A Novel Design of A Microstrip 3dB Coupler

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Abstract — This paper presents a novel design of branch 3dB coupler, it is designed and simulated by using FR4 substrate at the operating frequency 2.45 GHz in the ISM “Industrial Scientific Medical” band. The design is based on two different models, the T-model and combinational-model (T- and π-model) in order to reduce the size and improve the performances. After a theoretical study on the use of open stubs, we present the simulation results of this branch line coupler by using ADS from Agilent technologies and CST Microwave Studio. Good agreement is found between simulated and measured results.

Index Terms— Branch-line coupler, ADS, CST microwave Studio.

I. INTRODUCTION

The couplers are from of the most passive components used in modern communication systems [1]. These hybrid couplers are the key elements in the design of microwave devices such as power amplifiers, mixers and antenna systems due to their simplicity, wide bandwidth power distribution, and high isolation between ports [2-6].

This work is unscrewed into two parts. The first part devoted to the theoretical study of directional coupler with a detailed development of the 3 dB coupler. In the second part, we will discuss the conception, optimization and the achievement of a new coupler (3dB, 90°) structure which is build by using softwares ADS [7] and CST Microwave Studio [8].

II. THEORICAL STUDY OF COUPLERS

Couplers called “Branch-Line” as shown in fig.1, directional couplers are generally used for distribution to 3dB of energy, with a phase difference of 90° between the way “direct” and the way “coupled”[6-9]. This kind of coupler is commonly designed in microstrip technology, and is one of the couplers called “phase quadrature”.

![Fig.1. Branch Line Microstrip Structure](image)

According to fig.1 above, the power between the port 1 will be divided between the port 2 (direct path), and port 3 (channel coupled) with a phase difference of 90° between the outputs. No energy is transmitted to port 4 (isolated port).

The directional coupler is characterized by three parameters:

- Coupling: \[ C_{dB} = 10 \log \left( \frac{P_1}{P_3} \right) \]
- Directivity: \[ D_{dB} = 10 \log \left( \frac{P_3}{P_4} \right) \]
- Isolation: \[ I_{dB} = 10 \log \left( \frac{P_1}{P_4} \right) \]
We can observe that the coupler has a high level of symmetry. Each port may be used as an input. This symmetry is reflected by examining the S-matrix, since each line can be obtained by transposing the first.

III. NOVEL MICROSTRIP COUPLER STRUCTURE

A. Using T-model as equivalent of the quarter-length of transmission line:

In this model, we have two transmission lines which have the same characteristics (characteristic impedance \( Z_a \) and electrical length \( \theta_a \)) between these two transmission lines we have an open stub[10-11] which has the following characteristics (characteristic impedance \( Z_b \) and electrical length \( \theta_b \)) as shown in fig.2 and fig.3:

![Fig.2. The quarter wave-length transmission line](image)

![Fig.3. Equivalent quarter wave-length transmission line by using T-model](image)

The terms \( Z_o \) and \( \theta \) are respectively the characteristic impedance and electrical length of conventional branch line arms of the coupler. In order to reduce the quarter-wavelength transmission line, equivalent T-model of the transmission line is employed as illustrated in fig.3.

B. Using combinational-model(T- andπ-model) as equivalent of the quarter wavelength line:

In this model, we have four transmission lines which have the same characteristics (characteristic impedance \( Z_a \) and electrical length \( \theta_a \)), and three open stubs [12], the one of these stubs has the following characteristics (\( Z_b \) and electrical length \( \theta_b \)), for the two others stubs we have the same characteristics (characteristic impedance \( Z_c \) and electrical length \( \theta_c \)) as shown in fig.4:

T-model approach is adopted individually to reduce dimensions of the quarter-wavelength transmission lines which tend to miniaturize the microstrip branch-line couplers.

Defining the sets \( Z_o = [Z_a, Z_b] \), and \( \theta = [\theta_a, \theta_b] \), the equivalent T-model is shown in fig.3.

