Miniaturized Branch-line Coupler using Delta Stubs

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***Abstract*- A miniaturized branch-line coupler using delta stubs is proposed and implemented. The length of quarter-wavelength branch-line is reduced and a size reduction of 55% is achieved due to using the delta stubs. Measured S_{11}, S_{21}, S_{31} and S_{41} of the proposed coupler are better than -24, -3.2, -3.4 and -28 dB from 2.8- 3.2 GHz, respectively. And the phase difference between through and coupling ports of the coupler is within 90° ±1° at operating bandwidth. Performance and size comparisons are also implemented.**

Keywords—miniature; branch-line coupler; delta stubs

I. 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], meander lines [2], coupled lines [3], periodic slow-wave loading [4], radial stubs [5], triangular stub [6], left/right-handed elements [7] and other solutions in [8-11] were proposed for size reduction.

In this letter, a novel compact branch-line coupler is proposed and implemented. Delta stubs installed on each branch of the proposed coupler can be used to reduce physical length of each branch. The overall size of the proposed branch-line coupler is only 9 mm by 9 mm and it achieves a size reduction of 55% compared with a conventional branch-line coupler.

II. CIRCUIT DESIGN

Delta stub was -first proposed by De Lima Coimbra [12]. Its shape is an isosceles triangle as Greek letter "Delta". Although delta stub has been proposed for a long time, it is seldom used as impedance match element in microwave components design. Like radial stub, delta stub can present as a matching elements. Compared with radial stub, delta stub is a good alternative to be the radial stub, and it is useful in wherever a radial stub would be chosen and has simpler contour due to its straight sides, so it is easier to lay out on PCB.

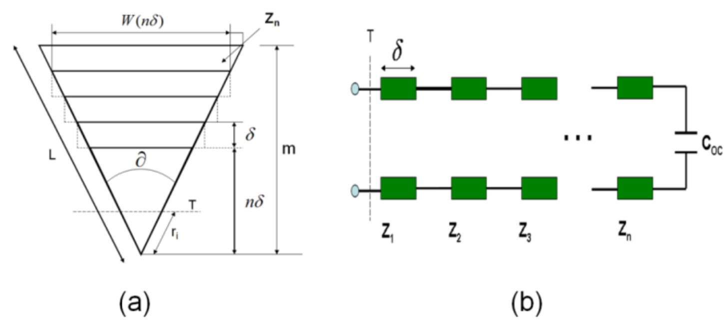

Figure 1. (a) Geometry of the delta stub (b) Equivalent circuit of delta stub

Coimbra [13] recommends modeling the delta stub by a series of n transmission line segments of length δ. The open end of the delta stub is transferred by the equivalent line length to a short circuit at the reference plane T, shown in Figure 2 and Figure 3. Tapered line can be treated as a series of transmission line with different characteristic impedance. The number, n, is chosen so each segment is $\delta \ll \lambda_g$ in length. Each segment's characteristic impedance is calculated with the standard microstrip line equations with the exception of the final section, which includes the open end discontinuity. Widths of each transmission line are computed by

$$W = 2n\delta tg(\partial / 2) \quad n = 0,1,...n \tag{1}$$

Thus in [11], when W/d⩾1, it's convenient to calculate the characteristic impedance of each segment by

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_e}[W/d + 1.393 + 0.667\ln(W/d + 1.444)]} \tag{2}$$

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\frac{1}{\sqrt{1 + 12d/W}} \tag{3}$$

where ε_r is the dielectric constant of PCB substrate, ε_e is the effective dielectric constant of a microstrip line, W is the width of microstrip line and d is the thickness of PCB substrate. For a load impedance , input impedance of a lossless transmission line with length L and a characteristic impedance of Z_0 can be computed by

$$Z_{in}(l) = Z_0 \frac{Z_L + jZ_0 tg\beta l}{Z_0 + jZ_L tg\beta l} \tag{4}$$

where β is the phase constant of the transmission. Since delta stub is considered as the cascaded interconnections of transmission line with equal incremental distance of δ, the input impedance at L+ δ ($\Delta Z = Z_{in} + dZ_{in}$) is

$$\Delta Z = Z_0 \frac{Z_{in} + jZ_0 tg(\beta\delta)}{Z_0 + jZ_{in} tg(\beta\delta)} \tag{5}$$

The input impedance of the delta stub can be found from the computation of the input impedance of each cascaded transmission line with incremental distance δ successfully.

According to (1)-(5) and with the help of CAD program optimization, we set the segments quantity n as 100 for calculating impedance of the delta stub, then electrical parameter for the delta stub can be derived by (1)-(5).

Figure 2 shows the layout with dimension parameters of the proposed compact branch-line coupler. Delta stub is installed on each branch of the proposed branch-line coupler. The reason for using the proposed structure is to obtain less physical length of quarter-wavelength branch. The two branches' characteristic impedance of a conventional branch-line coupler are 35 Ω and 50 Ω, respectively. To minimize the effects of conductor loss, radiation loss and prevention of spurious modes, the width of the microstrip branch lines are optimized.

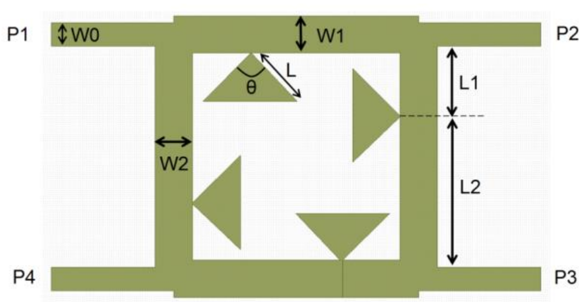

Figure 2. Structure of the proposed branch-line coupler with parameter definitions

TABLE I

OPTIMAL DEMENSIONS OF THE PROPSOED COUPLER

Parameter	W_0	W_1	W_2	L_1	L_2	L	θ
Unit (mm)	1.14	1.96	1.14	3	5.8	2.1	68°

Structure simulation and optimization was implemented using AXIEM simulator which is a full-wave electromagnetic solver based on a modified spectral-domain method of moments [14]. After optimization, final optimal dimensions of the proposed branch-line coupler are listed in Table 1 and dimensions parameters are defined in Figure 2.

