6-dB Branch Line Coupler

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1 ***Abstract*—This report presents a systematic approach for designing a 6 dB branch-line coupler (BLC). The design process begins with the synthesis of an ideal transmission line network using even–odd mode analysis, followed by implementation and simulation of a microstrip realization in Advanced Design System (ADS). Electromagnetic (EM) simulation is then performed using Keysight RFPro to validate the layout. The final design achieves a coupling of 5.8 dB at 3 GHz in the EM simulation.**

***Index Terms*—Advanced Design System, branch line coupler, even-odd mode analysis, RFPro.**

I. INTRODUCTION

DIRECTIONAL couplers are essential components in microwave and radio frequency (RF) systems, widely used for signal sampling, power monitoring, and isolation between components [1], [2]. Commonly used directional couplers include coupled-line couplers, Lange couplers, rat race couplers, and branch line couplers (BLCs), each offering distinct advantages based on design constraints and operating frequency. particularly popular for its simple planar structure and ease of implementation using microstrip technology. The BLC is typically designed for a 90-degree phase difference between outputs and equal power split, making it suitable for balanced mixers, modulators, and antenna feed networks.

To design a symmetric BLC, one can start with even–odd mode analysis to determine the required characteristic impedance of each transmission line (TL) section, as illustrated in Fig. 1, based on the desired coupling ratio. This initial analysis provides the foundation for synthesizing an ideal circuit model, which can then be translated into a microstrip layout for practical implementation. To demonstrate the procedure, a 6-dB BLC centered at 3 GHz was designed in this experiment. The synthesized layout was simulated and refined through both circuit schematic and electromagnetic (EM) simulation using Keysight Advances Design System (ADS) and RFPro. The finalized design results in a BLC with 5.8 dB at 3 GHz.

II. BRANCH LINE COUPLER SYNTHESIS AND IMPLEMENTATION

According to the even-odd mode analysis [1], the S-parameters describing the transmission and coupling behavior of the branch-line coupler (BLC) are given by:

$$S_{21} = jZ_{0a}/Z_0, \tag{1}$$
$$S_{31} = Z_{0a}/Z_{0b}, \tag{2}$$

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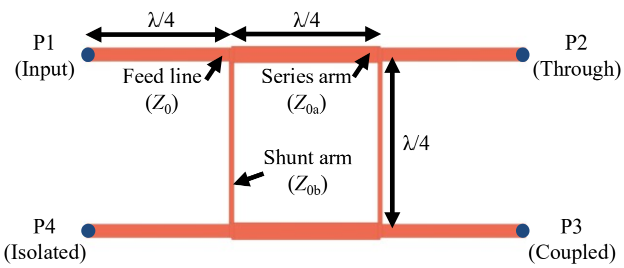

Fig. 1. Branch line coupler with feed lines.

TABLE I DESIGN PARAMETERS OF 6-DB BLC CENTERED AT 3 GHZ

Parameters	Series arms	Shunt arms	Feed lines
Z_0 (Ω)	25√3	50√3	50
θ	90°	90°	90°
w (mm)	1.86044	0.564737	1.501750
l (mm)	18.15020	18.82590	18.27750

where Z_{0a} and Z_{0b} are the characteristic impedance of quarter wave (electrical length θ = 90°) series and shunt arms, respectively (see Fig. 1).

It is important to note that the BLC is a reciprocal network (i.e., $S_{ij} = S_{ji}$), is matched at all ports ($S_{11} = S_{22} = S_{33} = S_{44} = 0$), and provides isolation at the center frequency ($S_{41} = S_{23} = 0$). The expressions in (1) and (2) also account for the quarter-wave feed lines that connect each port to the central branching section.

