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Compact Multilayer Hybrid Coupler Based on Size Reduction Methods

Young Kim[1, *] and Youngchul Yoon[2]

Abstract—This paper presents a compact multilayer hybrid coupler based on a microstrip via-transition and short transmission line with a capacitor on each side to reduce circuit size. The microstrip via-transition is connected to two microstrip lines in different layers to configure a sandwich structure. To reduce the passive component circuit size, the design method uses a microstrip via-transition and a short transmission line with capacitors on each side. To validate the microstrip via-transition and short transmission line with capacitor, a multilayer hybrid coupler is implemented at a center frequency of 2 GHz. The measured characteristics agreed well with the simulation results, and above 90% circuit-size reduction compared with conventional couplers was realized.

1. INTRODUCTION

The LTE system of modern wireless communication requires high-speed data processing and compact circuit size. To satisfy these industry demands, integration technologies have been developed, such as system on a chip (SOC) and MMIC etc. [1–3].

Many methods of vertical transitions in planar microwave circuits have been researched Vertical via-hole structures [4, 5] are most commonly used in integrated circuit designs. Because a via-hole transition has the characteristic of a low pass filter, design for high frequency is limited. Aperture-coupled transition [6, 7] can change the shape of an aperture or a microstrip terminal and obtain improved bandwidth, but it cannot be used as an appropriate design method. Finally, cavity-coupled transitions [8, 9] have been presented to transfer signals through several layers with a relatively narrower bandwidth.

In addition, various methods have been proposed to effectively reduce the size of the branch line hybrid couplers [10–17]. The size-reduction methods are T-mode approach using open stub with high-low impedance [10], artificial transmission lines [11], printed distributed capacitor [12], high-impedance transmission lines and interdigitated shunt capacitor [13], and coupled-line section [14], etc.

In this paper, we propose a multilayer compact hybrid coupler based on microstrip via-transition and short transmission line with a capacitor to realize circuit-size reduction. Because the conventional hybrid coupler consists of four $\lambda/4$ transmission lines, its circuit-size reduction is limited. To reduce a $\lambda/4$ transmission line, we use a multilayer sandwich configuration to connect the transmission line in different layers using a microstrip via-transition. In addition, because the $\lambda/4$ transmission line converts an arbitrary short-length transmission line using capacitors at both end side, the proposed component can be reduced more compared with the configuration presented in [18].

Figure 1 shows the multilayer sandwich configuration with a microstrip via-transition.

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* Corresponding author: Young Kim (youngk63@gmail.com).
[1] School of Electronic Engineering, Kumoh National Institute of Technology, 61 Daehak-ro, Gumi, Gyungbuk, Korea. [2] Department of Electronics Engineering, Catholic Kwandong University, 522, Naegok-dong, Gangneung-shi, Gangwon-do, Korea.

2. THEORY AND DESIGN

Figure 1 shows that the proposed sandwich configuration with a microstrip via-transition consists of two microstrip lines with the same width, a ground plane in the middle layer, via-holes to connect the two microstrip lines that exist in different layers, and a slot to separate the ground plane and via-hole. To realize good electrical performance of the sandwich configuration, the microstrip-via transition should operate with low loss, high return loss, and at a wide frequency bandwidth.

To obtain the desired transmission line performance using the microstrip-via transition, we sweep the slot size to realize optimum characteristics. In Figure 1, the microstrip-via transition has two parameters, via-hole diameter d and distance s between the via and ground, in order to satisfy the transmission line characteristics of low insertion loss and matching for sandwich configuration. The microstrip-via transition consists of a via-hole between two transmission lines on an epoxy PCB with dielectric constant $\varepsilon_r = 4.3$ and thickness $h = 0.787$ mm. In this case, we fix the diameter of the via-hole to $d = 0.4$ mm and the sweep slot size to between 0.2 and 0.5 mm.

