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A New Method to Improve Directivity Bandwidth of Directional Couplers

Zahra S. Tabatabaeian
Department of Electrical Engineering,
Ferdowsi University of Mashhad,
Mashhad, Iran.
z.taba@yahoo.com

Mohammad H. Neshati
Department of Electrical Engineering,
Ferdowsi University of Mashhad,
Mashhad, Iran.
neshat@um.ac.ir

Abstract— **In this paper a new technique is proposed to improve the directivity and directivity bandwidth of couplers. In this approach, a low pass filter has been inserted before isolation port. It is shown that this technique can improve coupling and coupling bandwidth. To show the performance of this approach, a coupler with small directivity bandwidth is considered. By implementing this technique on the structure, the bandwidth is increased from 0.6 GHz to 3.1 GHz.**

Keywords- low pass filter; directional coupler; directivity; coupling; isolation

I. INTRODUCTION

Microstrip coupled line directional couplers are widely used in microwave systems because of their easy wavy of fabrication, but they suffer from poor directivity especially when permittivity of the substrate is high [1]. In order to overcome this problem, several methods have been proposed using additive lumped elements [2-7], wiggly lines [8], multilayer structure [9], dielectric overlay on top of the coupled lines [10] and using negative refractive index line [11,12].

In this paper, a new method is presented to increase the directivity and directivity bandwidth of a directional coupler. This method is implemented by adding a low pass filter to a conventional coupler with a small directivity bandwidth. It is shown that the directivity bandwidth of the coupler greatly is increased.

II. THEORY OF OPERATION

Backward-wave directional couplers are based on the difference between the even and odd mode characteristic impedances of the applied structure. using inhomogeneous medium, such as microstrip, to realize directional couplers, the effective permittivity and thus the phase velocities of the operating even and odd mode differ. This leads to obtain a poor directivity directional coupler. To improve directivity, a few methods have been proposed. The key point of all these methods is compensation of phase velocity to have equal even and odd mode characteristics.

In the proposed scheme, a structure is added before the isolation port of a directional coupler. The proposed structure is a low pass filter with the stop band at the coupler pass band. So, for a signal with frequency at the stop band of the filter, it doesn't go through the isolation port and in turn reflects from this port. The reflected signal returns back to the coupler. In this case through port becomes coupling port, coupling port becomes through port, and input port becomes isolation port which lead to improve directivity bandwidth and coupling coefficient or through signals are enhanced.

A microstrip epsilon negative directional coupler was proposed in [13], which provides a very small directivity bandwidth. To improve its directivity bandwidth, a low pass filter is inserted close to the directivity port. The proposed directional coupler is shown in Fig 1. The pass band of the coupler is adjusted in the stop band of the added low pass filter.

The structure of the proposed filter is shown in Fig. 2, which is 5th order Chebyshev low pass filter. This is designed based on equations (1) to (3) [14].

$$f(x) = 9.39x^4 - 37.43x^3 + 54.9x^2 - 33x + 7.37 \quad (1)$$

$$l_{k+1} = \left(\frac{150 z_o}{n f(x) \sqrt{\varepsilon_e} Z_{high}} \right) g_{k+1} \quad (2)$$

$$l_k = \left(\frac{150 z_{low}}{n f(x) \sqrt{\varepsilon_{ce}} Z_o} \right) g_k \quad (3)$$

Where x is cutoff frequency (in GHz), l_{k+1} and l_k are the physical length (shown in Fig. 2), ε_{le} and ε_{ce} are the effective dielectric constant of inductive (smaller width) and capacitive (wider width) lines. Z_{high} and Z_{low} are impedances of inductive and capacitive lines respectively, Z_0 is the source and load impedances and g_ks are element values of Chebyshev low pass filter.

In this work, a fifth order Chebyshev response with 0.1 dB ripple and 1.7 GHz cutoff frequency is considered. The proposed structure is numerically investigated on Rogers RO4003 substrate with 3.36 dielectric constant. The thickness of the substrate is 0.813 mm. Dimensions of the proposed filter and coupler are listed in Table I and Table II respectively.

