Abstract – In this paper, a 3-dB directional coupler realized in fully planar microstrip technique has been proposed. It has been shown, that insertion of left-handed (LH) transmission line in-between two identical coupled-line subsections allows to increase nominal coupling coefficient of the resulting coupler. A via-less approximation of left-handed transmission line section using appropriately designed interdigital capacitor integrating required capacitance and inductance has been proposed. The utilization of the proposed bandpass structure allows to design 3-dB with neither additional SMD components nor vias. The exemplary circuit operating at \( f_0 = 5.3 \) GHz has been realized. A good performance of the circuit has been obtained confirming the applicability of the proposed approach.

Keywords-left- coupled-line directional coupler, coupling enhancement, left-handed transmission line

I. INTRODUCTION

Directional couplers are widely used components in microwave electronics [1]-[4]. The couplers are circuits, which consists of directly connected transmission lines or sections of coupled lines. The coupled-line directional couplers are very often utilized in many microwave systems, since they feature wider operational bandwidth than directly connected couplers. Due to the ease and low-cost of fabrication, the edge-coupled-line directional couplers are mainly realized using microstrip technique. However, in such circuits tight coupling is not possible to obtain in single-layer and such structure features unequal even- and odd-mode phase velocities, which deteriorates the resulting circuit’s performance. Realization of tightly coupled directional couplers in microstrip technique has been a subject of extensive research and among others, solutions like: Lange couplers [5], broadside-coupled CPW couplers [6], tandem-connected couplers [7] etc. have been proposed. Each of the above given methods allowing for realization of tightly coupled couplers in microstrip technique require either bindings, which make the manufacturing process more difficult or require multilayer structure. In [8]-[9], it has been shown, that by appropriate selection of LH transmission lines, inserted in-between two coupled lines almost any desirable coupling of the edge-coupled directional coupler realized in single-layer microstrip technique can be achieved.

In this paper, a 3-dB coupled-line directional coupler realized in single-layer microstrip technique has been proposed. An exemplary circuit operating at center frequency \( f_0 = 4.5 \) GHz has been realized using fully planar technique and in contrary to [8] does not require any vias to ground. The LH uncoupled transmission lines have been realized as one bandpass subsection of an appropriately designed interdigital capacitor integrating required capacitance and inductance fully approximating required properties. The theoretical analysis has been confirmed by experimental results.

II. THEORETICAL ANALYSIS

A general schematic diagram of a directional coupler featuring increased nominal coupling coefficient \( k_N \), than coupling coefficient \( k_R \) of the utilized coupled-line sections is presented in Figure 1. As seen, the circuit is composed of two uncoupled LH transmission lines and two coupled-line sections. It has been shown in [8], that in such a circuit, the nominal coupling coefficient depends on the coupling of the coupled-line sections as well as on the electrical length of both types of transmission lines. Appropriate electrical lengths for a given \( k_R \) and required \( k_N \) can be found as described in [8].

For further analysis and realization of an exemplary 3-dB coupler a dielectric structure presented in Figure 2 has been chosen. Geometry of the coupled-line section has been selected to obtain characteristic impedance \( Z_0 = 50 \) \( \Omega \) and to achieve possible highest coupling coefficient which is limited by the manufacturing technology (minimum spacing between coupled-lines). Resulting geometry is \( w = 0.56 \) mm while \( s = 0.08 \) mm what results in coupling of

\[ \text{Figure 1. A schematic diagram of the coupling enhanced directional coupler composed of section of LH transmission lines inserted in-between two coupled line sections [8].} \]

\[ \text{Figure 2. Cross-sectional view of the dielectric structure used for the design:} \quad h = 1.27 \text{ mm, } \varepsilon_r = 10.6. \]
C_a = -6 dB. Parameters of the coupled-line section have been listed in Table I. Calculated frequency characteristics of a directional coupler composed of such coupled-line section only are presented in Figure 3.

![Figure 3](image)


Based on the analysis presented in [8], in this particular design, insertion of LH transmission lines having electrical length \( \theta_0 = 42^\circ \) allows to increase the nominal coupling coefficient of the resulting coupler high as to the level of \( C_{\text{max}} = -2.6 \) dB. Additionally, electrical length of each of coupled-line sections needed to be adjusted to be \( \theta_R = 63.3^\circ \). As it can be seen in Figure 4, utilization of LH transmission lines allows to obtain significantly tighter coupling of the resulting coupler, than the coupling of the used coupled-line sections.

![Figure 4](image)

Figure 4. Ideal element calculated S-parameters of the coupling enhanced directional coupler with inserted LH transmission lines: \( \theta_0 = 42^\circ, C_a = -2.6 \) dB. Brown – transmission, pink – coupling, blue – match, red – isolation.

### III. EXPERIMENTAL RESULTS

To experimentally verify the presented in Section II theoretical analysis, the proposed coupled-line directional coupler has been designed in identical dielectric structure. Layout of final circuit has been presented in Figure 5. As seen, the circuit features fully planar realization and does not require any vias to the ground, which makes the manufacturing process easy. The proposed bandpass structure approximating LH line properties has been realized as interdigital structure integrating required capacitive and inductive elements. Geometry of the structure has been empirically selected in an iterative process. The designed coupling enhanced directional coupler has been electromagnetically analyzed using AWR Microwave Office software. Obtained frequency characteristics of the coupler have been shown in Figure 6. As it can be seen, directional coupler feature satisfactory performance in terms of output phase difference, input match as well as obtained coupling level being overcoupled than 3-dB. The bandwidth of the directional coupler has been slightly decreased due to the physical realization of LH transmission lines approximation – single subsection realized using integrated quasi-lumped LC elements [10].

![Figure 5](image)

Figure 5. Layout of the designed directional coupler featuring higher nominal coupling coefficient than the one of the utilized coupled-line.

![Figure 6](image)

Figure 6. S-parameters and phase difference between coupled and transmitted ports of the designed coupling enhanced directional coupler – result of EM calculations. Brown – transmission, pink – coupling, blue – match, red – isolation.

### IV. CONCLUSION

An approach to the design of fully planar 3-dB directional coupler realized using microstrip technique has been proposed. Previously reported coupling enhancement technique has been employed and novel realization of via-less high-pass structure approximating left-handed properties has been presented. Theoretically predicted performance has been experimentally verified by means of exemplary circuit design and electromagnetic analysis. The
obtained results proved the performance of the proposed approach.

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REFERENCES


