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Miniaturizated Microstrip Dual-Band Branch-Line Crossover with Two Inner Open Stubs

Yang Cui* **and Hitoshi Hayashi**

Abstract—In this letter, a microstrip dual-band band-pass crossover is proposed. By reducing the number of inner open stubs, miniaturization of a window-shaped crossover without reducing bandwidth can be achieved. An electromagnetic simulation and measurements are used to validate the compact ($0.35\lambda \times 0.35\lambda$) crossover with a wide bandwidth.

1. INTRODUCTION

With the development of wireless technology, an increasing number of wireless products have been proposed. A microwave crossover is a circuit that allows the crossing of two microwave transmission lines while maintaining proper isolation between them [1]. Compared with a non-planar crossover, a planar crossover is expected to have a lower insertion loss and a downward shift in operating frequency because of the removal of parasitic effects, wires, and vias. The 90° transmission line was replaced by a lumped-element circuit with a 90° phase lead using inductors and capacitors.

A planar crossover with two cascaded branch lines was proposed [2]. By using two or three branch-line sections with T-shaped transmission lines, a window-shaped dual-band crossover was developed by extending the conventional single-band crossover [3–5]. Moreover, a dual-band crossover with four inner quarter-wavelength transmission lines substituted by four asymmetrical transmission lines was reported [6].

The present letter proposes a planar dual-band crossover. By reducing the number of inner open stubs, miniaturization of the window-shaped crossover can be achieved. Fig. 1(a) shows a schematic diagram of the crossover proposed that uses four inner open stubs [6]. To miniaturize the crossover, we use fewer inner open stubs to free up internal space, as shown in Fig. 1(b).

2. DESIGN AND ANALYSIS ID

Figure 2(a) shows the equivalent admittances of the window-shaped crossover. The construction is symmetrical about XX' and YY'. In order to find the optimal size of the crossover, the S-parameters are obtained using even- and odd-mode theory. Based on the theory reported by Shao et al. [5], Y_{ee}, Y_{oe}, Y_{eo}, and Y_{oo} can be expressed as:

$$Y_{ee} = j\frac{2Z_A + 4Z_B \tan\theta_A \cot\theta_B}{2Z_A Z_B \cot\theta_B - Z_A^2 \tan\theta_A}, \tag{1}$$

$$Y_{oo} = -j\frac{2}{Z_A \tan\theta_A}, \tag{2}$$

$$Y_{eo} = Y_{oe} = j\left[\frac{2Z_B \tan\theta_A \tan\theta_B - Z_A}{2Z_A Z_B \cot\theta_B - Z_A^2 \tan\theta_A} - \frac{1}{Z_A \tan\theta_A}\right], \tag{3}$$

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* Corresponding author: Yang Cui (cuiyang0411@eagle.sophia.ac.jp).
The authors are with the Sophia University, Tokyo 102-8554, Japan.