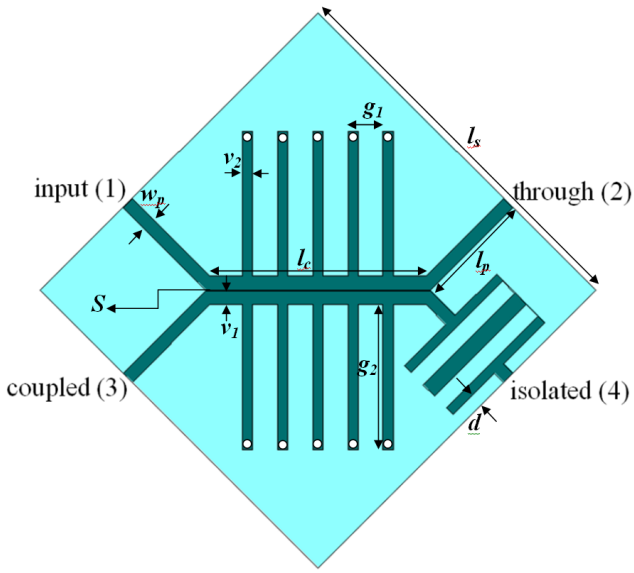

Figure 1. Structure of the proposed directional coupler with a low pass filter

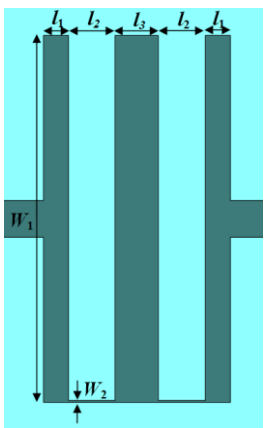

Figure 2. Structure of the appiled low pass filter

Table I. Dimensions of the proposed Chebyshev filter

Parameter	Value (mm)
W_1	20
W_2	0.1
l_1	1.24
l_2	2.88
l_3	2.08

TABLE II. DIMENSIONS OF THE COUPLER

Parameter	Value (mm)
S	0.2
g_1	5.4
g_2	22.3
v_1	2.1
v_2	1.6
l_p	18
w_p	2
Radius of via holes	0.5
l_c	33
l_s	60.4
d	2

III. SIMULATION RESULTS AND DISCUSSION

The proposed low pass filter is numerically studied by High Frequency Simulator Structure (HFSS). Simulated S parameters of the proposed filter are shown in Fig 3. It can be seen from this figure that a sharp response in transition band is obtained.

Also the frequency response of the directional coupler with and without Chebyshev low pass filter was studied. Fig 4 shows reflection coefficient of both couplers. It can be concluded that S_{11} is nearly the same for the two couplers and matching condition is quite good.

Through signal, S_{12} parameter, and isolation between ports, parameter S_{14} are shown in Fig 5 and Fig. 6 respectively. It can be seen that in case of without low pass filter, isolation bandwidth is very small, only 0.6 GHz, for S_{14} less than -25 dB, whereas for the proposed coupler with filter isolation bandwidth is around 3 GHz. Moreover, the coupling bandwidth is better, due to reflection of signal from low pass injected to the coupling port. This is shown in Fig 7 in which variation of S_{13} versus frequency of both coupler structures are shown. The scattering parameters of both couplers are summarized in Table III.

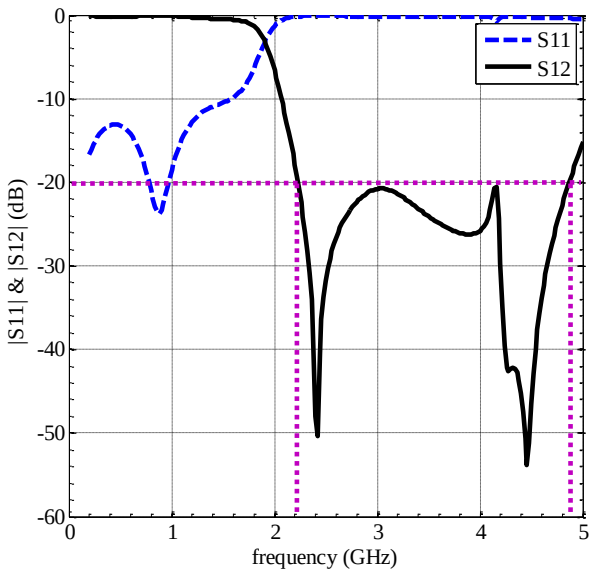

Figure 3. Simulated S parameters of the proposed 5th order Chebyshev low pass filter.

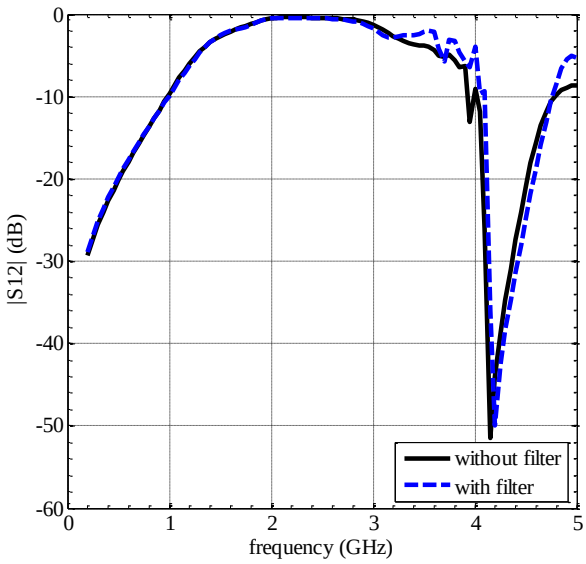

Figure 5. Simulated S_{12} parameters of the proposed coupler with and without low pass filter.