Figures 2(a) and (b) show the S-parameters of the slot size variation when the distance between the

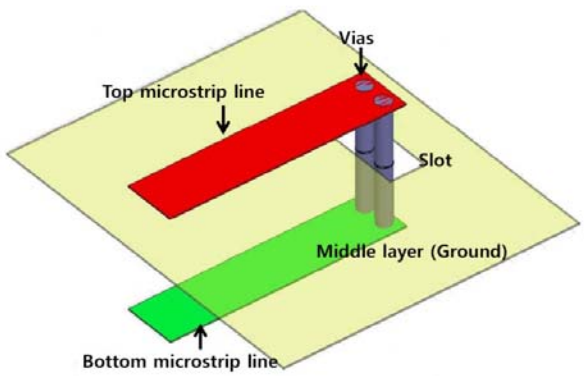
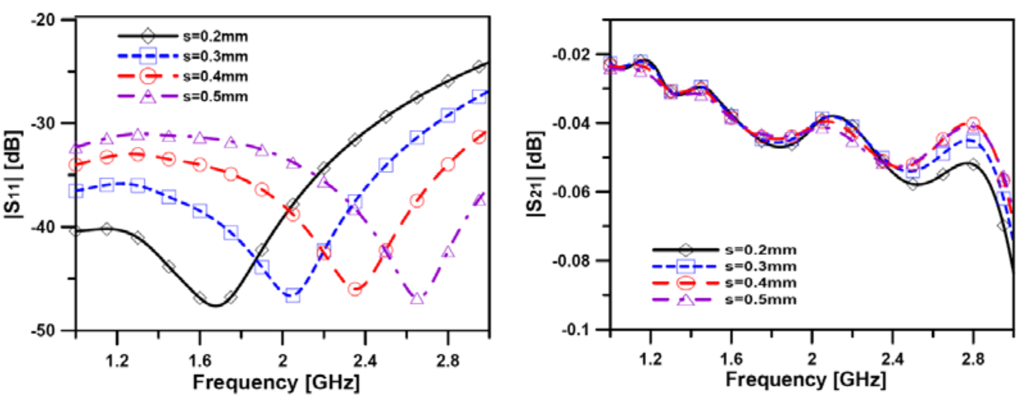
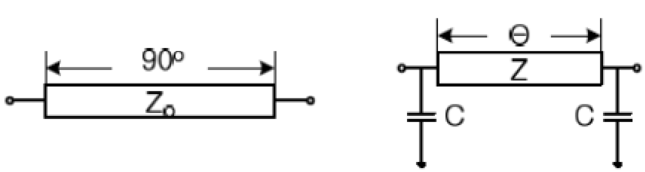


Figure 1. Proposed sandwich configuration with a microstrip via-transition.



(a) (b)

Figure 2. S-parameters of the slot size variation in a sandwich configuration, (a) $|S_{11}|$ and (b) $|S_{21}|$.



(a) (b)

Figure 3. (a) Conventional $\lambda_g/4$ transmission line. (b) Reduced-size circuit equivalent circuit to $\lambda_g/4$ transmission line.

via-holes and ground is varied from $s = 0.2$ mm to $s = 0.5$ mm. In addition, the sandwich configuration with a microstrip-via transition shows good performance at an operating frequency of 2 GHz. We design the via-hole diameter to $d = 0.4$ mm and the distance between the via-hole and ground to $s = 0.3$ mm to obtain an optimum transmission line with via-transition.

In addition, the circuit size reduction method uses a reduced-size transmission line ($\ll \lambda_g/4$) with capacitors at both end sides. The $\lambda_g/4$ transmission line can be replaced by a transmission line of characteristic impedance Z and electrical length θ and shunt capacitances C at either end. Figure 3 shows the $\lambda_g/4$ transmission line and the equivalent circuit of a reduced-size transmission line with capacitors at both end sides. In Figure 3, the two circuit parameters become the same if the values of reduced size circuit parameter Z and C are chosen as follows:

$$Z = \frac{Z_o}{\sin\theta}, \quad \omega C = \frac{\cos\theta}{Z_o} \tag{1}$$

where Z is the impedance value of the reduced-size transmission line, C the shunt capacitance of the reduced-size transmission line, θ the electrical length of the reduced-size transmission line, Z_o the $\lambda_g/4$ transmission line impedance value, λ_g the guided wavelength of design center frequency, and ω the angular frequency of design center frequency.

