Miniaturization of a Broadband Quadrature Hybrid Coupler Using Π-Model Transformation-Based Artificial Transmission Line

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Abstract **─** In this paper, a novel compact broadband quadrature hybrid coupler based on planar artificial transmission line is presented. This coupler can be used for WLAN application at 2.4 GHz. The planar artificial transmission line has been implemented using Π-model technique. The size of the proposed coupler is merely 38% of that of a conventional one. The compact coupler performs well wideband response.

Index Terms **─** Broadband quadrature, planar artificial transmission line, Π-model.

I. INTRODUCTION

The quadrature hybrid coupler is one of essential elements in microwave circuits. It has extensively been applied in integrated microwave circuits, e.g., power dividers, and in power combiners of various microwave circuits, e.g., balanced amplifiers, balanced mixers, phase shifters, and butler matrix. However, it occupies a large space due to the use of quarter wavelength transmission lines, especially at low frequencies. Therefore, our motivation by this work is to reduce the size of the broadband branch line coupler.

Recently designing compact passive microwave components using artificial transmission lines have drawn a lot of attention [1-7]. To design microwave circuit components with more size reduction and simple fabrication process, the planar artificial transmission line with a single layer printed circuit board can be a good option and it can create transmission lines with a wide range of characteristic impedances and electrical lengths [2-4].

In this paper, a new artificial transmission line (Π-model transformation-based) is presented and the compact quadrature hybrid coupler has been realized. By utilizing the proposed artificial transmission line, we demonstrate the circuit size of the coupler becomes merely about 38% of the conventional designs.

II. DESIGN AND ANALYSIS OF THE PROPOSED PLANAR ARTIFICIAL TRANSMISSION LINE

We have used the technique given in [2-4], to design an artificial transmission line with a characteristic impedance of 35.35 Ω and an electrical length of 90º on a 32-mil RO4003C substrate with a dielectric constant of 3.55 and a loss tangent of 0.0027. The final size of the line, however, needs to be fine-tuned by a full-wave simulation software, e.g., Ansoft HFSS, to include the parasitic coupling between the elements. The flowchart of design process is shown in Fig. 1.

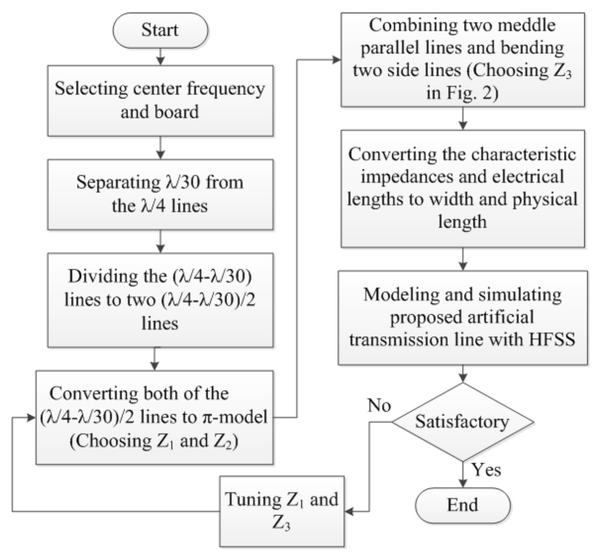

Fig. 1. Flowchart of the design process.

Figure 2 shows a simple equivalent circuit of the quarter wavelength transmission line using Π-model transformation, and as can be seen the length has become shorter.

Each pair of the transmission line is chosen with θ=π/4, amount of impedances and electrical lengths in Fig. 2 can be determined according to [2-4]:

$$Z_1 \sin\theta_1 = Z \sin\theta, \tag{1}$$

$$Y_2 \tan\theta_2 = (\cos\theta_1 - \cos\theta)/(Z_1 \sin\theta_1), \tag{2}$$

2.4 GHz is selected as the center frequency of the branch line coupler. We have separated λ/60 lines from the λ/4 lines to determine input and output terminals of

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each line. By choosing $Z_1=Z_2=85\ \Omega$, and assuming $Z=35.35\ \Omega$ and $\theta=39^o$ $((\lambda/4-\lambda/30)/2)$ in Equation (1), θ_1 will be 16^o. Then, after replacing Z_1, Z_2, θ, and θ_1 in Equation (2) θ_2 is found to be 32^o.