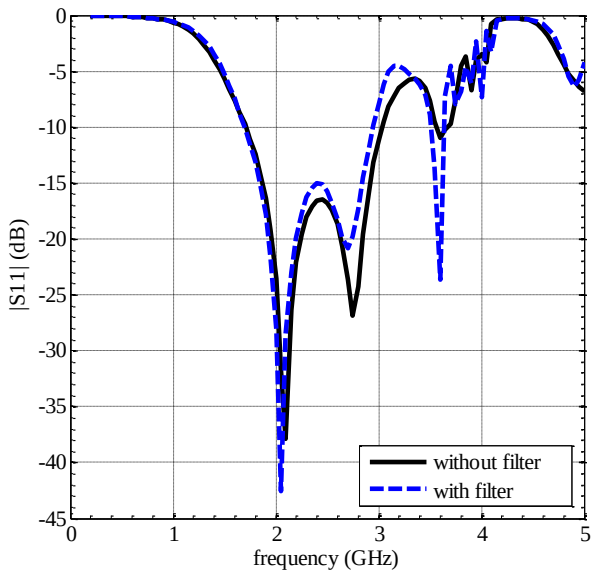

Figure 4. Simulated S_{11} parameters of the proposed coupler with and without low pass filter.

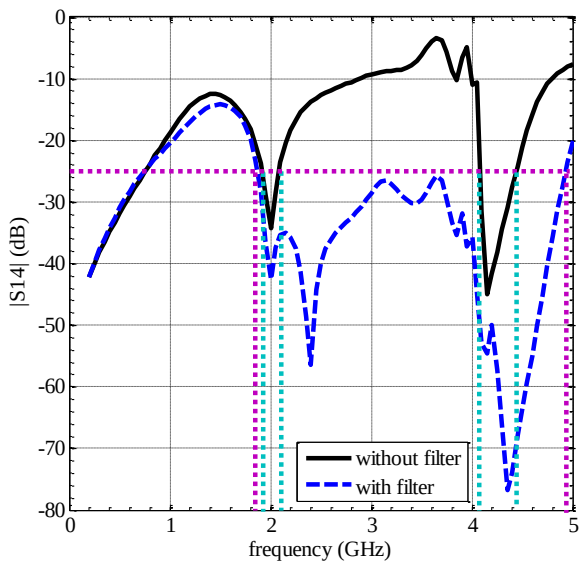

Figure 6. Simulated S_{14} parameters of the proposed coupler with and without low pass filter.

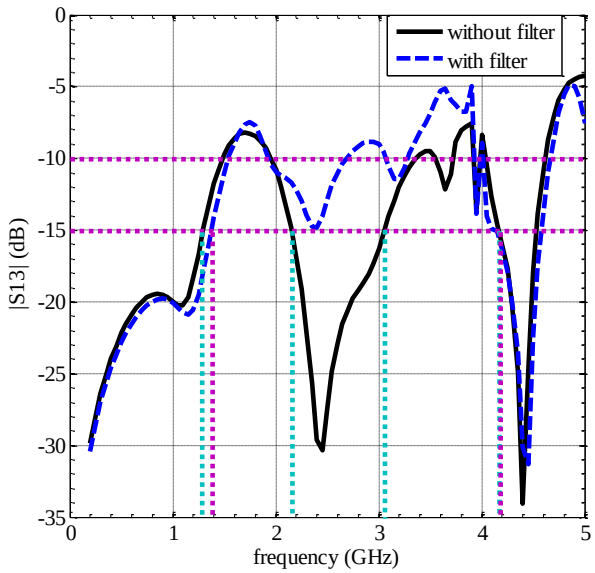

Figure 7. Simulated coupling, S_{13} parameters of both couplers versus frequency.

