

A Compact Branch-Line Coupler Using Discontinuous Microstrip Lines

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Abstract—We introduce a branch-line coupler using discontinuous microstrip lines whose size is significantly reduced relative to the standard design. We manipulate the reactive characteristics of discontinuities in its microstrip lines to achieve a physical size reduction of almost 60% with comparable performance.

Index Terms—Hybrid coupler, microstrip discontinuity, slow wave.

I. INTRODUCTION

BRANCH line couplers are used in microwave integrated circuits (MICs) as well as in monolithic microwave integrated circuits (MMICs), such as balanced mixers, balanced amplifiers and reflection type phase shifters [1]. Conventional couplers tend to consume expensive chip area, especially at low frequencies, thus many efforts have been made to reduce their size [2]. Lumped-element hybrid couplers are ready examples [3] of the attempt to miniaturize couplers, but lumped inductors and capacitors with the required values and high quality factors are not always available for use in MICs or MMICs. Slow-wave transmission lines are also promising candidates for size reduction [4], [5], but many employ complicated three dimensional structures that may be difficult to fabricate [6]. Thus, we seek a compact quarter-wavelength 3 dB branch line coupler that achieves a significant size reduction while maintaining MIC and MMIC process compatibility.

II. CIRCUIT DESIGN

Basic branch line couplers have four quarter-wavelength transmission lines with two different characteristic impedances. For a given transmission line, the ideal characteristic impedance Z_0 and phase velocity v_p are well known

$$Z_0 = \sqrt{\frac{L}{C}} \quad (1)$$

$$\lambda = \frac{v_p}{f} \quad (2)$$

$$v_p = \frac{1}{\sqrt{LC}} \quad (3)$$

From (1)–(3), it follows that the wavelength can be made small while the characteristic impedance is kept unchanged by

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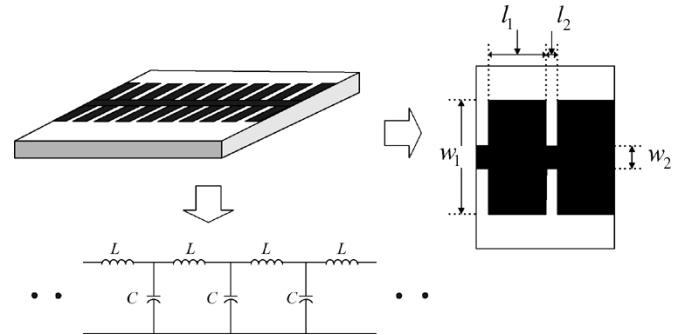


Fig. 1. Equivalent circuit of a transmission line with discontinuities.

increasing L and C with the same ratio. Yet both inductance and capacitance of microstrip are related to line width: inductance increases with decreasing line width, whereas capacitance increases with increasing line width.

For a given electrical length, the physical length of a transmission line, such as a microstrip, can be reduced by using a slow wave structure. In this letter, we designed a slow wave transmission line by employing discontinuities along it. A step discontinuity provides the line with additional inductance and capacitance. The discontinuous transmission line is made by placing a wide and short line and a narrow and short line in turn. Throughout this letter, those lines will be called a capacitive line and an inductive line, respectively. A transmission line with the repeated discontinuities can be modeled as shown in Fig. 1. In this equivalent circuit, L is equal to $L_c + L_i + L_d$ and C is equal to $C_c + C_i + C_d$. The notations used here are defined as follows:

- L_c, C_c inductance/capacitance per unit length which is induced by a capacitive line;
- L_i, C_i inductance/capacitance per unit length which is induced by an inductive line;
- L_d, C_d inductance/capacitance per unit length which is induced by discontinuities.

The inductance and the capacitance induced by discontinuities are dependent on the board thickness and the line width. For a step discontinuity, both of the inductance and the capacitance increase as width ratio of the two connected lines increases [7]. For our design, we used a board with 0.062 in thickness, whose dielectric constant is 2.2. Designed capacitive line width W_1 , capacitive line length l_1 , inductive line width W_2 , and inductive line length l_2 of discontinuous lines with 35.35 Ω and 50 Ω characteristic impedances are as follows:

$$35.35 \Omega : W_1 = 20.5, l_1 = 1.8, W_2 = 0.6, l_2 = 0.2$$

$$50 \Omega : W_1 = 11.6, l_1 = 1.8, W_2 = 0.3, l_2 = 0.2$$

(Unit : mm).