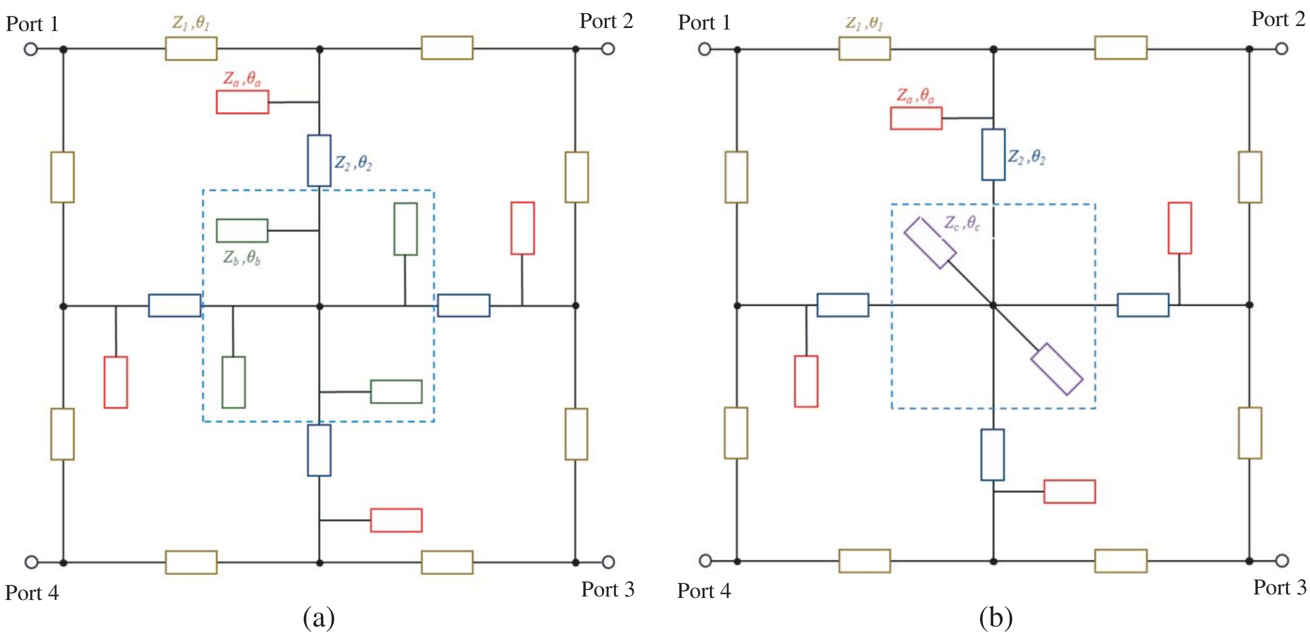

Figure 1. Comparison of two crossover structures. Schematic diagrams of (a) the crossover in [6] and (b) the proposed crossover with two inner open stubs.

where Z_A and Z_B are the characteristic impedances of the outer and inner branches, respectively.

The relationship between the pi-shaped transmission line and the inner branch Z_B is shown in Fig. 2(b). Based on the theory reported in [6], the impedances Z_2 and Z_b can be derived as:

$$Z_2 = \frac{Z_B \tan\theta_f}{\sin\theta_f}, \tag{4}$$

$$Z_b = \frac{Z_B \tan\theta_f}{\cos\theta_f}, \tag{5}$$

$$\theta_f = \frac{\pi}{1+f}, \tag{6}$$

where a quarter wavelength is selected for the electrical lengths θ_a, θ_b, and θ_2 of the asymmetrical transmission lines at f_0, which is the middle frequency between f_1 and f_2. The frequency ratio is $f = f_2/f_1$.

Impedance Z_c can be obtained from Fig. 2(c). Based on this theory, the relationship between Z_c and Z_b is:

$$Z_c = \frac{Z_b}{2} \tag{7}$$

3. SIMULATION AND MEASUREMENT RESULTS

To validate the proposed crossover, we used the simulator Microwave Office from National Instruments and fabricated the crossover on an FR4 substrate. Its dielectric constant, loss tangent, and layer thickness were 4.7, 0.016, and 1.6 mm, respectively. Using Eqs. (1)–(7), impedances Z_1, Z_2, Z_a, and Z_c for the proposed crossover were calculated to be 70.2, 70.2, 42.0, and 35.16 Ω, respectively. The crossover was operated at 290 and 870 MHz with a middle frequency of 580 MHz.

The theoretically calculated parameters were translated into physical dimensions with the aid of an electromagnetic (EM) simulation (Microwave Office). The layout of the proposed planar dual-band crossover is shown in Fig. 3. The physical lengths of $\theta_1, \theta_2, \theta_a$, and θ_c are 71, 73.5, 67, and 64 mm,