Because a conventional hybrid coupler has four $\lambda_g/4$ transmission lines with different impedance values, we designed a multilayer hybrid coupler with a sandwich configuration consisting of a transmission line and a short transmission line with capacitors at both end sides. This design uses Microwave Office from AWR Corporation.

3. SIMULATION AND EXPERIMENTAL RESULTS

To show the validity of the proposed compact multilayer hybrid coupler, we designed three hybrid couplers. In the first case, in order to show the validation of the microstrip-via transition and the reduction of circuit size, a 50-Ω $\lambda_g/4$ transmission line conventional hybrid coupler was converted into two $\lambda_g/8$ transmission lines using microstrip via-holes with sandwich configuration. In the second case, in order to reduce the circuit size, both the transmission line of short electrical length ($\ll \lambda_g/4$) with shunt capacitances at either end and the microstrip-via transition are used. A 35-Ω $\lambda_g/4$ transmission line conventional hybrid coupler was converted into a 70-Ω transmission line with electrical length of 30° and both end-side capacitors had a capacitance value of 1.60 pF. The 50-Ω $\lambda_g/4$ transmission line conventional hybrid coupler was the same as that in the first case. Finally, in the third case, to design smaller than second case hybrid coupler, we are used a microstrip-via transition with reduced-size circuit method. A 50-Ω $\lambda_g/4$ transmission line conventional hybrid coupler was converted to a 70-Ω transmission line with an electrical length of 22.5° and both end-side capacitors had a capacitance value of 3.0 pF. The 35-Ω $\lambda_g/4$ transmission line of conventional hybrid coupler was the same as that in the second case. The simulation and fabrication were performed at a center frequency of 2 GHz. The compact multilayer hybrid coupler constituted the transmission lines using an epoxy substrate with $\varepsilon_r = 4.3$ and thickness $h = 0.787$ mm.

Figure 4 shows the top, middle and bottom PCB layouts of the multilayer hybrid coupler in the

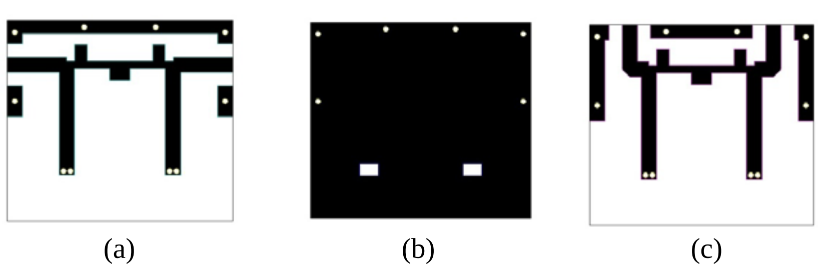


Figure 4. Layout of the fabricated multilayer hybrid coupler PCB in the second case. (a) Top layer patterns. (b) Middle layer patterns. (c) Bottom layer patterns.

second case. The top layer pattern is connected to the bottom layer transmission line pattern using a via-hole with a slot in the middle layer.

Figure 5 also shows the fabricated multilayer hybrid coupler for the three cases, in addition to the original hybrid coupler. The sizes of the hybrid couplers are as follows: original case ($\lambda_g/4\times\lambda_g/4$), Case 1 ($\lambda_g/4\times\lambda_g/8$) for only the transmission line with a sandwich configuration, Case 2 ($\lambda_g/12\times\lambda_g/8$) for the mixed configuration with a small-section transmission line with capacitors at the end sides, and Case 3 ($\lambda_g/12\times\lambda_g/16$) for only small section transmission line with sandwich configuration. λ_g represents the guided wavelength at 2 GHz with dielectric constant $\varepsilon_r = 4.3$. The figure shows that the circuit size is reduced to 50% in Case 1, 83% in Case 2, and 92% in Case 3 compared with the original hybrid coupler. Figure 6 shows the measured results. Table 1 lists the summary of the measured S-parameters for the four cases. The data show that the characteristics of the four hybrid couplers under different design methods are the same. Table 2 shows the comparison of the reported branch-line hybrid coupler.