The proposed branch-line coupler is fabricated on the RO4003C substrate with a dielectric constant of 3.38 and a thickness of 0.508 mm. The proposed structure saved 55% branch line's length compared with conventional quarter-wavelength microstrip line, which shows the size reduction in Figure 2.

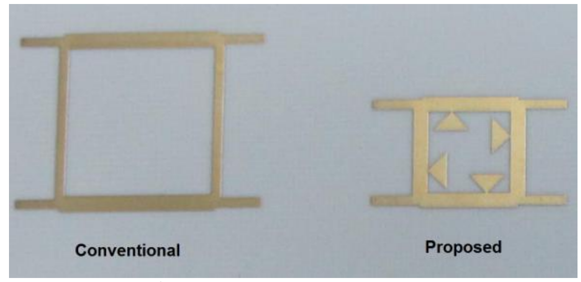

Figure 3. Photograph of the proposed branch-line coupler (right-side) and conventional one (left-side).

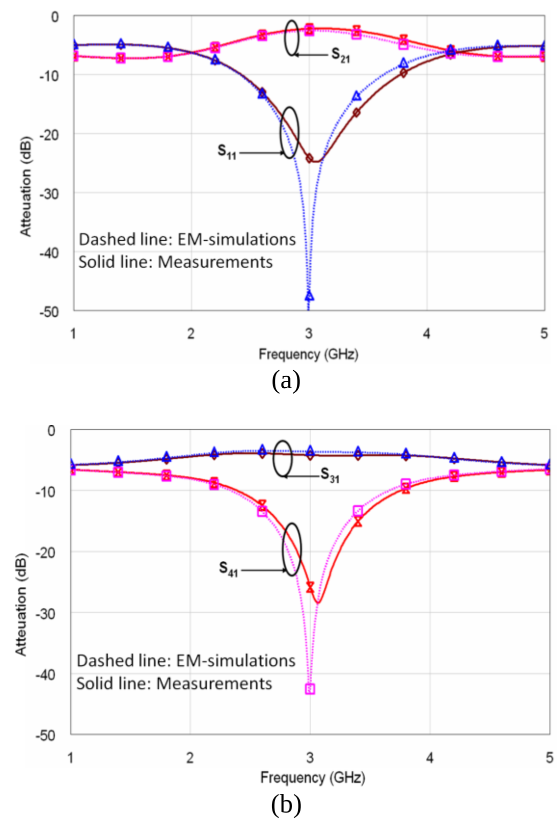

Figure 4 Simulated and measured S-parameters (a) S_{11} and S_{21}, (b) S_{31} and S_{41}

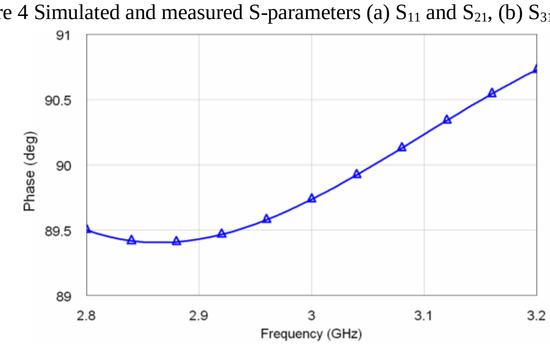

Figure 5 Measured phase difference between Port 2 and Port 3

III. SIMULATED AND MEASURED RESULTS

Figure 4 (a) and (b) show the simulated and measured S-parameters of the proposed coupler. The measurements agree well with the simulations. Measurements were carried out on an Agilent N5230C network analyzer. Measured S_{11}, S_{21}, S_{31} and S_{41} of the proposed coupler are better than -24, -3.2, -3.4 and -28 dB in operating band from 2.8 to 3.2 GHz, respectively. And the phase difference between through and coupling ports of the coupler is within $90^\circ \pm 1^\circ$ at operating bandwidth, shown in Figure 5. The tiny frequency shift between simulation and measurement is caused by the PCB fabrication tolerance.

IV. COMPARISONS AND DISCUSSIONS

We also implemented the size and performance comparisons with other branch-line couplers. And the results are summarized in Table II. The size reduction is 55% and its insertion loss in the operating band is only 3.2 dB for our coupler, which shows the smallest insertion loss. And although the size reduction is not as great as others, the structure of the proposed coupler is the simplest, which makes integrations easier and its fabrication yield higher.

Table II.

Size and performance comparisons

Coupler	Size reduction	Insertions loss
Conventional	0%	3.3 dB
[8]	75%	3.7 dB
[9]	75%	3.7 dB
[10]	92%	3.5 dB
[11]	67%	3.5 dB
This work	55%	3.2 dB

V. CONCLUSION

A compact branch-line coupler using delta stubs is proposed and implemented. The length of quarter-wavelength branch-line is reduced and a size reduction of 55% is achieved due to using the delta stubs. The structure of proposed coupler is simple for integration. Measured S_{11}, S_{21}, S_{31} and S_{41} of the proposed coupler are better than -24, -3.2, -3.4 and -28 dB at operating bandwidth, respectively. And the phase difference between through and coupling ports of the coupler is within $90^\circ \pm 1^\circ$ at operating bandwidth.

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