New High-Directivity Coupler Design With Coupled Spurlines

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Abstract—A new high-directivity coupler using coupled spurlines is proposed. The effective capacitances of coupled spurlines generate an isolation zero at any desired frequency due to their equalization effect on the odd-mode and even-mode phase velocities. The measurement results demonstrate an improved performance over the conventional parallel-line coupler in terms of the isolation and the coupling flatness.

Index Terms—Microstrip directional coupler, parallel-line coupler, spurline.

I. INTRODUCTION

MICROSTRIP directional couplers with conventional parallel-coupled lines are widely used in baluns, filters, and various microwave integrated circuits. However, their directivity deteriorates with frequency, which is resulted from the difference of the even-mode and odd-mode phase velocities. Various compensation techniques have been reported, which include adding a different dielectric overlay on the top of coupled lines [1] and wiggling the edges of coupled lines [2]. The compensation is also effective by adding reactive lumped elements to the coupled lines. Examples are the insertion of capacitors at the ends or the center of coupled lines [3] and the insertion of inductors between the collinear ports of coupled lines [4]. More than 30-dB improvement of directivity, compared with the uncompensated coupler, was reported. These techniques have drawbacks of either departing away from the planar structure, due to the addition of lump elements, or requiring special fabrication procedures for another dielectric overlay or wiggling the conductor edges.

In this letter, another new type of high-directivity coupler is proposed, which is composed of two coupled spurlines inter-connected with a section of coupled microstrips. The enhancement of the directivity is resulted from the generation of an isolation zero by the coupled spurlines. A spurline coupler was designed and measured to verify the proposed technique.

II. GENERATION OF ISOLATION ZERO BY COUPLED SPURLINES

The schematic of the proposed spurline coupler is shown in Fig. 1(a). This four-port network is reduced to the respective two-port even-mode and odd-mode networks, as shown in Fig. 1(b), by exciting the even-mode and the odd-mode voltage at two collinear ports. These reduced two-port networks include

Fig. 1. Schematic diagram of the proposed spurline coupler, (a) the whole circuit, (b) the reduced two-port circuit ($k = 'e'$ for the even mode and $'o'$ for the odd mode circuit), and (c) the further simplified circuit.

two spurlines inter-connected by a microstrip line, where the spurline is with the coupling coefficient C_{spur} , the electric length θ_{1k} and the characteristic impedance Z_{1k} , and the centre microstrip line is with θ_{2k} and Z_{2k} . The notation $k = 'e'$ denotes for the even-mode network and $'o'$ for the odd-mode network. For further simplification, the spurline is replaced with a section of microstrip line, θ_{1k} and Z_{Ak} , shunted with a capacitor C_k [5]. Then the respective even-mode and odd-mode networks can be represented a cascade of three sections of microstrip lines loaded with the capacitors at both ends, as shown in Fig. 1(c), where

$$C_k = \sqrt{\frac{(1 - C_{\text{spur}})^3}{1 + C_{\text{spur}}}} \frac{1}{\omega Z_{1k}} \quad \text{and} \quad Z_{Ak} = \frac{Z_{1k}}{\sqrt{1 - C_{\text{spur}}^2}}. \quad (1)$$

The loaded capacitor C_k increases the effective unit-length capacitance of the cascaded microstrip line so that the phase velocity is reduced. Since the odd-mode impedance Z_{1o} is

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Fig. 2. (a) Structure in circuit and EM simulations and (b) photograph of the designed spurline coupler.

less than the even-mode impedance Z_{1e} of the spurline, the odd-mode loaded capacitance C_o becomes greater than C_e . Hence the odd-mode phase velocity is slow down to a greater extent compared with that of the even mode. The equalization of the odd-mode and even-mode velocities can be achieved by properly designing the coupling coefficient C_{spur} of the spurlines. When the odd-mode and even-mode velocities are equal, an isolation zero is obtained, which in turn results in infinite directivity. Note that the capacitance C_k in (1) depends on the frequency, its equalization effect is valid over a limited bandwidth around the center frequency once the coupling coefficient of the spurline is designed.

III. SIMULATION AND MEASUREMENT RESULTS

To demonstrate the high performance of the proposed spurline coupler, an example of -10 dB coupler at 2.4 GHz was designed. In order to obtain accurate design, it is crucial to include the layout discontinuities and nonadjacent coupling. Both the circuit simulator (Microwave Office) and the electromagnetic simulator (IE3D) were performed to optimize the performance. The structure considered in simulations and the

Fig. 3. Simulation performance of the spurline coupler and the conventional parallel-line coupler.

Fig. 4. Measurement and EM simulation performance of the spurline coupler.

circuit photograph are shown in Fig. 2, respectively. During the course of performing the circuit and EM simulations, we find that the isolation zero and input/output matches are sensitive to the connecting junction discontinuities of spurlines with main coupler lines. This results in shifting the frequency of the isolation zero or even diminishing the isolation zero. This effect can be compensated by adding a section of microstrip at each ports of symmetrically coupled spurlines ($W_1 = W_2$ and $S_1 = S_2$) or by using asymmetrically coupled spurlines ($W_1 \neq W_2$ and $S_1 \neq S_2$), where the former method was used in this design example. The physical dimensions of the fabricated spurline coupler are $W_1 = W_2 = 0.6$ mm, $S_1 = S_2 = 0.2$ mm, $L_1 = 3.3$ mm, $L_2 = 10.2$ mm, $W_3 = 1.8$ mm, $W_4 = 0.6$ mm, and $L_4 = 6.2$ mm. For comparison, the conventional parallel-line coupler was also made, which has the coupling length $L = 17.4$ mm, the line-width $W = 1.06$ mm, and the spacing $S = 0.13$ mm. Both the circuit sizes are about the same but the proposed spurline coupler has moderate line spacing requirement, which alleviates the fabrication accuracy.

The circuit simulation of the designed spurline coupler from Microwave Office shows that the isolation zero exists at 2.4 GHz, as seen from Fig. 3. This significantly improves the isolation around 2.4 GHz compared with the conventional

parallel coupler. The coupling amplitude of the spurline coupler has flatter response up to 4 GHz, 0.5-GHz wider than the conventional one. Fig. 4 dictates the measurement and EM simulation results. The isolation zero was measured at 2.35 GHz, slightly shifted from the EM simulation. In spite of this frequency shift, the existence of isolation zero enhances the isolation to 47.5 dB, limited by the finite dielectric and conductor losses of the substrate. Good agreement between measurement and simulation is found.

IV. CONCLUSION

A new high-directivity spurline coupler is proposed, which is composed of two coupled spurlines inter-connected with a parallel-coupled line. The equivalent capacitances of the spurlines slow down the odd and even modes to different extents such that their velocities are equalized once the coupling coefficient of the spurlines is properly designed. The simulation and measurement results all confirm the existence of the existence of isolation

zero, which gives a directivity-enhancement around the desired frequency. Flatter coupling response and up to 47.5-dB isolation was achieved compared with the conventional parallel-line coupler. This technique can be applied to multilayer broadside couplers or tight-coupling structures for achievement of high directivity and better output magnitude balance.

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