Given a coupling of 6 dB, the calculation using (2) and (3) yields Z_{0a} = 25√3 Ω and Z_{0b} = 50√3 Ω. The dimensions of corresponding microstrip lines can be calculated using LineCal tool in ADS. In this study, the substrate is Rogers RT/duroid 5880 with a thickness of 0.5 mm, relative permittivity $\varepsilon_r = 2.2$, and loss tangen tanδ = 0.0009). The metallization is a 30-µm-thick conductor with conductivity σ = 41 MS/m. The resulting microstrip dimensions are summarized in Table I. o interconnect the three TLs, three-way tee junctions with matched widths are employed, as depicted in a schematic diagram in Fig. 2. This schematic diagram is then converted to a layer shown in Fig. 1 using a command in ADS and simulated in RFpro for EM finite element analysis (FEM).

III. Simulations and Discussions

To investigate the impact of physical realization of the BLC, three levels of implementation, i.e., an ideal TL network, a microstrip line network, and a generated layout are simulated and compared. Fig. 3 compares the magnitudes of the simulated S-parameters, while Fig. 4 compares the phases of S_{21} and S_{31}. The comparison reveals that the circuit level simulations of the ideal and microstrip networks are in close agreement, with minor discrepancies likely resulting from the effects of the tee junctions. In contrast, the EM simulation of the physical layout

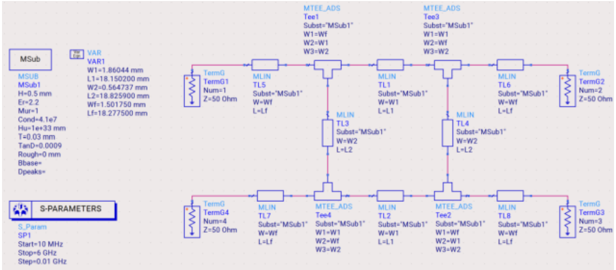

Fig. 2. Schematic diagram of a microstrip BLC in ADS.

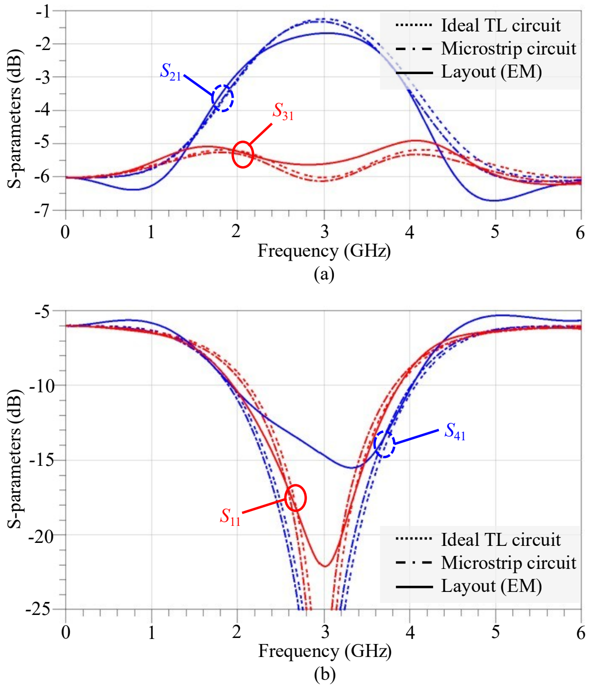

Fig. 3. Simulated S-parameter magnitude comparisons between three design layers: (a) S_{21} (blue) and S_{31} (red), and (b) S_{11} (red) and S_{44} (blue).

