A New Configuration of a Microstrip 180° Hybrid Reconfigurable Coupler

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Abstract— In this paper, we have studied the characteristics of a 180° microstrip hybrid coupler at 2.45 GHz. The primary objective of this study is to validate the various design steps associated with this circuit. We analyze the coefficients of transmission, reflection, isolation, and phase shift at the output. The final structure undergoes validation using two electromagnetic solvers—one based on the moments method and the other on the Finite Integration Technique. The simulation results are found to be consistent in terms of performance and S-parameters. The proposed structure is validated on planar technology and implemented on an FR4 substrate. After that we have integrate a tuning technique based on varactor diode biased in reverse mode which behaves as a variable capacitor permitting to obtain a reconfigurable 180 microstrip coupler. The tuning technique was validated into simulation by modeling the varactor by capacitor.

Keywords—180°coupler; reconfigurable coupler

I- Introduction

Couplers play a crucial role in communication systems [1-10]. In this article, we present a reconfigurable coupler. By incorporating eight capacitors into the 180° coupler, we enable the alteration of the frequency band without changing the coupler's dimensions. The reconfigurable 180° hybrid coupler exhibits a change in frequency band by adjusting capacitor values, allowing flexibility in its application. The 180° coupler, serving as a 3dB directional coupler with a 180° phase shift between its two outputs, can also operate when the two outputs are in phase.

Figure 1 illustrates that a signal applied to port 4 is evenly split into two components with a 180° phase shift at ports 2 and 3, while port 1 remains isolated. Conversely, if the input is applied to port 1, it is evenly divided into two in-phase components at ports 2 and 3, with port 4 isolated. Signals input into ports 2 and 3 will combine at port 1, and the difference between the two signals will appear at port 4.

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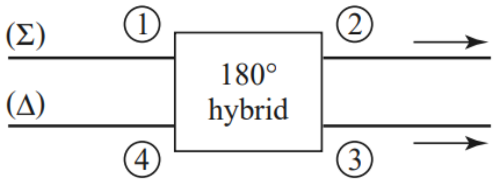

Fig 1: The block diagram of a 180° hybrid coupler

II- Design theory

The scattering matrix S of a reciprocal network, without losses and adapted on the four ports is:

$$S = \begin{bmatrix} 0 & s_{12} & s_{13} & s_{14} \\ s_{21} & 0 & s_{23} & s_{24} \\ s_{31} & s_{32} & 0 & s_{34} \\ s_{41} & s_{42} & s_{43} & 0 \end{bmatrix}$$

If the network is lossless, we obtain the following system of equations

$$(s_{13}s_{23}^* + s_{14}s_{24}^* = 0) * s_{24}^* \quad (1)$$

$$(s_{14}s_{13}^* + s_{24}s_{23}^* = 0) * s_{13}^* \quad (2)$$

The following particular solution can be obtained by choosing a phase reference:

$$s_{12} = s_{34} = \alpha \quad (3)$$

$$s_{13} = \beta e^{j\theta} \quad (4)$$

$$s_{24} = \beta e^{j\varphi} \quad (5)$$

$$S = \begin{bmatrix} 0 & \alpha & \beta e^{j\theta} & 0 \\ \alpha & 0 & 0 & \beta e^{j\varphi} \\ \beta e^{j\theta} & 0 & 0 & \alpha \\ 0 & \beta e^{j\varphi} & \alpha & 0 \end{bmatrix}$$

A difference will be formed at port 4. Hence, ports 1 and 4 are referred to as the sum and difference ports, respectively. The scattering matrix of the ideal 3 dB 180◦ hybrid thus has the following form:

$$S = \frac{-j}{\sqrt{2}} \begin{bmatrix} 0 & 1 & 1 & 0 \\ 1 & 0 & 0 & -1 \\ 1 & 0 & 0 & 1 \\ 0 & -1 & 1 & 0 \end{bmatrix}$$

The rate of direct power transfer between 1 and 2:

$$\frac{P_2}{P_1} = |s_{12}|^2 = \alpha^2 = 1 - \beta^2 \quad (6)$$

The power transfer rate by coupling between 1 and 3:

$$\frac{P_3}{P_1} = |s_{13}|^2 = \beta^2 \quad (7)$$

For an ideal directional coupler ($s_{14} = 0$) :

$$I = D = \infty$$

III- Physical Dimensions

To design the 180° coupler by calculating dimensions L, W, and R, Table 1 presents the various dimensions used in design the coupler.

