*Progress In Electromagnetics Research M, Vol. 3, 205–215, 2008*

# IMPROVEMENT THE CHARACTERISTICS OF THE MICROSTRIP PARALLEL COUPLED LINE COUPLER BY MEANS OF GROOVED SUBSTRATE

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**Abstract**—An effective method for improving the characteristics of the microstrip parallel coupled line coupler is proposed. Some grooves are oriented parallel to the strips and just next to them. It can be shown that an appropriate depth of the grooves can be used for equalizing the even- and odd-mode phase velocity in a coupled microstrip lines with proper geometrical dimensions. Sets of design graphs are derived for various depths of grooves as a parameter and with curves that implies phase velocity equalization curves. The simulated scattering parameters for couplers in conventional and proposed topology show the efficacy of the new grooved substrates.

## 1. INTRODUCTION

Directional couplers are key components in many RF applications [1–10]. Among various coupler configurations, The Microstrip parallel coupled-line coupler is widely used from microwave circuits due to its simple configuration and ease of fabrication. Its analytical development and design procedures for Butterworth and Chebyshev models are described in several references [11–14]. However, despite the aforementioned advantages, it suffers from their limited directivity and isolation. This shortcoming is related to the inhomogeneous dielectric medium surrounding the microstrip conductors, which causes the odd-mode wave to propagate faster than the even-mode wave in the coupled microstrip lines [11].

Various methods have been proposed in the literature to improve the directivity and isolation of the microstrip parallel coupled-line coupler. Dielectric overlay is proposed to decrease the odd-mode phase velocity of the microstrip coupled-line to compensate for the difference in phase velocities [15].

In Another approach, wiggly line has been proposed to compensate the phase velocity difference and improve performance of the microstrip coupled-line coupler [16].

In another technique, lumped capacitances are added at the ends of the microstrip coupled-line coupler to increase the electrical length of the odd-mode at the design frequency [17]. However, the capacitors values are restricted by the modal phase velocity difference.

Another attempt tries to compensate the difference in phase velocities by introducing ground-plane aperture to the ground plane of the coupler [18].

In this paper we propose a new method to improve the directivity of the microstrip coupled-line coupler using grooved substrate. The proposed method is straightforward and the coupler configuration is simple for fabrication and application. The grooves are cut along the outer edge of each coupled-line of the conventional filter. It is shown that for a strip width and gap spacing of coupled stages, there is a unique value of groove depth that makes the even- and odd-mode phase velocities equal.

Designing graphs are derived at the center frequency for various groove depths and the even- and odd-mode equal phase velocity curves are added to them. In the next step, the designer should try to choose the even- and odd-mode characteristic impedances of the coupler as close as possible to the equal phase velocity curves. It could be done by choosing appropriate impedances for output ports of the coupler. Finally, a 15 dB coupler is designed and simulated on the grooved substrate. The simulated results show a good improvement in the performance of the coupler.

## 2. PROPOSED STRUCTURE

Figure 1 shows the microstrip parallel coupled-line coupler together with its various parameters. The geometry of coupled microstrip lines including the field distributions for even- and odd-mode is shown in Fig. 1. As the figure shows, the even- and odd-mode phase velocities are different for coupled microstrip lines due to their different field configuration in the vicinity of air-dielectric interface. The energy of electric and magnetic fields for odd-mode are more concentrated between the strips in both air and dielectric region, while for the even-mode they are more concentrated in the dielectric region.

