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Compact Slow-Wave Branch-Line Coupler Using Crossing Bond Wires

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Abstract—This paper proposes a compact and miniaturized branch-line coupler using a crossing bond wire structured slow-wave branch line (CBWSWB). The proposed coupler achieves a size reduction of 82% compared with a conventional implementation. Measured S_{11}, S_{21}, S_{31} and S_{41} of the proposed coupler are better than -24, -3.7, -3.7 and -28 dB at 3 GHz, respectively. Furthermore, the phase difference between through and coupling ports of the coupler is within 1°.

1. INTRODUCTION

Branch-line couplers are widely used in microwave circuits, such as balanced mixers, balanced amplifiers, phase shifters and frequency discriminators. However, conventional branch-line coupler consists of four quarter-wavelength branches which occupy a very large area, especially at low frequency. Accordingly, many methods using lumped elements [1–3], meander lines [4], coupled lines [5], open stubs [6], right/left handed transmission lines [7, 8] and periodic slow-wave loading [9–11] have been proposed for size reduction. Lim and Lee proposed a slow-wave transmission line with a SWF of 4.5 using bond wires [12] and used it to design a compact branch-line coupler with a size reduction of 69% [13] compared with a convention microstrip one. Zhou et al. proposed a miniaturized power divider using crossed bond wires, which achieved 80% size reduction compared to a conventional Wilkinson power divider [14].

In this paper, CBWSWB is proposed to design a compact branch-line coupler for size reduction. Adopting much longer crossing bond wires, a slow-wave factor (SWF) of 7.3 is achieved, which is 82% size reduction compared with the couplers proposed in [12, 13].

2. THE PROPOSED SLOW-AVE BRANCH LINE

For a given transmission line, the wavelength λ is well known

$$\lambda = \frac{1}{f\sqrt{LC}} \tag{1}$$

where L and C are the equivalent distributed inductance and capacitance of the transmission line, respectively. From Eq. (1), the wavelength can be smaller by increasing L and C. Yet, capacitance C is related to microstirp islands' area, and inductance is related to length of bond wires. Capacitance C can be increased by increasing microstirp islands' area, but this approach results in larger circuit size.

The idea that we propose is to obtain bond wires as long as possible for larger (longer) inductance and higher slow-wave factor. Crossing bond wires are proposed for longer (larger) inductance without

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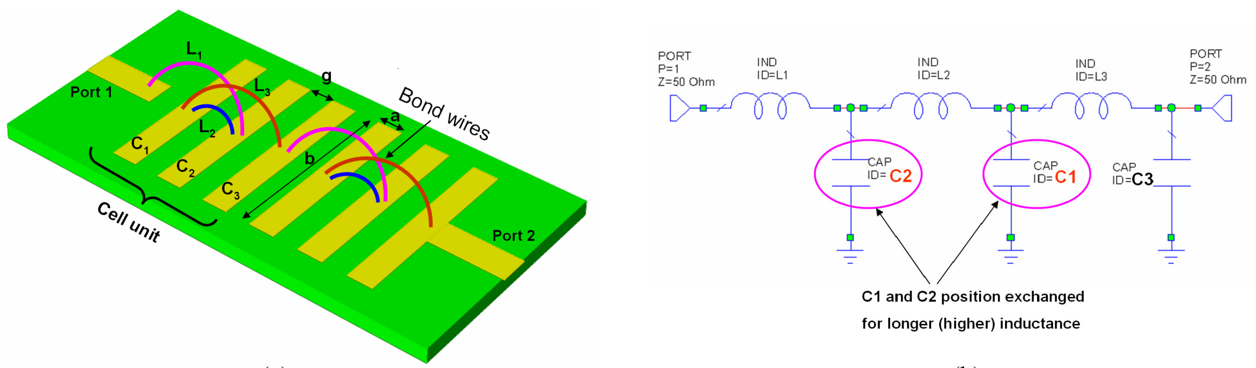
increasing circuit's size than conventional direct bond wire interconnection. The inductance of a bond wire ($l \ll d$) can be calculated by [15]

$$L = 2 \times 10^{-4} l \left[\ln \frac{4l}{d} + 0.5 \frac{d}{l} - 1 + 0.25 \tanh(4\delta/d) \right] \quad (2)$$

where l and d are the length and diameter of a bond wire, respectively. δ is the material's skin depth. According to Eq. (2), inductance of a bond wire can be greatly increased by increasing its length. Crossing bond wires can provide much higher inductance because they are much longer than conventional bond wire interconnections.