Table 1: Dimensions of the calculated simple coupler

Dimensions	Values (mm)
R	16.51
L1	17.29
L2	51.87
W1	1.6
W2	3

$$Z_0 = 50\ ohm \qquad (8)$$
$$Z_c = Z_0\sqrt{2} \qquad (9)$$

$$\theta = \beta L = \frac{2\pi}{\lambda} L_1 = \frac{2\pi}{\lambda}\frac{\lambda}{4} = \frac{\pi}{2} \qquad (10)$$
$$AB = L_1 = \frac{\lambda}{4} = \frac{2\pi R\alpha}{360} \qquad (11)$$

The final structure of the proposed 180° coupler is depicted in Figure 2 in both layout and schematic forms, as illustrated in Figure 3, utilizing eight equal capacitances.

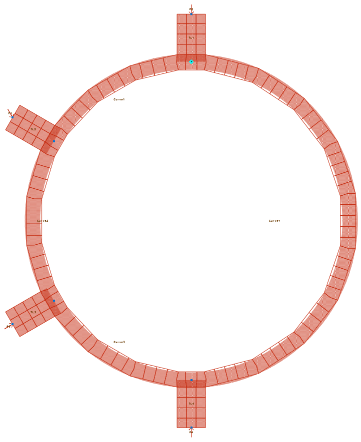

Fig 2: 180° simple coupler structure

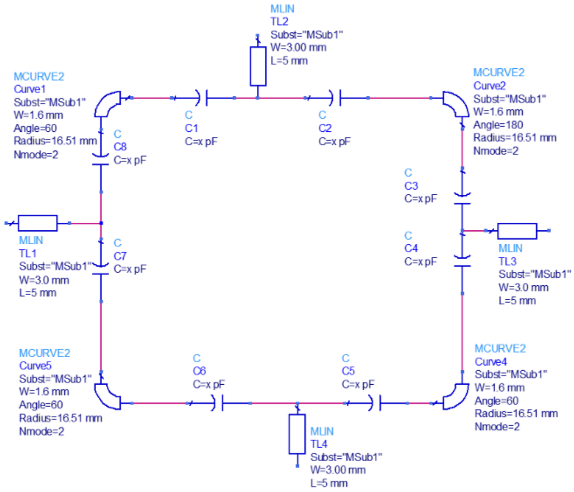

Fig 3: Electrical circuit of a reconfigurable 180° hybrid coupler in ADS schematic

Using eight capacitors allows us to easily have good control over the microstrip 180°coupler.

IV- Simulation and results

In this section, we employed an electromagnetic solver based on the moments method and associated two capacitors in each port to enhance, and to tune the frequency band of the microstrip coupler. The following figures present the simulation results of this reconfigurable 180° hybrid coupler in terms of isolation, insertion loss, reflection, phase, and phase. It is evident that the variation in capacitance (C) directly influences coupler performance, as illustrated in Figure 4, in terms of isolation, as well as the transmission coefficient, as shown in Figure 5. A good matching of input impedance around 2.45 even when changing the capacitance value.