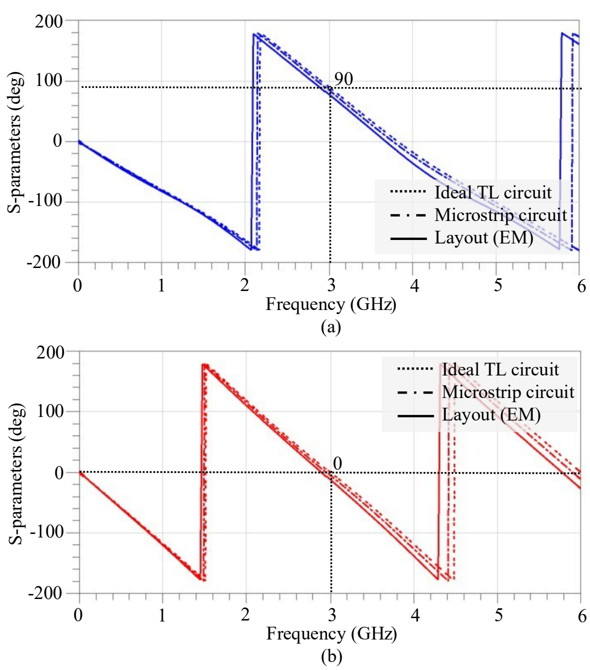

Fig. 4. Simulated S-parameter phase comparisons between three design layers: (a) S_{21} and (b) S_{31}.

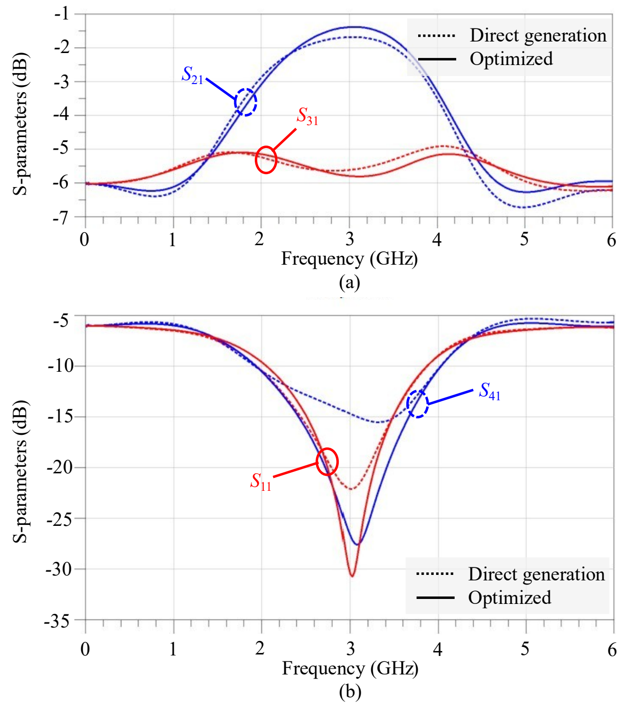

Fig. 5. Simulated S-parameter magnitude comparisons between layouts from direct generation and optimization: (a) S_{21} (blue) and S_{31} (red), and (b) S_{11} (red) and S_{44} (blue).

TABLE II OPTIMIZED PARAMETERS OF THE BLC

Parameters	Series arms	Shunt arms	Feed lines
w (mm)	1.86044	0.580737	1.5057325
l (mm)	18.0212	18.265123	18.2755

shows more pronounced deviations, highlighting the influence of parasitics, discontinuities, and radiation effects introduced during physical realization, which are not captured in circuit level simulations. Nevertheless, the phase comparisons indicate that the phase difference between Ports 2 and 3 remain roughly 90° in every case despite the offsets.

To compensate for electromagnetic effects, the layout dimensions were adjusted to optimize performance. As a result, S_{21} and S_{31} responses slightly improved, achieving a better coupling of 5.8 dB at 3 GHz, as shown in Fig. 5(a). Moreover, both the input port matching and isolation are significantly enhanced compared to the layout directly generated from the calculated transmission line network, as indicated in Fig. 5(b). The optimized dimensions are listed in Table II.

For completeness, Fig. 6 illustrates a sequence of electric field (E-field) propagation inside the optimized BLC, obtained from a near-field simulation in RFPro. The results confirm that the signals exiting Ports 2 and 3 are 90° out of phase, while the wave propagation toward Port 4 is effectively canceled, as expected from an ideal BLC.