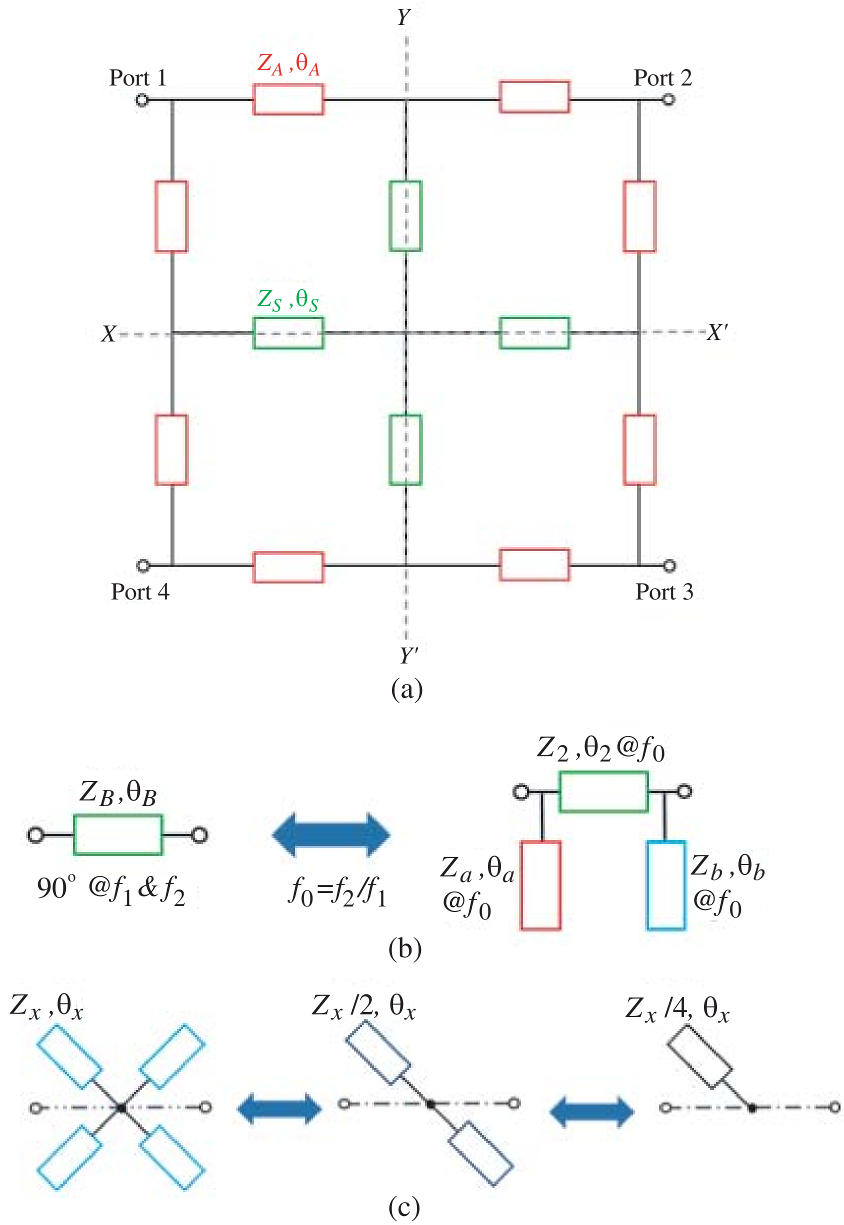

Figure 2. (a) Equivalent admittances for window-shaped crossover. (b) Replacement with asymmetrical transmission line. (c) Schematic of inner open stubs.

respectively. Because twisted microstrip lines are used, we can miniaturize the circuit to $0.35\lambda \times 0.35\lambda$ ($X = 103.57$ mm).

The results of EM simulation for the proposed crossover are shown in Fig. 4. The central frequency is 560 MHz, and the insertion losses at 280 and 840 MHz are 0.44 and 1.61 dB, respectively. The bandwidths below −10 dB are 263.8–327.8 MHz and 789.6–859.1 MHz in the frequency range 0.01 to 1.18 GHz.

The measurement results for the proposed crossover are shown in Fig. 5. The central frequency is 580 MHz, and the insertion losses at 290 and 870 MHz are 0.96 and 2.35 dB, respectively. The bandwidths below −10 dB are 272.3–335.1 MHz and 823.7–899.4 MHz in the frequency range of 0.01 to 1.18 GHz. Fig. 6 shows a photograph of the fabricated crossover.

Because of manufacturing errors, the central frequency has a 20-MHz deviation from the designed

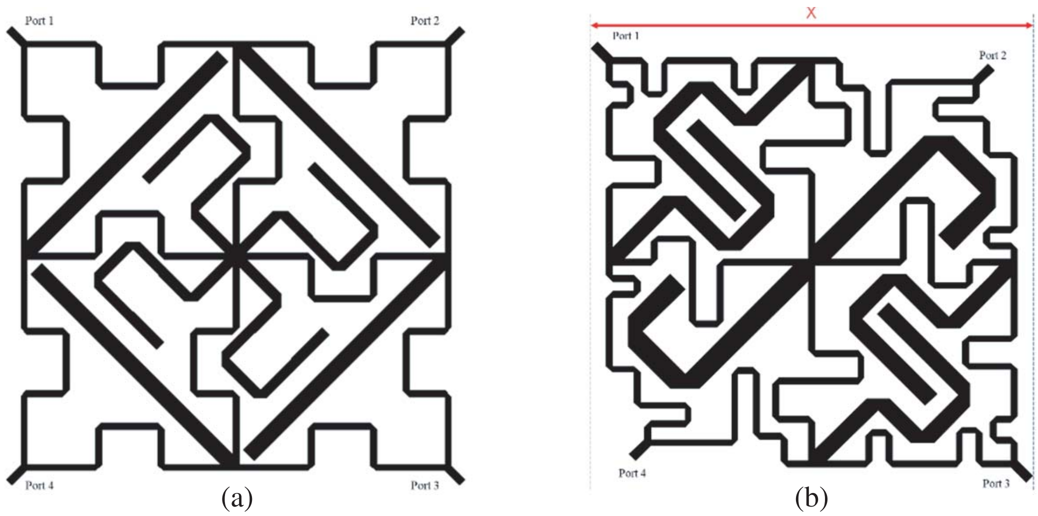

Figure 3. Comparison of two crossovers. Layouts of (a) crossover reported by Tang [6] and (b) proposed planar dual-band crossover.

