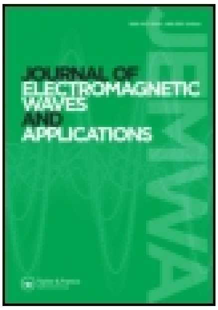

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High directivity DGS-based coupler

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This paper reports a new design of microstrip directional coupler with high directivity. This directional coupler uses corrugated coupled lines and floating conductor in the ground plane of microstrip to enhance coupling. Based on this structure, directional coupler having 4.4% bandwidth has been designed at 4500 MHz with 10 dB coupling and 35 dB directivity. The designed directional coupler has been fabricated and tested for the validity of the design. Measured results are presented in this paper.

Keywords: coupling; directivity; directional coupler; microstrip

1. Introduction

Directional couplers are the key passive microwave components used for distributing or tapping signals in various microwave subsystems such as power amplifiers, detectors, modulators, mixers, phase shifters, and antenna arrays for the use in communication systems. Printed edge-coupled line directional couplers are well known and require a close spacing (less than 100 μ) to achieve the tight coupling. This poses a constraint in the fabrication using the printed circuit board (PCB) technologies, and hence, limits the applications of these couplers.

On the other hand, directional couplers with high directivity are often needed in many communication systems.[1] Achieving directivity of better than 20 dB is difficult in conventional coupled line directional couplers. There are several ways reported in literature to achieve high directivity and tight coupling in coupled line couplers.[2–6] In [2], re-entrant mode microstrip coupler is designed for achieving high directivity characteristics. Patterned ground plane structure is used in [3] to design a directional coupler with 3 dB coupling. In [4], high directivity coupler is designed in suspended microstripline medium and the air gap between the substrate and the ground is varied for the equalizations between the even and odd modes to achieve high directivity. Wiggly coupled lines or corrugated coupled lines are used in the construction of directional coupler for phase velocity equalization in [5] for achieving high directivity. A capacitive compensation technique is applied with coupled lines in [6] to increase the directivity level. This capacitive loading is done at the bends of the coupled line edges.

Design of a directional coupler with high directivity is a challenging problem. Hence, this paper proposes a new structure to achieve high directivity with enhanced

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coupling characteristics in coupler configuration. Section 2 describes the construction of high directivity directional coupler using wiggly coupled lines and floating conductor in the ground plane. Simulation results are presented for the validation of the design. Experimental results of the designed coupler are reported in Section 3. Section 4 concludes the present paper.

2. Design of high directivity directional coupler

The popular symmetric directional coupler configuration using edge coupled line structure is shown in Figure 1. One-quarter wave transmission line is adjacent to another transmission line at a spacing "*s*". The spacing "*s*" between the parallel coupled lines will be a critical issue in achieving tight coupling between the arms. This limits this standard structure for the application where tight coupling is essential.

Coupler is analyzed based on the even and odd mode propagation characteristics of the parallel coupled lines. The coupling factor is related to even and odd mode impedances of the coupled lines using [1]

$$K = \frac{Z_{oe} - Z_{oo}}{Z_{oe} + Z_{oo}} \tag{1}$$

where Z_{oe} and Z_{oo} are the characteristic impedances for the even and odd modes respectively for the parallel coupled lines. The coupling factor 'K' for 10 dB coupling is 0.32 and the required spacing "*s*" is 90 µ for the structural parameters listed in Table 1.

For the structural parameters listed in Table 1, the isolation is 20 dB for the conventional 10 dB coupler. Hence the structure shown in Figure 2 has been proposed in this paper to achieve coupling of 10 dB and high directivity better than 35 dB. The proposed directional coupler uses wiggly coupled lines along with the floating conductor in the ground. Dimensions of the wiggly coupled lines are shown in Figure 3. The wiggly lines improve the directivity characteristics of the coupler, whereas the floating conductor in the ground plane increases the coupling between the lines. The coupler structure is simulated using the IE3D from mentor graphics.[7] Rigorous optimization was carried out to achieve the required coupling and isolation.

Directional coupler is designed for the frequency band of 4400–4600 MHz. Figure 4 shows the simulation characteristics of the proposed directional coupler along with the conventional coupler. For the proposed coupler, the isolation is better than 45 dB over the band of operation, whereas the conventional coupler offers only 20 dB isolation over the band. The spacing "*s*" for the conventional coupler 90 µ which may be difficult to fabricate. The dimensions of the proposed high directivity 10 dB coupler are

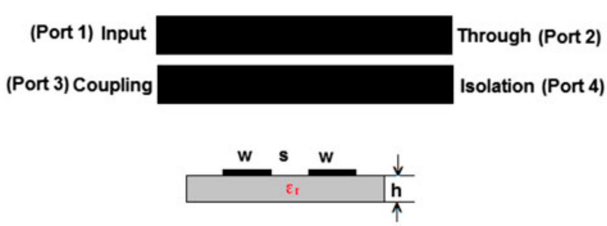

Figure 1. Conventional directional coupler.

Table 1. Microstrip structural parameters.

