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I-SEEC 2012

Proceeding - Science and Engineering (2013) 187–193

Proceeding
Science and Engineering

www.iseec2012.com

Science and Engineering Symposium
4th International Science, Social Science, Engineering and Energy Conference 2012

A Novel Structure of Microstrip Coupled Bandstop Filter Based on Shorted Step-impedance Transmission Lines

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Abstract

This paper presents a novel structure of microstrip coupled bandstop filter based on shorted step-impedance transmission lines (SITL). The modified coupled lines with SITL have bandstop frequency response , which can used for bandstop filter implementation. To verify the satisfication between theory and experiment. A 1.8 GHz bandstop filter is fabricated on FR4 substrate. The measurement results show -31.85 dB insertion and – 7.74 dB return loss.

Selection and/or peer-review under responsibility of Faculty of Science and Technology, Kasem Bundit University, Bangkok.

Keywords : Bandstop filter, step-impedance, inductivity element.

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1. Introduction

Quadrature microstrip parallel-coupled lines are widely utilized for many wireless and microwave circuits such as Marchand balun, filters, resonators and various microwave integrated circuits because they can easily be incorporated into and implemented with other circuits [1],[2]. However, many unwanted effects in those circuits are already mentioned and unavoidably, which is resulted from the inhomogeneous dielectric of the substrate. Through this structure, phase velocity of the even-mode in microstrip parallel-coupled lines is slightly lower than the odd-mode phase velocity. Which in turn lead the parallel-coupled lines exhibits poor directivity. Through having various disadvantages, parallel-coupled lines is still preferable in microwave circuits design due to its integrating capability. Many techniques have been developed to compensate the inequality of modes phase velocities of the parallel couplers. These techniques can be classified into two main categories, which are lumped and distributed compensation approaches.

The lumped compensation techniques can be categorized into two well known techniques, which are capacitive [5],[6] and inductive [7],[8] compensation techniques. The distinct advantage of the lumped compensation technique is its simple design procedure because the closed-form design equations can be derived.

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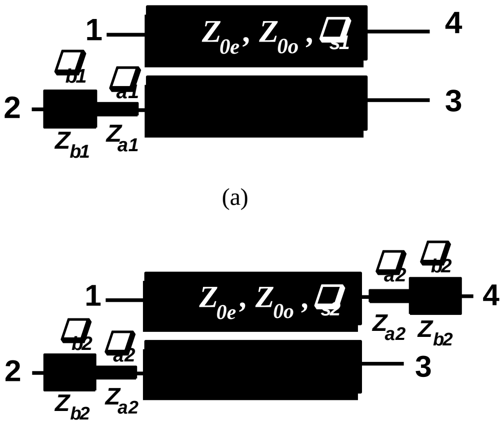
But, the important disadvantages of the techniques are from the lumped components' parasitic and difficulty in layout [9].



(a)

(b)

Fig.1. Schematic of the proposed a) singly- and b) doubly step-impedance transmission line compensated parallel-coupled lines

As the coupler sizes' is considered, the lumped compensated parallel-coupled lines is about the uncompensated parallel-coupled lines, since the length compensated parallel-coupled lines is shorter than that of the uncompensated coupled lines. The methodology based on the distributed techniques is to modify either the parallel-coupled line structures [1],[2] ,dielectric layer [3], or ground plane patterns [4], such that the phase velocities of both modes are equalized. No external components or extra spaces are needed for this approach. The main disadvantage of this approach is lack of closed-form design equations, meaning that the design task relies heavily on the electromagnetic simulation (EM) stage which in turn consumes much effort and computing time. Moreover, techniques based on these approaches are often not suitable for some standard fabrication processes, thus more cost demand is unavoidably required.

Here we present a simple all microstrip step-impedance transmission line compensation technique to improve the directivity of parallel-coupled lines. Section II presents the idea of the singly- and doubly-step impedance resonators compensated parallel-coupled lines. The technique can be achieved high-directivity by connecting the SIRs in series with coupled and through ports of the parallel-coupled lines. Simulated and measured results of the proposed compensation couplers will be illustrated in Section III. The paper is finally concluded in Section IV.