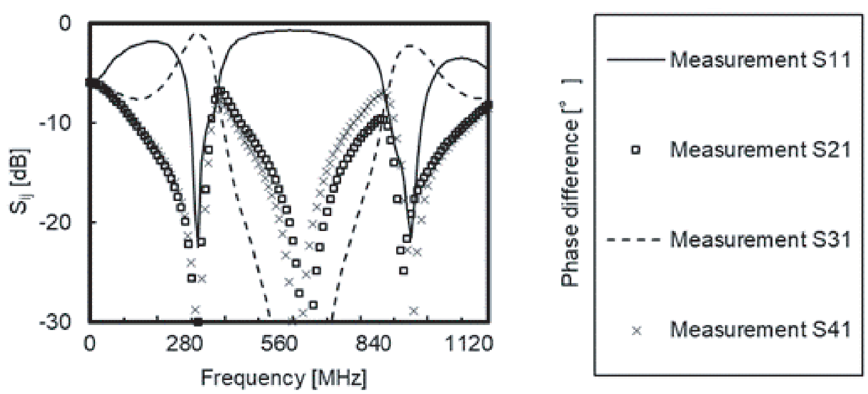

Figure 4. EM simulation results for proposed crossover.

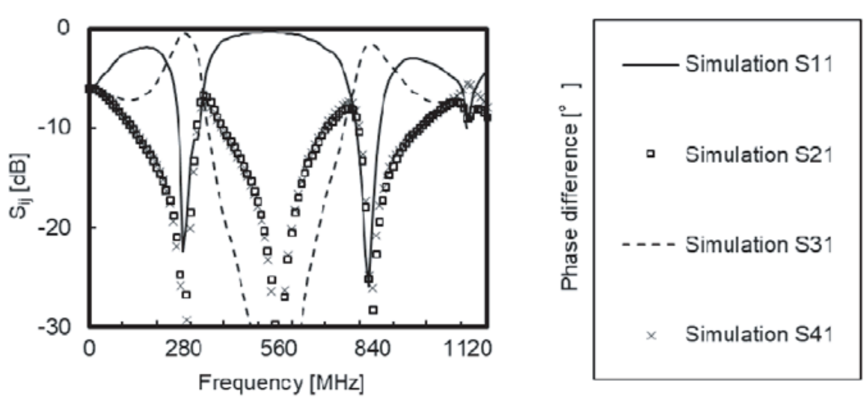

Figure 5. Measurement results for proposed crossover.

value. However, the two passband frequencies satisfy the theoretical formulas (4)–(6). Table 1 compares the characteristics of the proposed crossover with those of recently reported microstrip dual-band crossovers.

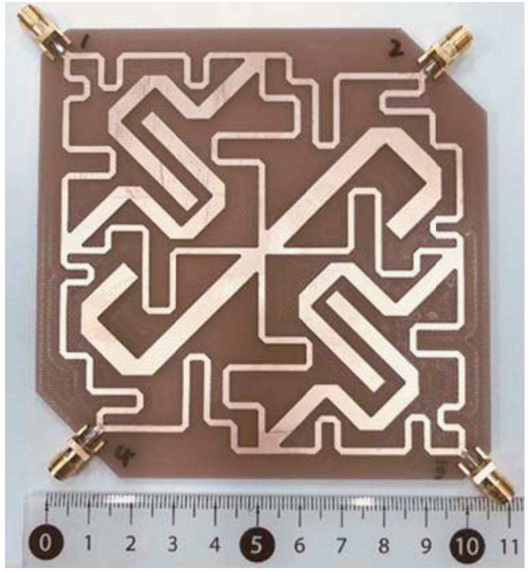

Figure 6. Photograph of fabricated microstrip dual-band crossover.

Table 1. Comparison of recently reported microstrip dual-band crossovers.

Reference	Structure	Dual-band (GHz)	Bandwidth (MHz) @ $\lvert S_{11}\rvert \leqq -10\,\mathrm{dB}$	Substrate	Size ($\lambda \times \lambda$)
[3]	Three-section branch-line coupler	1.0/2.0	15/15	Duriod	0.3×0.3
[4]	Two-section pi-shaped branch-line coupler	0.9/2.45	80/80	Rogers RO4003C	0.28×0.34
[5]	Window-shaped crossover with T-shaped structure	1.0/2.3	180/180	Duroid 5880	0.69×0.69
[6]	Window-shaped crossover with π-shaped structure	0.5/1.5	110/110	Rogers RO4003	0.38×0.38
This letter	Dual-band branch-line crossover with two inner open stubs	0.29/0.87	63/77	FR4	0.35×0.35

4. CONCLUSION

In this letter, a microstrip dual-band band-pass crossover that uses an inexpensive FR4 substrate is proposed. Reducing the number of inner open stubs allows miniaturization of the crossover. According to the results of EM simulation and measurements, the two band-pass bandwidths of the proposed crossover have good performance. Good agreement was obtained between simulation and measurement results.

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