By cutting two grooves just next to and in parallel with the microstrip lines, the amount of energy for the even-mode in the air

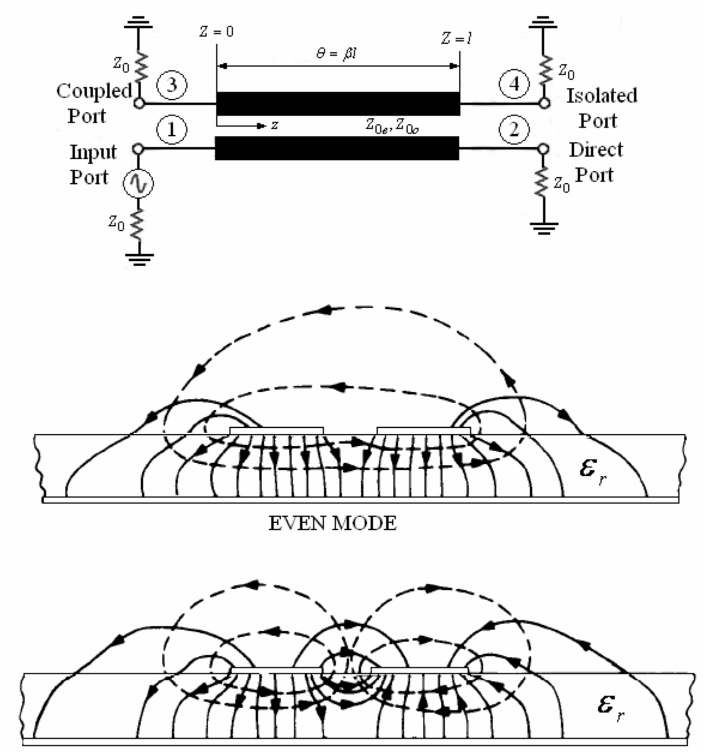


**Figure 1.** Microstrip parallel coupled-line coupler and its field distribution for even- and odd-mode.

region is increased, while for the odd-mode it is maintained almost unchanged. As the depth of the grooves is increased the amount of energy for the even-mode in the air region is also increased and the modal phase velocity difference is decreased. So, it can be possible to equalize the modal phase velocity by choosing appropriate values for grooves depth and width. However, phase equalization is restricted due to small amount of the fringing energy.

Figure 2 shows the proposed modified microstrip parallel-coupled lines. As it is shown, the grooves are the only difference between the proposed and the conventional coupled lines. The depth of the grooves is limited from zero to the substrate thickness. However, the realizable depth is also limited by board tolerable strength.

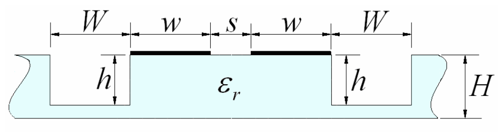


**Figure 2.** Cross sections of the proposed parallel-coupled lines.

## 3. COUPLER DESIGN

In order to design a coupler with center frequency equal to 1 GHz and on a grooved substrate, it is necessary to derive some design graphs which relate the modal characteristic impedances $Z_{oe}$ and $Z_{0o}$ to the strips width and gap spacing. The designed graphs are derived using HFSS and for an FR4 board with a thickness of 1.57 mm and dielectric constant equal to 4.4 and at $f = 1\,\text{GHz}$.

The main question in this step was the proper value of the groove depths. Since the variation of the modal characteristic impedances versus the groove depths are not too rapid, so five appropriate values for the groove depths have been chosen. The selected values for the depths of the grooves are equal to 0.25, 0.5, 0.75, 1.0 and 1.25 mm. The groove width $(W)$ is selected equal to 2 mm. Unfortunately, for the groove depth equal to 0.25 mm, as the normalized strips width and gap spacing vary from 0.1 up to 2, no modal phase velocity equalization point occurs. So, the design graph corresponding to this value is no longer considered.

The design graphs corresponding to the groove depths equal to 0.5, 0.75, 1.0 and 1.25 mm are shown in Fig. 3 to Fig. 6, respectively. The strip conductor thickness has been assumed equal to zero. It is essential to have equal modal phase velocity at the center frequency, so the phase velocity equalization curves are derived at $f = 1\,\text{GHz}$. The phase velocity equalization curves are shown by the doted line in the design graphs.