2. The Proposed Techniques

The fundamental concept in this technique is to achieve high-isolation performance by the generation of isolation zero ($S_{13} = 0$) between input and isolated ports of the parallel-coupled lines, which in turn results in a high directivity performance of the coupler. As the previous inductive compensation techniques [8],[9], which involves connecting external single or multiple inductive components series with the coupler's ports. The techniques in this paper are achieved by applying step impedance transmission line to enhance the directivity and isolation of microstrip parallel-coupled lines. The proposed techniques are then, so called singly- and doubly-step impedance transmission line compensation technique.

A. Step Impedance Resonator

Generally, step impedance resonators (SIR) is a non-uniform transmission line, which were used in the filter design so as to reduce the circuit sizes [15], to push the spurious passband to the higher frequency, and even to suppress the multiple spurious passband [16]. The step impedance resonator employed in this paper was shown in Fig. 2, it is made of two transmission line sections with two different characteristic impedances Z_a and Z_b with corresponding electrical lengths θ_1 and θ_2, respectively. The input impedances looking in to section *b*, $Z_{in}(b)$ with load $Z_L = \infty$ terminated at one end and the input impedance looking in to section *a*, $Z_{in}(a)$ with load impedance $Z_L = Z_{in}(b)$ can be written as

$$Z_{in}(b) = -jZ_b \frac{1}{\tan\theta_b} \tag{1}$$

$$Z_{in}(a) = jZ_a \frac{(Z_a \sin\theta_a \sin\theta_b - Z_b \cos\theta_a \cos\theta_b)}{(Z_a \sin\theta_b \cos\theta_a + Z_b \sin\theta_a \cos\theta_b)} \tag{2}$$

In the technique, $Z_a > Z_b$, so the impedance ratio $R_z = Z_b / Z_a$ is align between $0 \le R_z \le 1$. The parameters Z_a, Z_b and θ_1, θ_2 should be selected to control transmission coefficient S_{21} satisfied the condition $S_{21}(2f_0) = 0$.

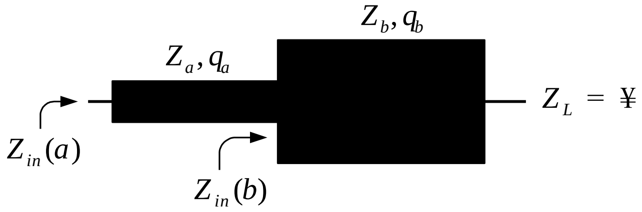


Fig.2. Schematic of the employed two-sections step impedance resonator (SIR)

B .Singly-Step Impedance Resonator Compensated Coupler

In this technique, one section of SIR is series connected at coupled port of parallel-coupled lines as shown in Fig. 1 (a). The isolation coefficient (S_{31}), in term of coupler electrical parameters (Z_0, Z_{0e}, Z_{0o}, ε_{effe}, ε_{effo}), is obtained by terminating port 2, 3, and 4 with the characteristic impedances of the lines Z_0, while port 2 is terminated with voltage source with the output impedance Z_0. The optimum directivity (about 20 dB) at center frequency f_0 is occurred when the signal transmission of port 1 and 3 is enforced to be nearly zero or $S_{31}(f_0) \approx 0$, which will occurred as the input impedance of singly SIR section $Z_{in}(a)$ is also enforced to be

$$\begin{aligned} Z_{ST1}(f_0) &= -\frac{j\left(Z_{0o}^2 Z_{0e} \sin\theta_0 - Z_{0e}^2 Z_{0o} \sin\theta_e\right) + 2Z_0 Z_b + Z_0 Z_a}{Z_a + Z_b} \\ &= Z_{in}(a) \end{aligned} \tag{3}$$

Where $Z_a = jZ_0(\sin\theta_0 - \sin\theta_e)$ and $Z_b = Z_0^2(\cos\theta_0 - \cos\theta_e)$, $Z_{ST1}(f_0)$ is the singly-series compensation impedance which related to parallel-coupled lines' electrical parameters and $\theta_e = \pi/2$ is the even-mode electrical length of the coupled lines, $\theta_o = (\pi/2)\Theta =$ is the odd-mode electrical length of the coupled lines and $\Theta = \sqrt{\varepsilon_{effo}/\varepsilon_{effe}}$.