Substrate thickness "h"	0.8 mm
Substrate permittivity "ε_r"	4.4
Loss tangent	0.002
Line width "w"	1.6 mm (50 Ω)

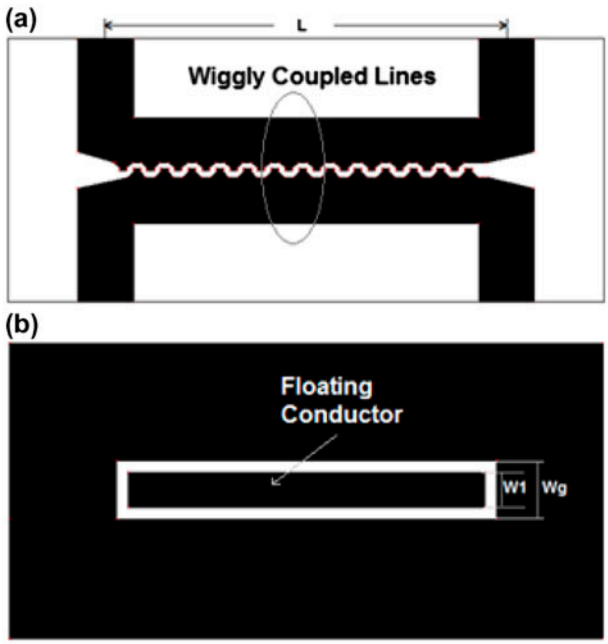

Figure 2. The proposed high directivity coupler. (a) Top layer, (b) bottom layer.

listed in Table 2. The length of the coupled lines is quarter wavelength at the center frequency of operation (1500 MHz) and the corresponding physical length is 11.6 mm.

Figure 5 shows the simulation results of high directivity coupler without floating ground conductor. Results show that the coupling for this coupler is 15 dB and isolation is 25 dB. It can be observed in the proposed coupler that the floating conductor in the ground has improved the coupling to 10 dB and the isolation to 45 dB. This improvement in coupling is due to the increase in the even mode characteristic impedance due to the additional series capacitance between the coupled lines and newly introduced floating conductor.

Table 3 compares the performances of the proposed directional coupler against the couplers published in open literature.[8,9] This comparison clearly shows that the proposed directional coupler offers higher performance in terms of coupling and directivity.

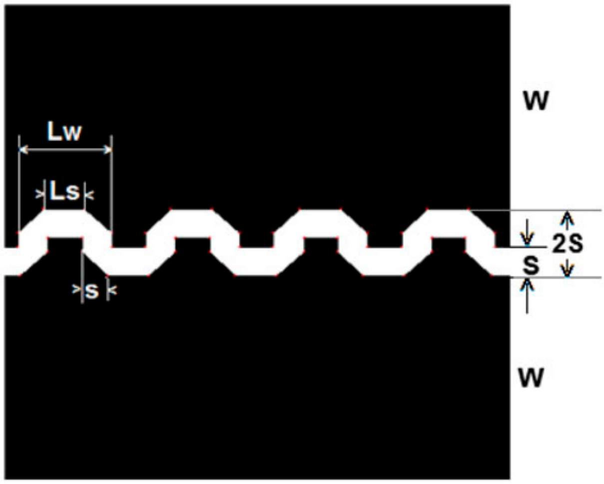

Figure 3. Dimensions of wiggly structure (top layer).

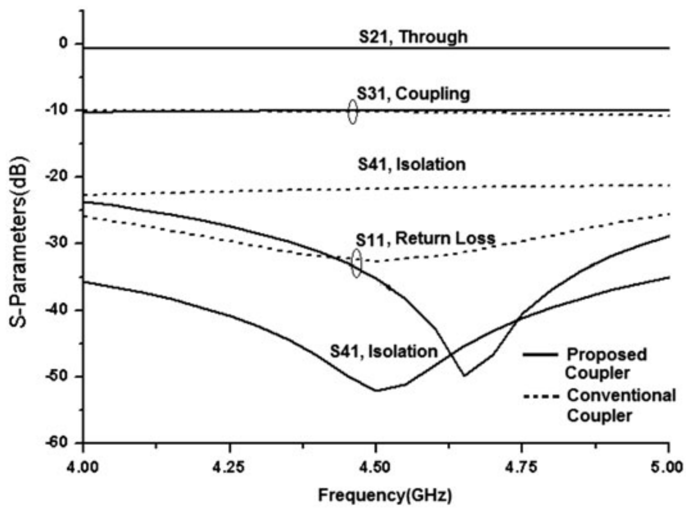

Figure 4. Simulation results of the proposed coupler.

Table 2. Dimensions of high directivity coupler.