Parallel coupled-line coupler can be designed by employing following simple analytical design equation [1–4].

$$\begin{cases} Z_{0e} = Z_0\sqrt{\dfrac{1+k}{1-k}} \\[2ex] Z_{0o} = Z_0\sqrt{\dfrac{1-k}{1+k}} \end{cases} \tag{1}$$

where $Z_{0e}$ and $Z_{0o}$ indicate the even- and odd-mode characteristic impedances of the conventional coupled line, respectively, $Z_0$ denotes

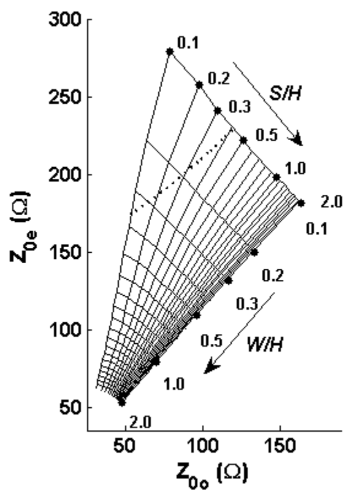


**Figure 3.** Even-and odd-mode design graph for grooved substrate coupled lines with grooves depth equal to 0.5 mm.

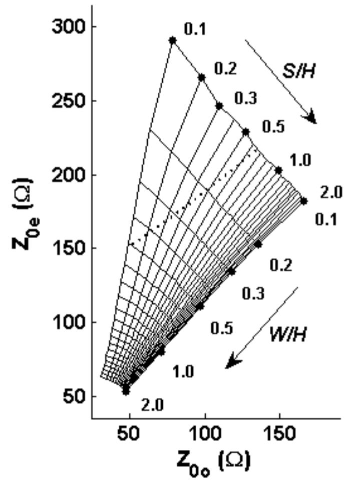


**Figure 4.** Even-and odd-mode design graph for grooved substrate coupled lines with grooves depth equal to 0.75 mm.

the output port impedances of the coupled-line, and $k$ is the midband voltage coupling coefficient which can be expressed as

$$k = 10^{-\frac{C}{20}} \tag{2}$$

where, $C$ denotes the coupling factor of the coupler. In order to design a coupler with improved directivity, the modal characteristic impedances of the designed coupler must be selected as close as possible to the phase velocity equalization curves. As indicated from Equation (1), for constant coupling, this could be done just by selecting appropriate value for system impedance $Z_0$.

On the other hand, we have only one degree of freedom to place the coupler modal characteristic impedances as close as possible to the phase velocity equalization curves. Finally, the system impedance of the coupler could be converted to 50 ohm using some quarter wave transformer at each output port of the coupler.

To demonstrate the performance of the proposed technique, a 15 dB single-section coupler is designed. The coupler has been designed for all four different groove depth of using Figs. 3 to 6 and therefore, four different couplers with different dimension and almost the same frequency response were achieved. However, the later one with grooves