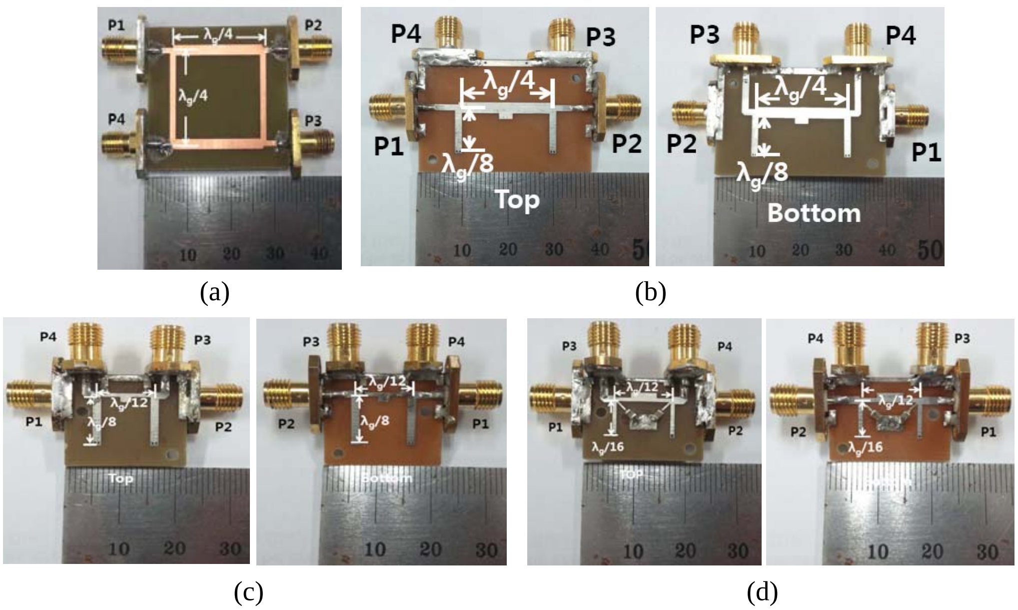


Figure 5. Top and bottom photographs of the implemented reduced size multilayer hybrid coupler. (a) Original. (b) Case 1. (c) Case 2. (d) Case 3.

Table 1. Summary of the measured S-parameters in the four cases at 2 GHz.

	S_{11} (dB)	S_{21} (dB)	S_{31} (dB)	S_{22} (dB)	S_{33} (dB)	S_{44} (dB)	S_{41} (dB)
Original	−26.2	−2.95	−3.70	−24.2	−47.2	−29.6	−27.1
Case 1	−21.2	−3.21	−3.32	−19.2	−18.5	−17.6	−22.8
Case 2	−22.7	−3.36	−3.09	−24.8	−26.5	−35.1	−34.2
Case 3	−22.9	−3.19	−3.1	−23.8	−21.1	−19.6	−29.1

Table 2. Comparison of the reported branch-line hybrid coupler.