Line width "*w*"	1.6 mm (50 Ω)
Spacing "*s*"	200 µ
Width "W_g"	1.7 mm
Width "W_1"	1 mm
Length "*L*"	11.6 mm
Length "Lw"	0.6 mm
Length "Ls"	0.25 mm

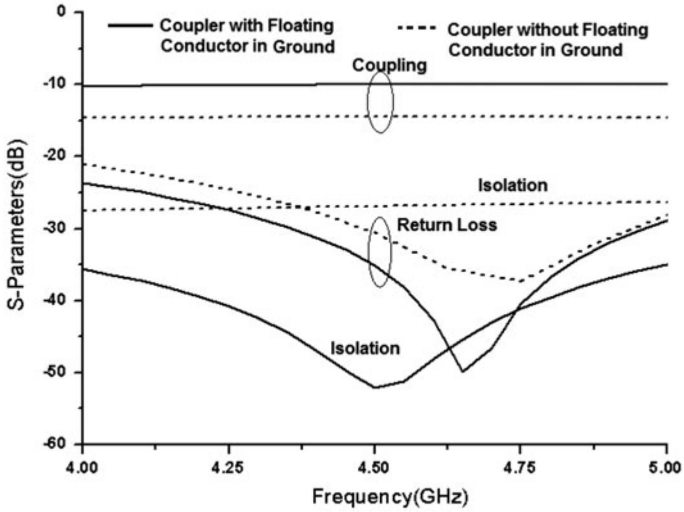

Figure 5. Simulation performance of proposed coupler with and without floating conductor in the ground.

Table 3. Comparison of similar directional couplers.

Directional coupler	Spacing "*s*" (μm)	Coupling (dB)	Isolation (dB)
Proposed coupler	*200*	*10*	*45*
Conventional coupler	90	10	20
Coupler without floating conductor in ground	200	15	25
Coupler proposed in [8]	130	10	37
Coupler proposed in [9]	Not specified	10	40

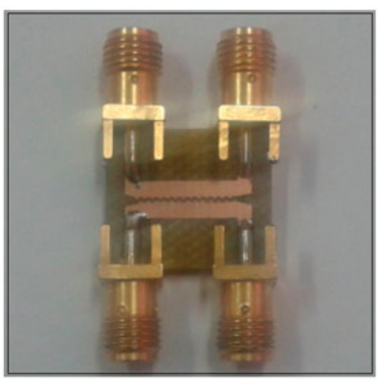

Figure 6. Assembled high directivity coupler.

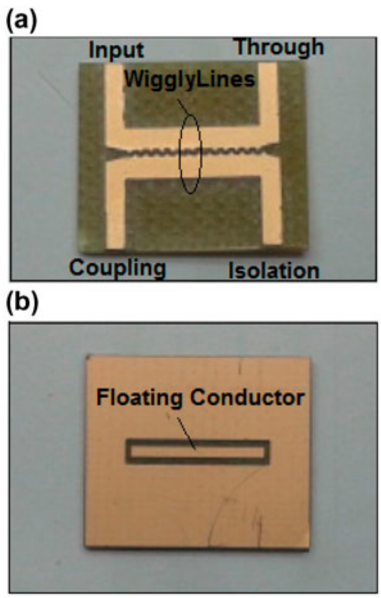

Figure 7. Layers of coupler. (a) Top, (b) bottom.

3. Experimental results

An experimental coupler has been fabricated using standard PCB fabrication technique. Photograph in Figure 6 shows the experimental high directivity 10 dB microstrip coupler with connectors. the top and bottom layers of the proposed high coupler are shown in Figure 7. The wiggly coupled lines are seen in Figure 7(a). Figure 7(b) shows the floating conductor at the bottom layer. Measured return loss, insertion loss, coupling,

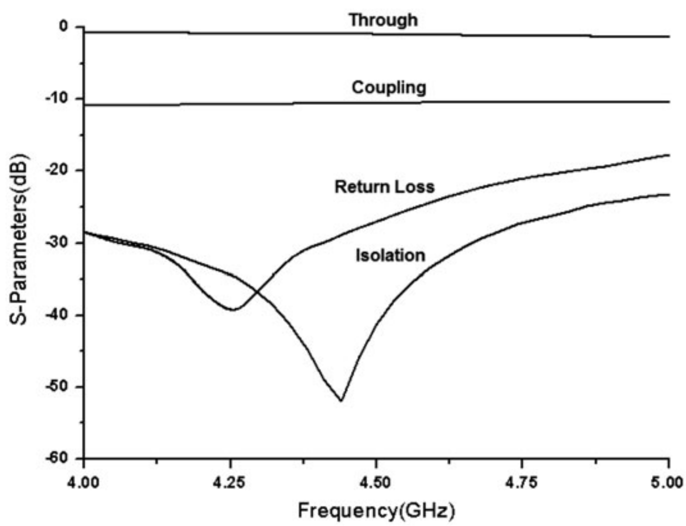

Figure 8. Measured characteristics of high directivity coupler.

and isolation are shown in Figure 8. The achieved coupling is 10.7 ± 0.1 dB. Measured insertion loss is less than 0.7 dB and minimum return loss is 25 dB over 4350–4550 MHz. Experimental results show a better isolation (more than 45 dB) and better directivity (more than 35 dB). There is a frequency shift of 50 MHz. This could be attributed to the tolerances in fabrication.

4. Conclusions

In this paper, a high directivity microstrip directional coupler has been designed and tested. The reported directional coupler is based on the concept of wiggly coupled lines and floating conductor in the ground plane. Floating conductor in the ground has resulted in improvement of coupling. An experimental coupler has been designed, fabricated, and tested to validate the concept.

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