Now it is time to combine the second black line with the first white line and the bends (Fig. 3) which can be determined as follows:

$$Y_3 \tan\theta_3 = 2Y_2 \tan\theta_2 , \tag{3}$$

By choosing $Z_3=45\ \Omega$ and replacing Z_2 and θ_2 in Equation (3), $\theta_3=32^o$ is calculated. After simulation and tuning Z_1 and Z_3 are changed to 95 Ω and 50 Ω, respectively.

We can convert the characteristic impedances and electrical lengths to width and physical length according to [8]. All the design parameters can also be adjusted for other frequencies.

Finally, the characteristic impedances and electrical lengths were converted to microstrip transmission lines as shown in Fig. 4: L=18.5 mm, w=3 mm, w_1=1.8 mm, L1=5.5 mm, w_2=3 mm, L_2=10 mm, w_3=0.65 mm and w_4=.5 mm. The simulated characteristic impedances and phase delays of 90^o, 35.35 ohm conventional and artificial transmission lines versus frequencies are presented in Fig. 5, which shows a good agreement between them.

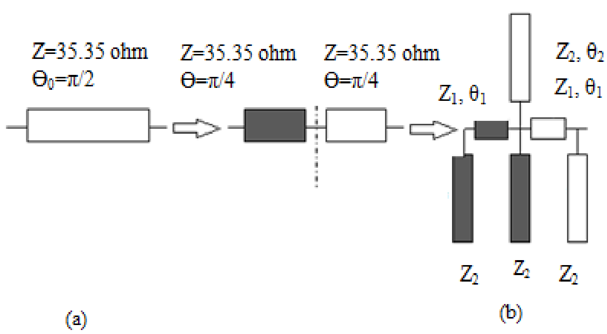


Fig. 2. (a) Conventional quarter wavelength transmission line with Zo = 35.35 Ω, and (b) using two Π-model lines (1st stage).

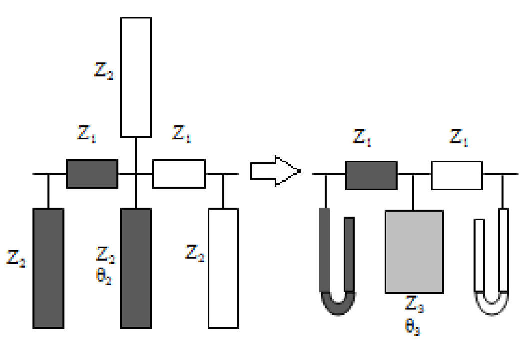


Fig. 3. Combination of the compact Π-model with the bends (2nd and 3rd stages).

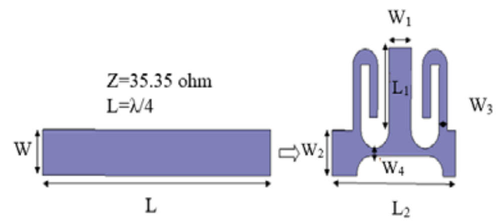
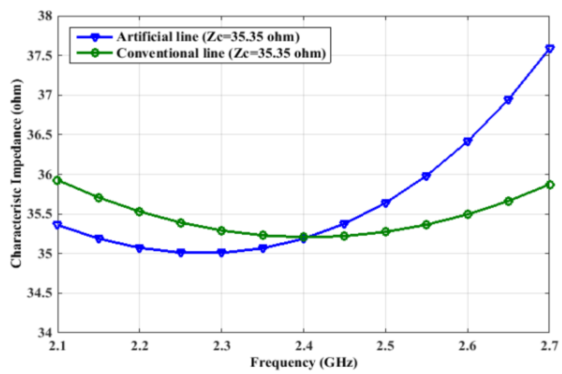
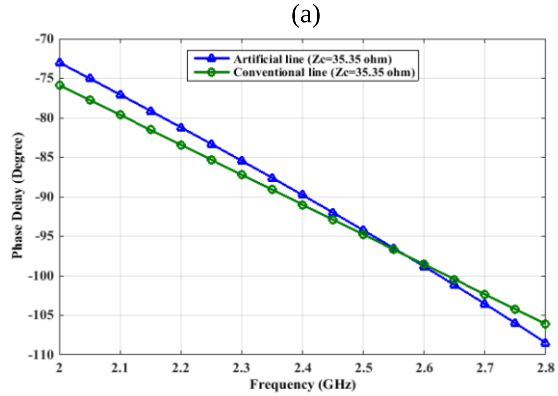


Fig. 4. Layout of the conventional quarter wavelength microstrip transmission line with $Z_o=35.35\ \Omega$ and the artificial microstrip transmission line.