V. CONCLUSION

The simulation-based experiment provides an insight into the design and implementation of a BLC. While even–odd mode analysis provides accurate predictions for ideal transmission line circuits, increased realism in simulations—from microstrip

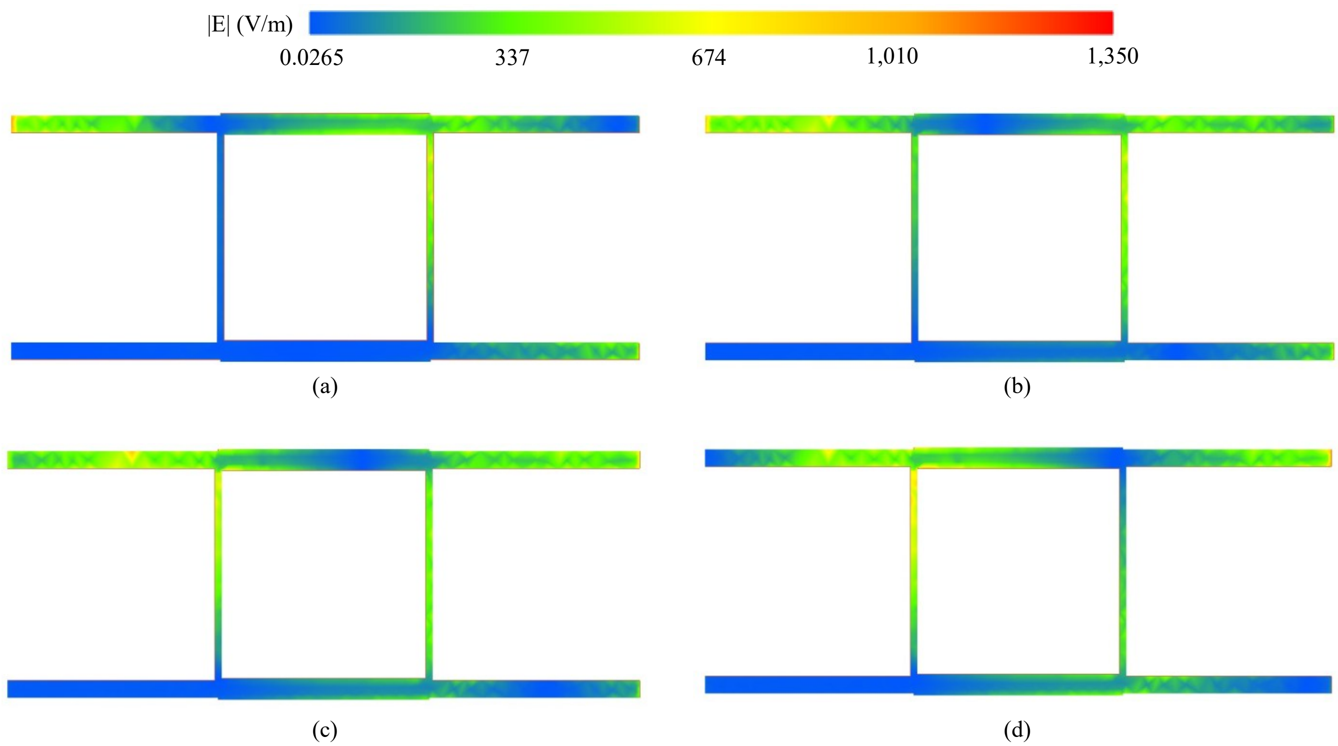

Fig. 6. A sequence of E-field propagation inside the BLC when the phases of the propagating wave are (a) 0°, (b) 30°, (c) 60°, and (d) 90°.

circuits to EM layout simulations—reveals growing discrepancies due to electromagnetic interactions and structural discontinuities. Nonetheless, the theoretical synthesis serves as a reliable starting point, requiring only minor tuning to achieve near-optimal results. In addition to demonstrating a systematic design process, the study also highlights a key characteristic of the BLC: the 90° phase difference between the through and coupled output ports.

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