Figures 1(a) and (b) show the schematic diagram and its cell unit equivalent circuit of the proposed CBWSWB, respectively. Crossing bond wires L_1 and L_3 connect interval microstrip islands for longer length without increasing circuit size. In Figure 1(b), bond wires L_1, L_2 and L_3 have no mutual coupling effect due to none parallel sections of bond wires.



(a) (b)

Figure 1. (a) Schematic diagram of the proposed CBWSWB and (b) its equivalent circuit of cell unit.

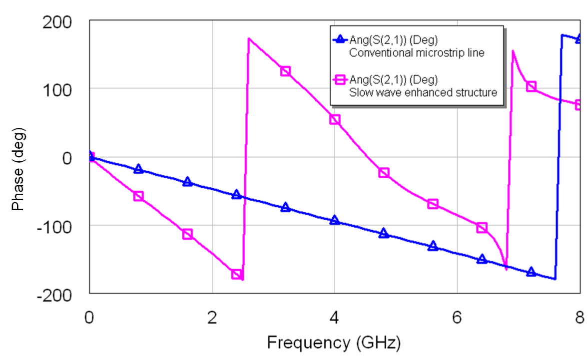


Figure 2. Phase comparison (Simulated) of the proposed CBWSWB and conventional microstrip line with the same physical length.

Performance of the proposed CBWSWB with two cell units is simulated using Microwave Office software [16]. The simulated dimension parameters in Figure 1(a) are: $a = 0.5$ mm, $b = 4.9$ mm and $g = 0.2$ mm. Figure 2 shows the phase comparison of the proposed CBWSWB and conventional microstrip line with the same physical length of 3.7 mm (Two cell units length long). The electrical length of the proposed CBWSWB with two unit cells is 280° (unwrap the red square dotted curve in Figure 2) at 3 GHz, whereas electrical length of the same physical length of a conventional microstirp line is only 70°. So SWF of the proposed CBWSWB is 4 times of that for a microstrip line with same physical length at 3 GHz. SWF of a conventional microstrip line is 1.83 at 3 GHz based on ROOC4003 substrate with a dielectric constant of 3.38. So SWF of the proposed CBWSWB is 7.3 (4 times of 1.83) due to using crossing bond wires for longer (larger) inductance instead of conventional bond wire interconnections.

3. THE PROPOSED COUPLER

Figures 3 and 4 show a schematic diagram and photograph of the proposed branch-line coupler, respectively. The conventional microstrip line branches are replaced by the proposed CBWSWBs, and the golden bond wires with a diameter of 25.4 µm are used to construct the proposed CBWSWBs.

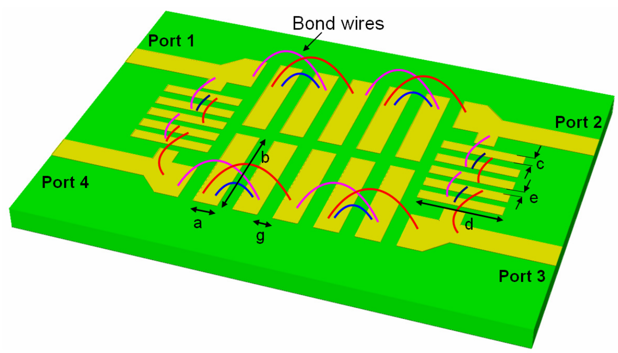


Figure 3. Schematic diagram of the proposed branch-line coupler.

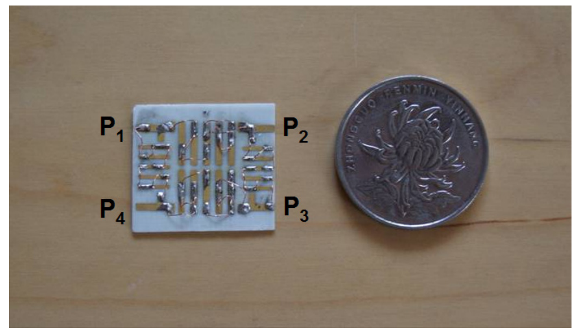


Figure 4. Photograph of the proposed branch-line coupler.

The proposed coupler is fabricated on an RO4003C substrate with a dielectric constant of 3.38 and thick length of 0.508 mm. Four ports of the coupler are all 50 Ω with a microstrip width of 1.14 mm. 35.35 Ω and 50 Ω characteristic impedances are as follows (Parameters a, b, c, d, e and g are defined in Figure 3):

35.35 Ω branch line: $a = 0.5$ mm, $b = 4.9$ mm and $g = 0.2$ mm

50 Ω branch line: $c = 0.8$ mm, $d = 6.1$ mm and $e = 0.2$ mm.