(a)



(b)

Fig. 5. (a) Simulated characteristic impedances of 90^o, 35.35 ohm conventional and artificial transmission lines, and (b) simulated phase delays of the 90^o, 35.35 ohm conventional and artificial transmission lines.

III. DESIGNS OF MINIATURIZED BROADBAND QUADRATUREHYBRID

According to [9], characteristic impedances of the broadband branch-line couplers, shown in Fig. 6 are 35.35 Ω and 119 Ω.

In order to miniaturize the size of the branch-line coupler, the artificial transmission lines have been developed to replace with the original quarter wavelength transmission lines.

The circuit layout of the compact quadrature hybrid coupler is shown in Fig. 6. The four artificial transmission lines of the hybrid coupler are initially designed, and then fine-tuned to include the parasitic coupling between the lines, using Ansoft HFSS [2-3].

The second vertical transmission line has been replaced with a dual transmission line as explained in [4]. The length of all vertical transmission lines is 20 mm. If further size reduction is required it can be achieved by meandering the high impedance vertical lines.

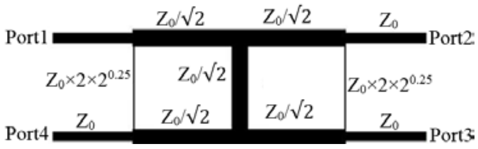
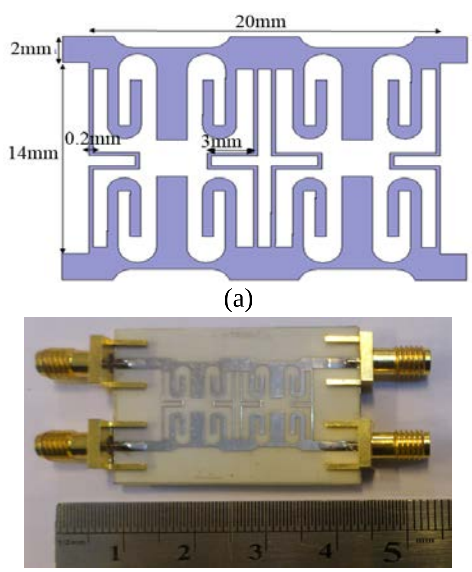


Fig. 6. Structure of the conventional broadband branch line coupler.

A photograph of the proposed compact quadrature hybrid coupler is shown in Fig. 7 (b), and the simulation and measurement results are illustrated in Fig. 8. As can be seen, the measurement results are found to be in good agreement with the simulations.

Figure 8 (b) shows the phase difference between the output ports. The phase difference between outputs is maintained at 90º (+/-2º across the bandwidth).

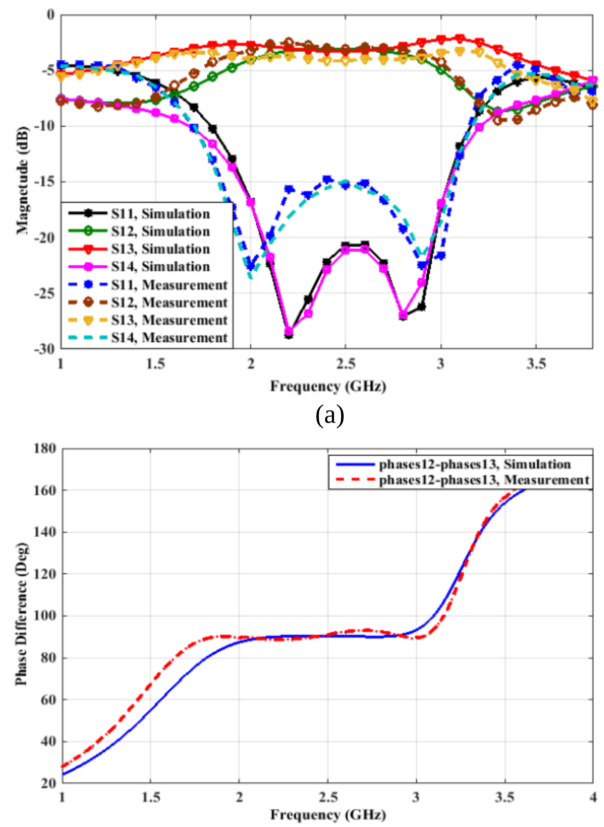
Finally, a size reduction of about 62% is obtained as can be observed in Fig. 7. In addition, the S-parameters of the compact coupler (Fig. 8) show good balance between the coupled ports, the coupling at the port 2 and 3 are around 3±0.6 dB because port 1 serves as the excitation for the 2-2.8 GHz frequency band. The simulated return loss and isolation are greater than 20 dB.