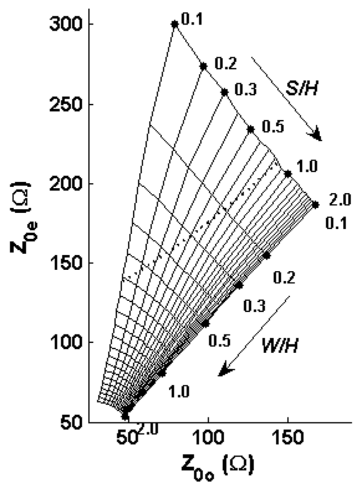


**Figure 5.** Even-and odd-mode design graph for grooved substrate coupled lines with grooves depth equal to 1.0 mm.

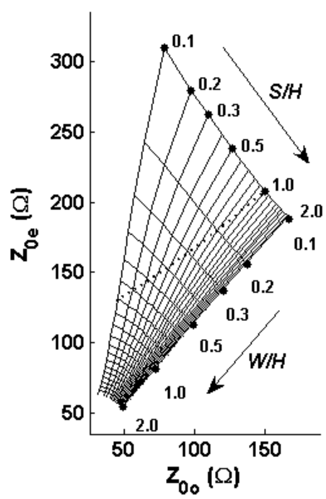


**Figure 6.** Even-and odd-mode design graph for grooved substrate coupled lines with grooves depth equal to 1.25 mm.

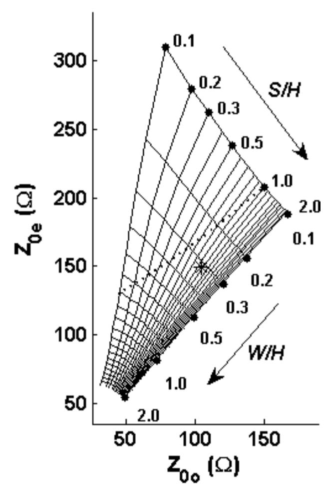


**Figure 7.** Locations of the modal characteristic impedances of the designed coupler on even-and odd-mode design graph related to the grooves depth equal to 1.25 mm.

depth equal to 1.25 mm had the easiest dimensions to realize. Fig. 7 shows the designed graph related to the designed coupler including the location of the even- and odd-mode characteristic the location of the even- and odd-mode characteristic impedances indicated by pentagrams which is corresponding to the system impedance equal to 125 ohm.

As indicated from Fig. 7, the even- and odd-mode characteristic impedances for the designed are equal to 149.6 and 104.4 ohm, respectively. The designed coupler dimensions on the grooved substrate are shown in Table 1. Selecting larger system impedances for the coupler lead to modal characteristic impedances closer to the phase velocity equalization curve and undoubtedly better coupler performance, but this improvement is at the price of inappropriate coupler geometrical dimensions.

**Table 1.** Proposed coupler dimensions.

| | |
|---|---|
| **Coupled-line length:** | 48 mm |
| **Coupled-line widths:** | 0.56 mm |
| **Gap width:** | 1.52 mm |
| **Groove widths:** | 2 mm |
| **Impedance inverter length:** | 42.6 mm |
| **Impedance inverter width:** | 1.25 mm |

For comparison reasons a conventional microstrip parallel coupled-line coupler with the same specifications on the same substrate has been also designed. The dimensions are also included in Table 2. The length of the conventional coupler is a little shorter than the length of the proposed designed coupler. It is due to the effect of grooves in reducing the even- and odd-mode effective dielectric constant.

**Table 2.** Conventional coupler dimensions.

| | |
|---|---|
| **Coupled-line length:** | 41.2 mm |
| **Coupled-line widths:** | 2.9 mm |
| **Gap width:** | 1.0 mm |

The designed couplers have been simulated using HFSS. The simulated scattering parameters of the conventional and the proposed

