (spacing between GND plane and the signal line) are 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.

The parameters G_1 varies from 80 to $100 \mu\text{m}$ which shown in Fig. 3 keeping a W/G_1 report as the resulting

impedance of access remains close to 50 Ω. From the Fig. 6, we can be clearly seen that the S-parameters vary on a regular way with the G_1 parameter; when the G_1 increases; the isolation loss with a negative sign also increases. The frequency was influenced by the variation of G_1 , the circulation frequency is 12.6 GHz for $G_1=100 \mu\text{m}$ and it becomes 13.5 GHz for $G_1=80 \mu\text{m}$. The best performance is obtained at the $G_1 = 80 \mu\text{m}$ with the insertion loss of 0.21 dB and isolation of 38.25dB. This value was selected of our circulator.

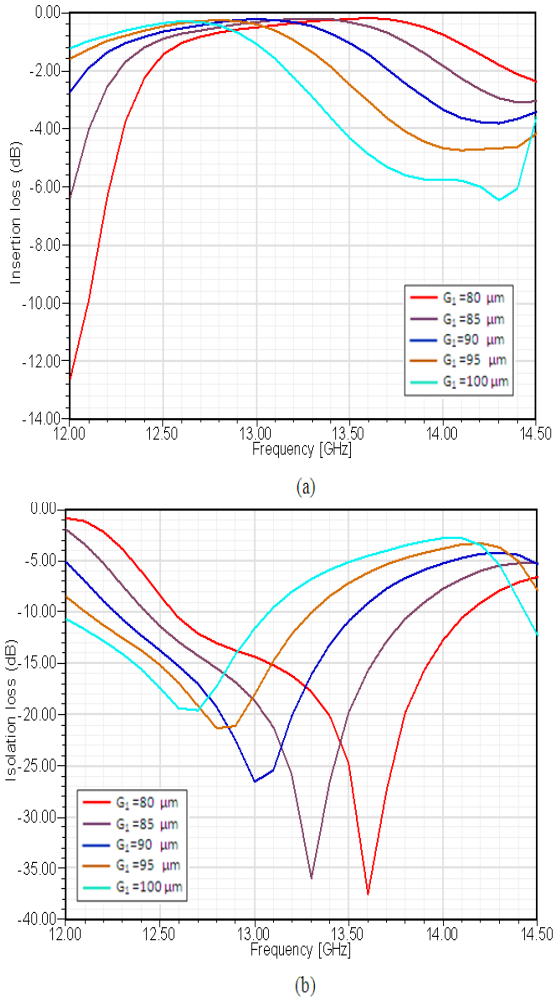


Figure 6. Dependence of S-parameters on the G_1 (a signal line-to-GND spacing). (a) Insertion loss, (b) Isolation loss

Another set of simulation is done to quantify the effect of G_2 (spacing between GND plane and the signal line) on the S-parameters (show Fig. 7).

The G_2 parameter varies from 300 and 900 μm . The S-parameters (S_{12} and S_{11}) are sensitive to variation of the G_2 parameter. The non-reciprocity gets the best performance at $G_2 = 900 \mu\text{m}$ for a $|S_{12}| = 33.24 \text{ dB}$ (see Fig. 7.a) and the best return loss for a $|S_{11}| = 27.67 \text{ dB}$

(see Fig. 7.b). The degradation of G_2 was reached to the disappearance of the non-reciprocal effect of component.

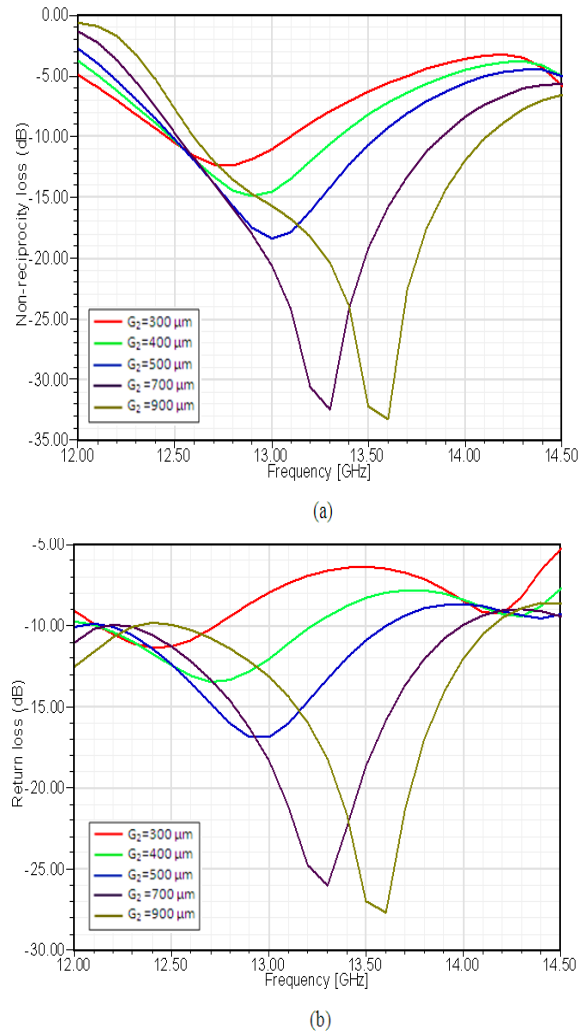


Figure 7. Dependence of S-parameters on the G_2 (spacing between GND plane and the signal line). (a) Nonreciprocity loss, (b) return loss.

V. CONCLUSION

We have studied numerically a new structure of a coplanar circulator having a central conductor triangular. We presented the different geometric and magnetic parameters of the structure. Our circulator is based on a magnetic material of ferrite of 1mm thickness. This work has allowed us to improve the performance of circulator studied. Indeed we compared our work with that proposed by ZAHWE [7] who studied a coplanar circulator with a ferrite layer of 1mm thickness. The comparison allowed to obtain the following results shown in the Table II:

TABLE II. COMPARISON BETWEEN OUR RESULTS AND THOSE PUBLISHED IN [7]

Authors	S ₂₁ (dB)	S ₃₁ (dB)	S ₁₁ (dB)	The circulation frequency (GHz)
ZAHWE	-0.65	-15.03	-18.5	9.98 GHz
EI-BOUSLEMTI	-0.21	-32.53	-29.27	13.5 GHz

Reading these results, it appears that the performance of our circulator was highly elevated.

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