In order to relate the models in fig.2 and fig.3, we obtain the ABCD matrix (\( L=\lambda_g/4 \), \( \theta=\beta l=\pi/2 \)) equation given by:

\[
\begin{bmatrix}
A & B \\
C & D
\end{bmatrix} =
\begin{bmatrix}
0 & JZ_o \\
JY_o & 0
\end{bmatrix}
\]

Where \( A=D=1+Z_a/Z_b \), \( B=Z_a(2+Z_a/Z_b) \) and \( C=1/Z_b \).

Where \( [\theta_a, \theta_b] \) are the electrical lengths of T-model transmission line.

By using the expression for T-model in [13-15], we can express the equations for Equivalent quarter wave-length transmission line by using T-model as shown in equation (1) and equation (2):

\[
Z_o = \frac{Z_o}{\tan \theta_c}
\]

\[
Y_b \tan \theta_b = \frac{2}{Z_o \tan \theta_c}
\]

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II. SIMULATION RESULTS OF THE COUPLER

The new miniaturized 3dB coupler is simulated by using an FR4 substrate with relative permittivity 4.4, loss tangent 0.025 and thickness h=1.58 mm. This coupler is designed at a frequency of 2.45 GHz. It is designed and simulated by using Momentum integrated into ADS and CST Microwave Studio electromagnetic simulators.

A. ADS results:

After many series of optimizations, the final circuit is presented in fig.6; the coupler has as dimensions 24.5x 21 mm²:

The S parameters of the coupler are given in fig.7:

\[
\begin{align*}
Y_b \tan \theta_b &= \frac{Z_o \sin 4\theta_b - Z_o}{(Z_o \tan 2\theta_b)^2} \\
Y_c \tan \theta_c &= \frac{Z_o \cot 2\theta_c - Z_o}{Z_o Z_o} \\
Z_o &= \frac{Z_o(\sqrt{\cos^2 2\theta_c + 4 - \cos 2\theta_c})}{2 \sin 2\theta_c}
\end{align*}
\]
As shown in fig. 7, we have good isolation and good matching input impedance less than -20dB in the frequency band [2.20GHz, 2.73GHz], with an insertion loss around -3dB.

The phase difference between the output ports of the coupler is depicted in fig. 8. The phase difference is 91.73° at the resonance frequency 2.45 GHz. Such value is acceptable for all receivers since ±5° error is negligible and indicates good transmission percentage.

### B. CST Microwave Studio results:

After the validation of the 3dB coupler in ADS we have simulated this circuit by using CST Microwave Studio that is 3D electromagnetic software, the novel structure of the branch line couple is shown in fig.9:

![The 3D coupler structure in CST Studio](image)

Fig. 9. The 3D coupler structure in CST Studio

S parameters results are presented in fig.10:

![S Parameters versus frequency](image)

Fig.10. S Parameters versus frequency

As shown in fig.10, we have good performances of the simulated coupler.

![S-parameter phase in degrees versus frequency](image)

Fig.11. S-parameter phase in degrees versus frequency

The phase difference is about 87° at the resonance frequency 2.45 GHz.

According to the figures above, we can deduce that we have the same results between ADS and CST results.

### III. ACHIEVEMENT AND MEASUREMENT

After the comparison of simulation results on CST Microwave Studio and ADS, the coupler structure is achieved by using LPKF machine as presented in fig.16:
Fig. 16. The photograph of the proposed coupler

Measurement was performed with a vectorial network analyzer (HP 8719ES). The entire area of the fabricated coupler is 24.5 x 21 mm². The bandwidth is 2.25-2.75 GHz.

The simulation and measurement results are shown in Fig. 17:
According to the figures above, after have compared simulated results of CST and measurement, we can deduce that we have a good agreement.

IV. CONCLUSION
This study permits to validate into simulation and fabrication a novel microstrip 3dB Branch-Line coupler structure, by conducting firstly a theoretical study by using the different equations giving the equivalence between a quarter wavelength transmission line and a new model based on open stubs. This new model is the key to develop a novel structure of 3dB coupler at any frequency, measurement and simulation results of this coupler are validated in the ISM band centered at 2.45 GHz, with good isolation, good matching input impedance, this structure has -3dB as a coupling coefficient and 90° for the phase between the output ports. The dimensions of this novel design are 24.5x21 mm².

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REFERENCES