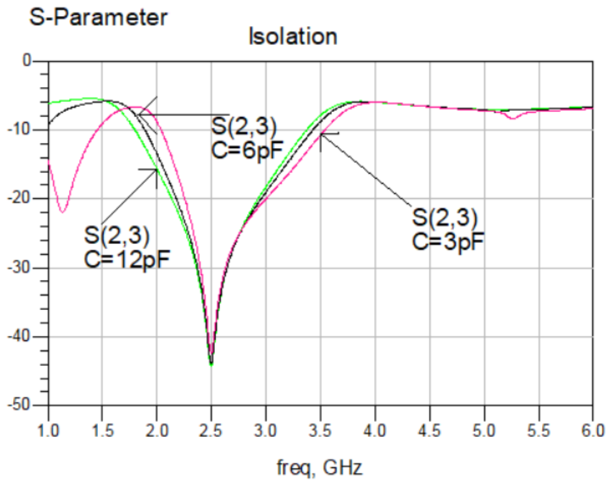

Fig 4: Isolation coefficient versus frequency

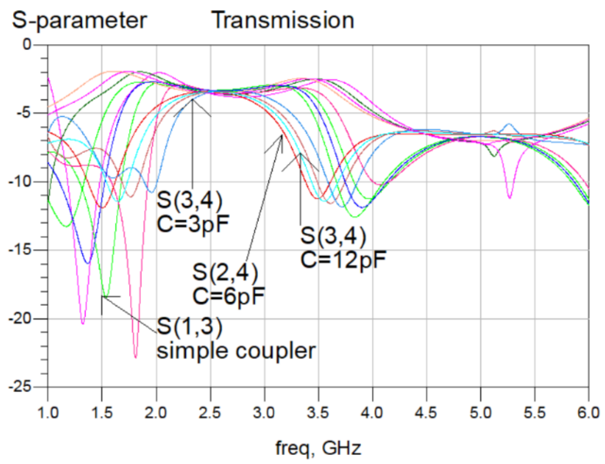

Fig 5: Transmission coefficient versus frequency

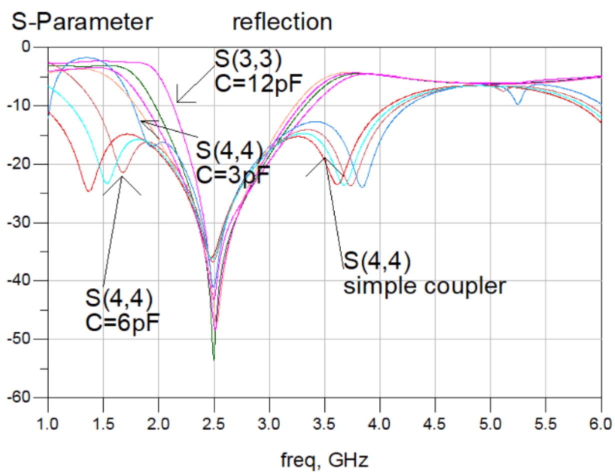

Fig 6: Reflection coefficient versus frequency

Figures 7 and 8 represent the phase shift coefficients, S(1,2) and S(1,3), with a capacitance value of c = 3.0 pF. Additionally, the coefficient values S(4,3) and S(4,2) are illustrated with a capacitance value of c = 6.0 pF .

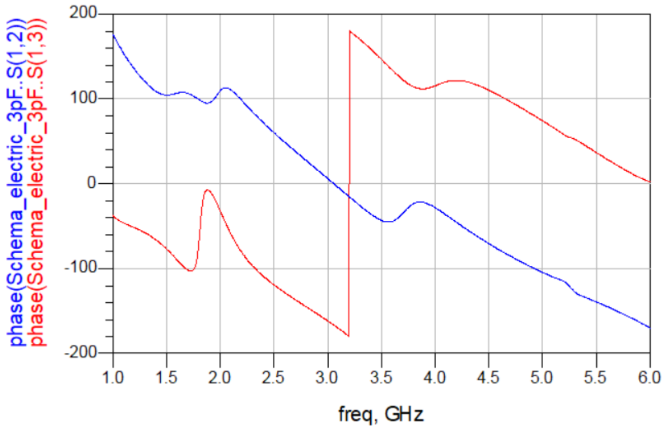

Fig 7: Phase shifts between S_{43} and S_{42} versus frequency

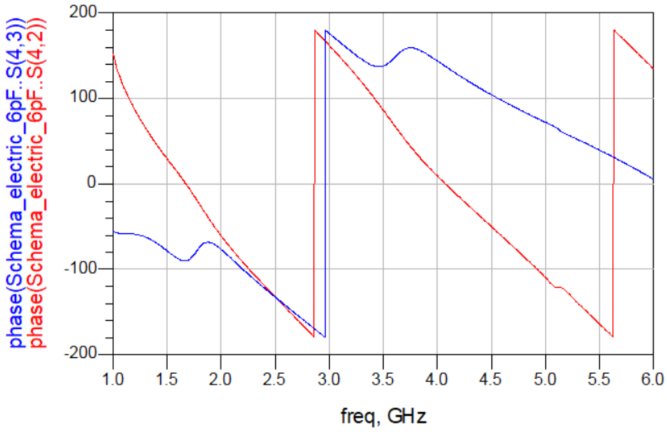

Fig 8: Phase between the "through" and coupled ports versus frequency

The various results presented of the coupler showcasing the S parameters of this structure. The results prove to be interesting in terms of insertion loss, reflection, isolation, phase, and phase shifts. This coupler can be seamlessly integrated with planar circuits like antennas. The added capacitances offer the flexibility to change the frequency band based on the chosen capacitance value, without altering the dimensions of the coupler. We can conclude that the proposed configuration yields significant results when using various values for the eight capacitances employed in building the coupler.

V- Conclusion

This study validates the design of a reconfigurable 180° hybrid coupler using eight capacitors, demonstrating its effectiveness across multiple frequency bands. To further extend its applicability, future steps may involve validating the same circuit for other technical specifications. A prospective enhancement to this work is the integration of varactor diodes into the passive structure, allowing for frequency band tuning. This transformation, without altering the dimensions, turns the coupler into a reconfigurable 180° hybrid coupler. Applying a reverse voltage on the varactors enables the modification of the varactor capacitors, facilitating the tuning of the frequency band. This technique opens avenues for achieving a reconfigurable frequency band for the proposed coupler.

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