TABLE I
DISTRIBUTED ELEMENT VALUES PER MM OF DISCONTINUOUS AND CONTINUOUS LINES (UNITS: nH FOR INDUCTANCE, pF FOR CAPACITANCE)

Discontinuous 35.35 Ω line					
L_c	L_i	L_d	C_c	C_i	C_d
0.07	0.06	0.29	0.263	0.003	0.067
Discontinuous 50 Ω line					
L_c	L_i	L_d	C_c	C_i	C_d
0.11	0.073	0.27	0.16	0.003	0.019
Continuous 35.35 Ω line					
L			C		
0.16			0.13		
Continuous 50 Ω line					
L			C		
0.23			0.091		

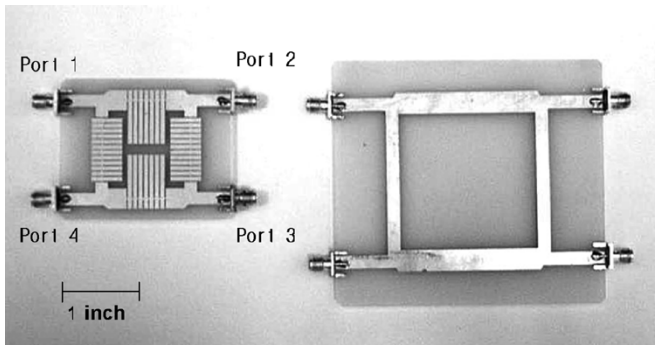


Fig. 2. Size comparison of new (left) and conventional branch line (right) couplers.

Distributed inductances and capacitances per mm of discontinuous lines with these dimensions and continuous lines are shown in Table I for comparison. All values are distributed for 1 mm length. Inductive lines are 0.2 mm long and capacitive lines are 1.8 mm long in this example. Therefore, this table shows the values for a 0.1 mm inductive line and a 0.9 mm capacitive line to make a 1 mm discontinuous line. L_d and C_d should also include coupling effects between capacitive lines when they are very close. Many studies have been done to analyze step discontinuities [8]. However, most of them assumed long transmission lines at both sides of a discontinuity, and they can't be directly used when discontinuous sections are close. So, instead of using those methods, L_d and C_d in Table I were calculated by measuring image impedance. Then, phase velocity of a discontinuous transmission line is

$$v_p = \frac{1}{\sqrt{(L_c + L_i + L_d)(C_c + C_i + C_d)}}. \quad (4)$$

So, from Table I it is obvious that the discontinuous transmission line is much shorter than the conventional transmission line for the same electrical wavelength.

III. EXPERIMENTAL RESULTS

Fig. 2 shows the compact coupler and a conventional coupler for comparison. The area of the conventional coupler is 415 mm² versus 170 mm² for the compact one, about 60% smaller. Both couplers were built on Rogers RT5880 high

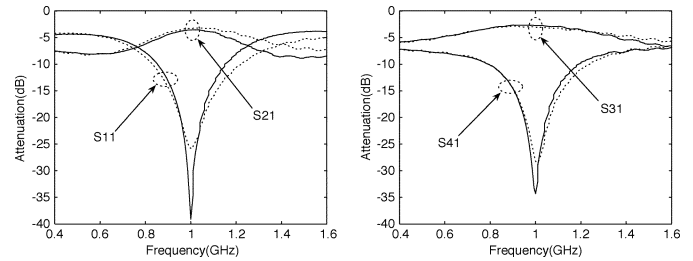


Fig. 3. Measured S -parameters for the new (solid) and the conventional (dotted) branch-line coupler.

frequency board material ($\epsilon_r = 2.2$, dielectric thickness = 0.062 in, copper thickness = 17 μm).

The configuration consists of 35.35 Ω lines having discontinuities made from 16.33 Ω plain lines and 50 Ω lines with discontinuities made from 26.23 Ω plain lines. In Fig. 2, Ports 1, 2, 3, and 4 correspond to the input, through, coupled and isolated port, respectively. Fig. 3 shows the measured S -parameters for the proposed branch line coupler and the conventional one using a center frequency of 1 GHz. As shown, the proposed branch-line coupler has comparable performance to the conventional one, which is on the right in Fig. 2. The measurement result in Fig. 3 also gives the reflection and isolation. At the center frequency, both of them are around -35 dB. Measured phase difference between port 2 and port 3 is $90^\circ \pm 0.5^\circ$ at operating bandwidth.

IV. CONCLUSION

A novel compact branch-line coupler that employs discontinuous microstrip lines is demonstrated. At 1 GHz, a 60% device size reduction is achieved compared with traditionally fabricated branch-line couplers. The measured S -parameters for the compact branch-line coupler shows good agreement with conventional one. So this new design should have many applications in the circuit where conventional branch-line coupler is used.

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