	[10]	[11]	[12]	[13]	[14]	This work
Frequency (GHz)	2.45	0.915	3.5	0.8365	0.9	2.0
Measured $\lvert S_{21}\rvert$, $\lvert S_{31}\rvert$ (dB)	3.1/3.2	3.42/3.72	3 ± 1	3.9 ± 0.1	3 ± 0.5	3.19/3.1
Isolation (dB)	36.2	40.0	35	28.9	40	29.1
Percentage of reduction	64.2	73	62	73.2	90.4	92
PCB dielectric constant	4.7	3.55	2.33	4.22	2.2	4.3

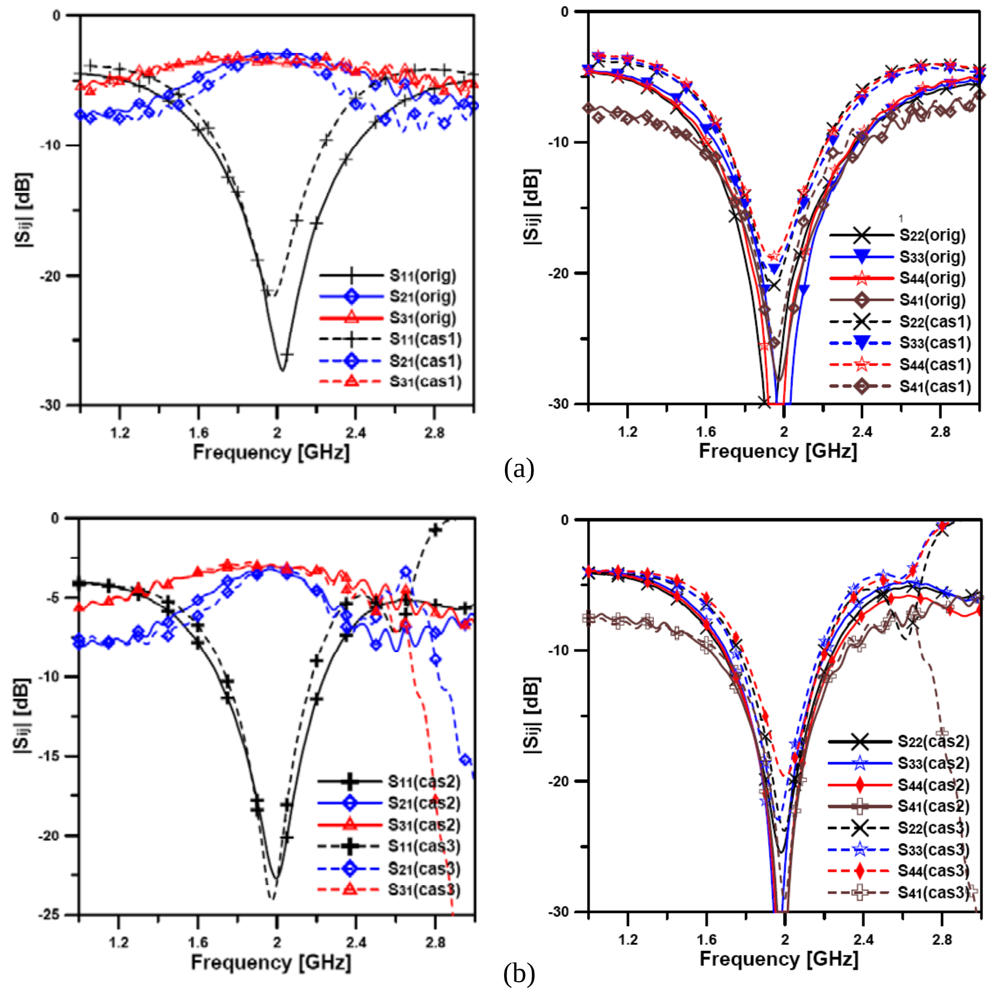


Figure 6. Measured S-parameters of the proposed compact multilayer hybrid coupler. (a) S-parameters of the original and Case 1 hybrid coupler. (b) S-parameters of Case 2 and Case 3 hybrid coupler.

4. CONCLUSION

This paper has presented a compact multilayer hybrid coupler with a transmission line with sandwich configuration and a small-section transmission line with end-side capacitors. Compared with the original hybrid coupler, the proposed hybrid coupler showed a maximum size reduction of 92%. The characteristics of the compact hybrid coupler remained the same. This design method can be used to reduce the component sizes of RF and microwave devices.

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