(a)

(b)

Fig. 7. (a) Circuit layout of the miniaturized quadrature hybrid coupler, and (b) photograph of the proposed miniaturized quadrature hybrid coupler.



(a)

(b)

Fig. 8. Simulated and measured results of the proposed quadrature hybrid coupler: (a) S-parameters and (b) phase difference between S_{12} and S_{13}.

These results confirm that the proposed coupler has a desirable performance, and therefore we have met our goal of achieving a compact and broadband branch line coupler.

The simulated and measured results show good agreement across the entire band of 2-2.8 GHz at center frequency of 2.4 GHz with 800 MHz band width. Table 1 summarizes the performance of the proposed quadrature coupler and previous designs. The superior performance of the proposed design has been confirmed.

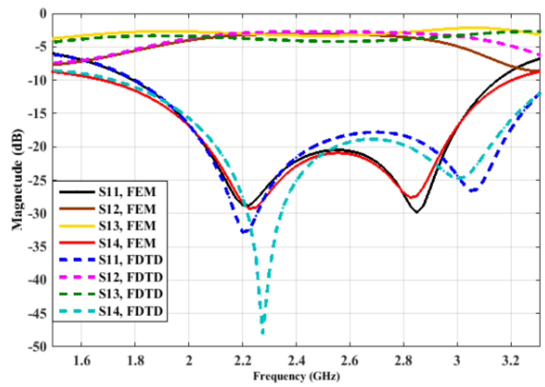
Table 1: Comparison of various quadrature hybrid couplers

	Relative Area	Fabrication	Band Width
Conventional	100%	Single Layer	
Chiang [1]	34%	Additional lumped element	Narrow
Chun [3]	45%	Single layer	Wide
Sun [5]	60%	Single layer	Narrow
Eccleston [6]	49%	Single layer	Narrow
Liu [10]	42%	Double layer	Narrow
Iran-Nejad [11]	47%	Single layer	Wide
This Work	38%	Single layer	Wide

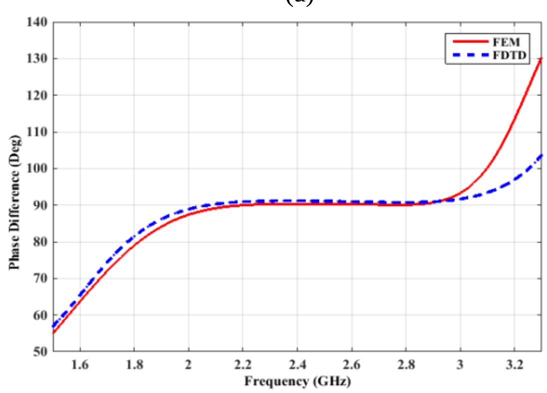
IV. COMPARISON OF APPLIED NUMERICAL METHOD SOLUTION (FEM) AND FINITE DIFFERENCE TIME DOMAIN (FDTD)

We have applied HFSS, a finite element method (FEM) solver for electromagnetic structures, for EM computations of the proposed quadrature hybrid. Additionally, we can apply another EM numerical method, such as finite difference time domain (FDTD), to solve the proposed structure and compare them afterwards.

Figure 9 shows a good agreement between S-parameters of both FEM and FDTD, solved by HFSS and CST software's, respectively.



(a)



(b)

Fig. 9. FEM vs. FDTD solving for the proposed structure: (a) S-parameters and (b) phase difference

V. CONCLUSION

A new planar artificial transmission line incorporated with Π-model technique has been proposed and demonstrated. This artificial transmission line is capable of synthesizing microstrip lines with a wide variety of characteristic impedances and electrical lengths.

By utilizing the proposed artificial transmission line, a compact broadband hybrid coupler has successfully been designed for WLAN applications. This coupler has low insertion loss, negligible phase imbalance, and significant size reduction of 62%. The proposed artificial transmission line is also expected to find applications in microwave circuits such as butler matrix.

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