So, physical length of 50 Ω and 35.35 Ω branch-line are $5a + 6g = 5 \times 0.5 + 6 \times 0.2 = 3.7$ mm and $5c + 6e = 5 \times 0.7 + 6 \times 0.2 = 4.7$ mm, whereas a quarter-wavelength branch is 15.3 mm on ROOC 4003 substrate. The proposed CBWSWB reduces 82% area of the proposed coupler compared with a conventional microstrip one.

Simulation was implemented using AXIEM solver, which is electromagnetic simulation software based on the method of moment (MoM). Measurements were carried out on an Agilent N5230C network analyzer. Figures 5(a) and (b) show the simulated and measured S-parameters of the proposed coupler. Measured S_{11}, S_{21}, S_{31} and S_{41} at 3 GHz are better than −24, −3.7, −3.7 and −28 dB, respectively. Measured phase difference between Port 2 and Port 3 is $90° \pm 1°$ at operating bandwidth, shown in Figure 6.

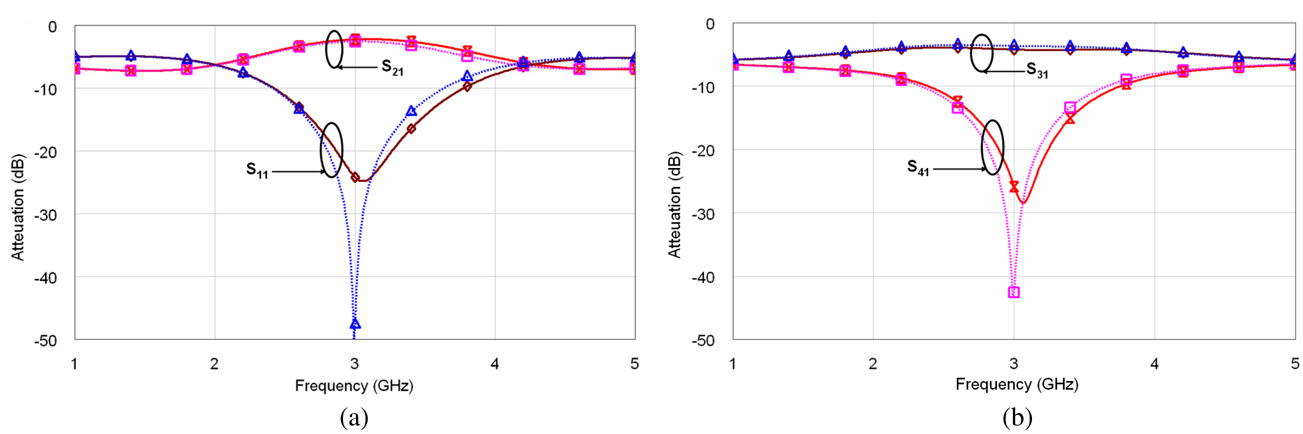


Figure 5. Simulated and measured S-parameters: (a) S_{11} and S_{21}, and (b) S_{31} and S_{41}.

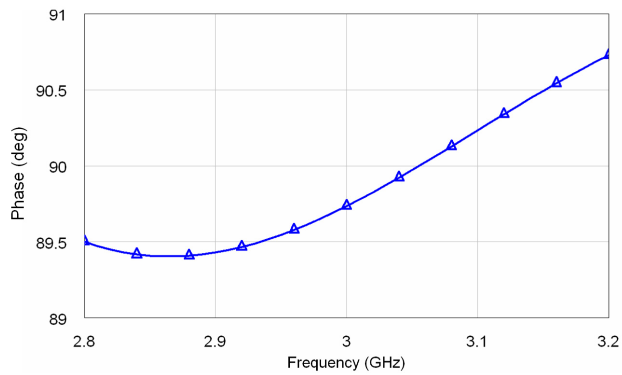


Figure 6. Measured phase difference between Port 2 and Port 3.

4. CONCLUSION

A slow-wave effect branch-line coupler using crossing bond wires is proposed and achieves a size reduction of 82% compared with a conventional one. The higher SWF is achieved using crossing bond wires, which can provide longer (higher) inductance. Measured S_{11}, S_{21}, S_{31} and S_{41} of the proposed coupler are better than -24, -3.7, -3.7 and -28 dB at 3 GHz, respectively. And the measurements agree well with the simulations.

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