C. Doubly-Step Impedance Resonator Compensated Coupler

In this technique, two sections of SIR are series connected at coupled and through ports of parallel-coupled lines as shown in Fig. 1 (b). The isolation coefficient (S_{31}), in term of coupler electrical parameters can be derived as the mentioned singly-compensation technique. The maximum directivity (more than 30 dB) at center frequency f_0 is occurred when the signal transmission of port 1 and 3 is null or $S_{31}(f) = 0$, its will occurred as the input impedance of doubly SIR sections $Z_{in}(a)$ are enforced to be

$$\begin{aligned} Z_{ST2}(f_0) &= \frac{j\left(Z_{0e}^2 Z_{0o}\sin\theta_e - Z_{0o}^2 Z_{0e}\sin\theta_0\right) - Z_0^2 Z_a - 2Z_0 Z_b}{Z_b + Z_0 Z_a} \\ &= Z_{in}(a) \end{aligned} \tag{4}$$

Where $Z_{ST2}(f_0)$ are the doubly-series compensation impedances that related to parallel-coupled lines' electrical parameters.

3. Design and Experimental Results

To validate the performance of developed techniques the design examples of 10-dB uncompensated and the proposed singly- and doubly- step impedance resonator compensated parallel-coupled lines deigned at f_0 of 0.9 GHz on RF60 substrate $(\varepsilon_r = 6.0,\ h = 1.52$ mm, and $\tan\delta = 0.002)$ were designed and fabricated. In the design, the experiment The SIR sections in both techniques were designed by using $Z_a = 100\ \Omega$ and $Z_b = 70\ \Omega$, while θ_a and θ_b were achieved by optimization. The design parameters of prototype of uncompensated and the proposed couplers corresponded to equations (3), (4) were listed in Table I. The simulated results of uncompensated and the both proposed couplers were shown in Fig. 3 (a) and (b). The EM simulator Sonnet-Lite™ is used to simulate the couplers and meander lines inductors behavior. Fig. 4 shows EM simulated results of the proposed coupler. An excellent directivity and isolation improvement can be obviously observed.

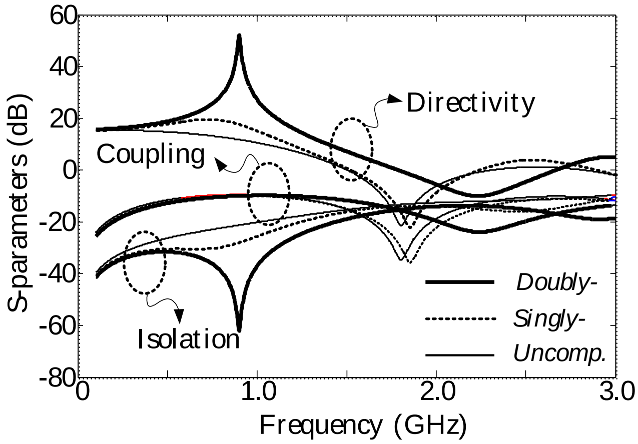


Fig. 3. Simulated results of uncompensated (……..) the singly (——) and doubly-(———) SIR compensated coupler

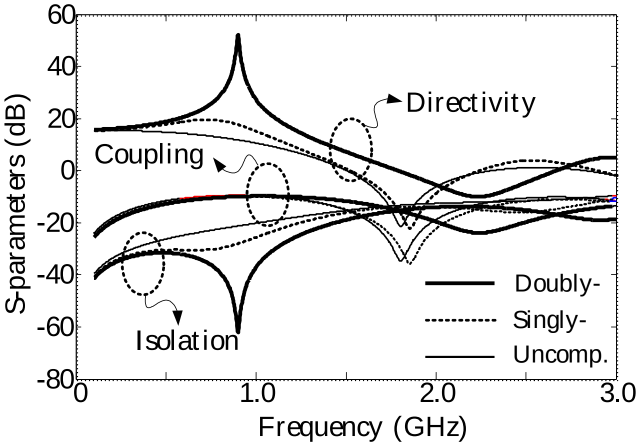


Fig. 4. EM simulated results of uncompensated (……..) the singly (——) and doubly-(———) SIR compensated coupler