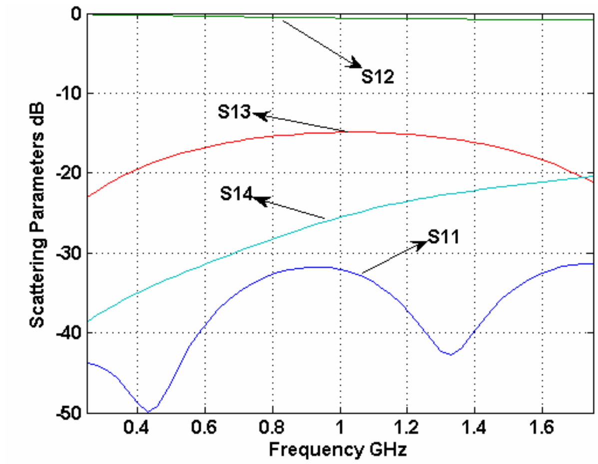


**Figure 8.** Simulated performance of the conventional coupler.

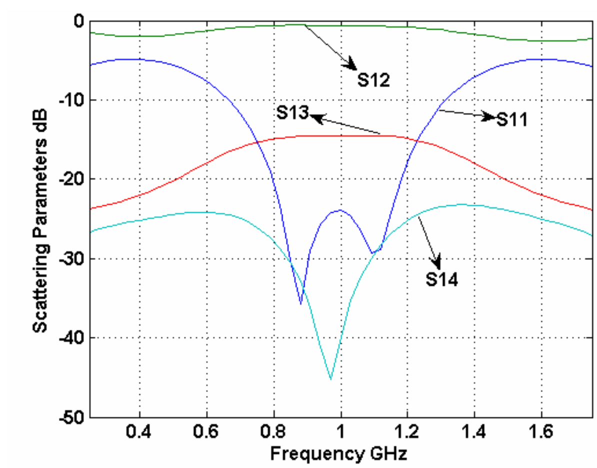


**Figure 9.** Simulated performance of the proposed coupler.

coupler are presented in Fig. 8 and Fig. 9, respectively. Comparison of the figures shows a good improvement in proposed coupler performance. The Geometry of the proposed coupler is shown in Fig. 10. For better comparison, the directivity variations of the conventional and proposed couplers are also shown in Fig. 11. As it is seen, the directivity of the coupler is better than 15 dB in 25% bandwidth which indicates the effectiveness of the proposed coupler and design procedure.

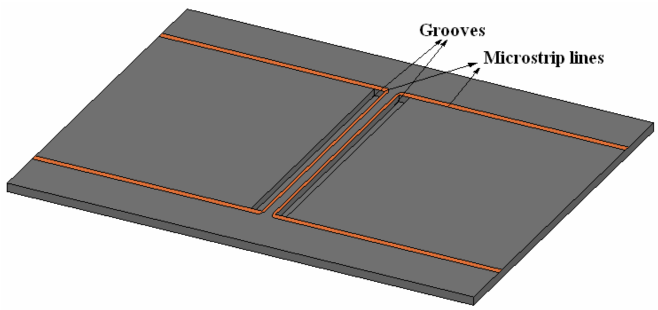


**Figure 10.** Geometry of the proposed coupler.

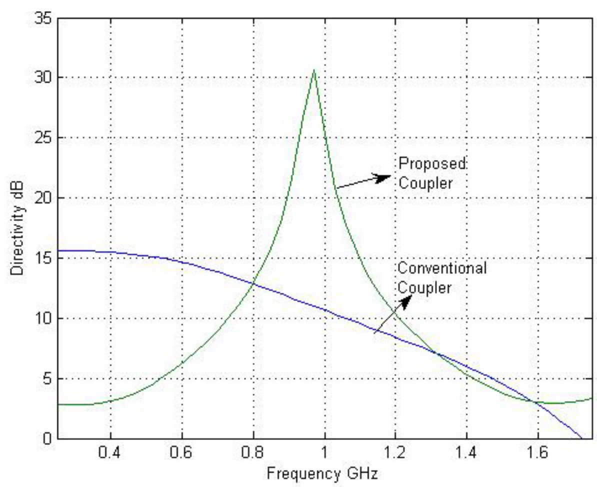


**Figure 11.** Directivity variation of the conventional and proposed coupler.

## 4. CONCLUSIONS

A novel and effective structure has been proposed to improve the directivity of microstrip parallel coupled-line couplers. It could be easily implemented by cutting two grooves with proper width and depth along the microstrip coupled lines and just beside to them. The design process has been explained and the required design graphs have been derived for an example. It has been shown that different designs could be achieved by selecting different groove depth. The coupler design has been conducted by placing the modal characteristic impedances of the coupler as close as possible to the phase velocity equalization curves. Finally, a typical 15 dB coupler was designed by the proposed technique. The simulated results show the usefulness of the proposed coupler structure and the effectiveness of the design technique has been confirmed.

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