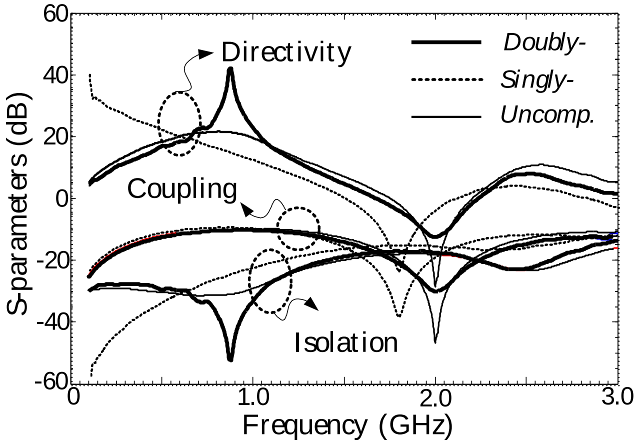
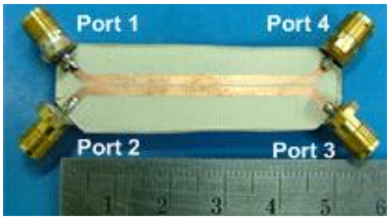
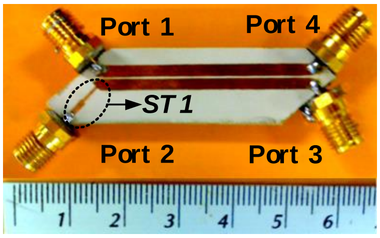


Fig. 5. Measured results of uncompensated (……..) the singly (——) and doubly-(———) SIR compensated coupler.

The EM simulated directivity and isolation at frequency f_0 are more than 43 dB and 50 dB, which is more than 25 dB improvement compare to the uncompensated coupler. In this work, all measurement is done by HP8753E vector network analyzer calibrated from 0.1 to 3.0 GHz. The HPVEE6.0™ software was used to collect the experimental data via GPIB card. Sonnet-Lite™ and Matlab® were used for simulation, data processing, and display.



(a)



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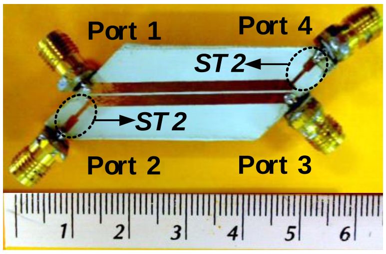

(c)

Fig. 6. PCB photographs of (a) uncompensated, (b) the singly- and (c) the doubly-SIR compensated couplers

The measured results of the proposed compensated singly- and doubly- SIR compensated compared with uncompensated couplers in Fig. 5. The directivity and isolation performances from the singly- and doubly-compensated techniques are 6 dB and 12 dB better, respectively, than those of the uncompensated coupled lines from 0.8 GHz to 1.0 GHz. At the f_0 of 0.9 GHz, the doubly-compensated design provides isolation and directivity performance approximately 25 dB better than the uncompensated coupled lines, while the singly-compensated design achieves around 7dB improvement. The photograph of uncompensated and the both singly- and doubly-SIR compensated couplers are shown in Fig. 6.

4. Conclusions

A singly-and doubly step impedance resonator compensated techniques are proposed to enhance the directivity of microstrip parallel-coupled lines. The techniques are very simple to design and fabricated, since its all microstrip structures, over 6 dB and 30 dB directivities enhancement for both proposed couplers as inductively-compensated techniques are achieved in our experiments. However, the complete closed form design equations will be developed in the future to simplify the design procedures. The proposed couplers are suitable to use in many wireless and microwave applications.

Acknowledgements

The authors are grateful to acknowledge Prof. Dr. Wolfgang Menzel and Prof. Dr. Da Gang Fang for their usefulness suggestions about the ideas of this work and include Taconic Inc., to support RF60-0600 and RF35-0600 microwave substrates.

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Appendix A.

Table I Parameters of The Previous Works

Techniques	Lumped Components	Coupler's Length (θ,rad)	W,S,L (mm)
Uncomp.	-	0.50π	1.76, 0.38, 40.0
Singly-Inductive	L_s = 2.38 Nh	0.43π	1.76, 0.38, 35.0
Doubly-Inductive	L_d = 2.51 nH	0.46π	1.76, 0.38, 35.0
Dydyk-Capacitive	C_D = 0.447 pF	0.50π	1.76, 0.38, 40.0
March-Capacitive	C_M = 0.454 pF	0.45π	1.76, 0.38, 35.0