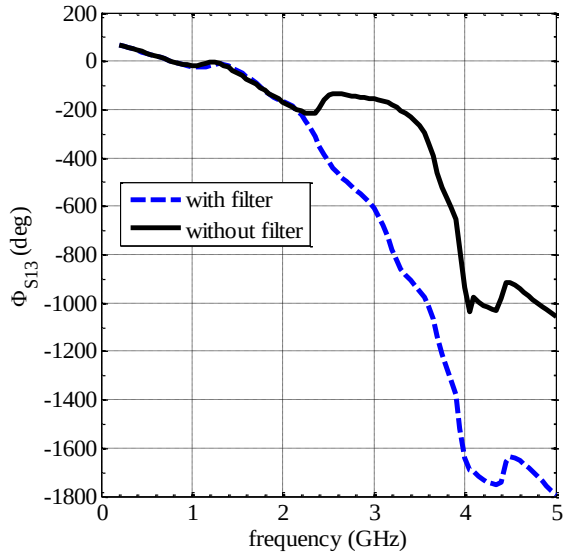

Figure 9. Simulated $\Phi(S_{13})$ parameters of the proposed coupler with and without low pass filter.

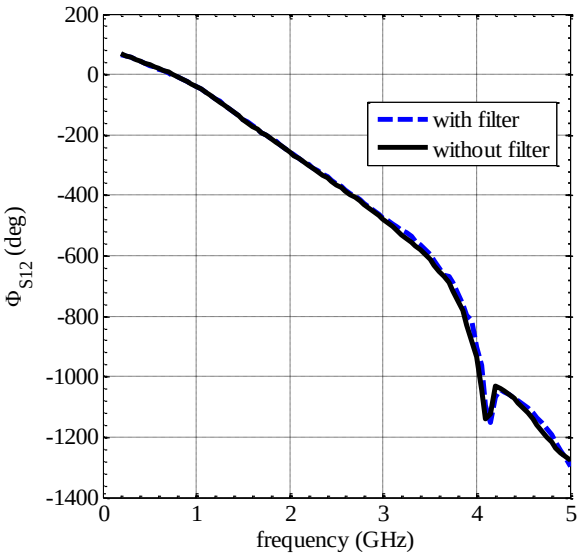

Figure 8. Simulated $\Phi(S_{12})$ parameters of the proposed coupler with and without low pass filter.

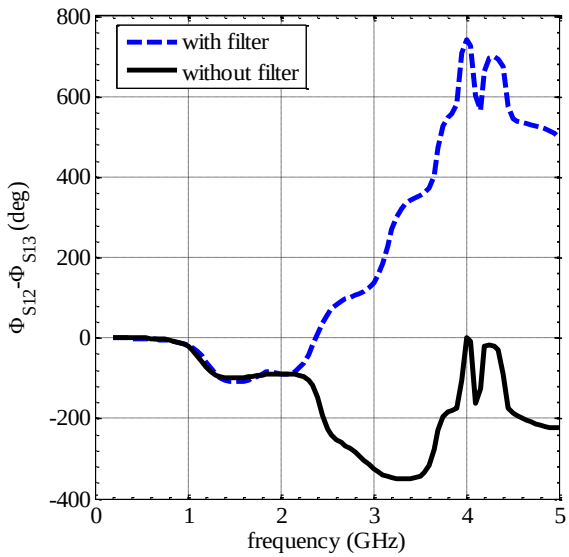

Figure 10. Simulated $\Phi(S_{12})$-$\Phi(S_{13})$ parameters of the proposed coupler with and without low pass filter.

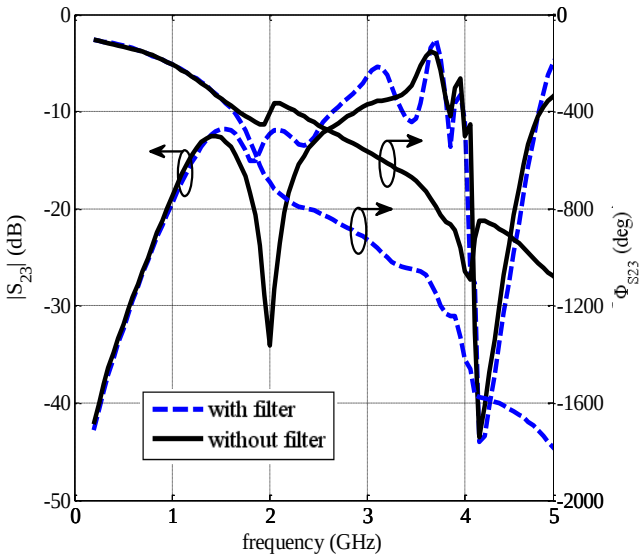

Figure 11. Simulated S_{23} parameters of the proposed coupler with and without low pass filter

Table 3. Changes in Frequency Response

parameter	Changes in frequency response
S_{11}	No changes
S_{12}	No changes
S_{13}	Coupling bandwidth is improved from 1.8 GHz to 2.8 GHz
S_{14}	Directivity Bandwidth is improved from 0.6 GHz to 3.1 GHz

IV. Conclusion

A new method to improve directivity of directional couplers is proposed in this article. According to this method, a structure, low pass filter, with stop band in the pass band of the coupler is inserted before the isolation port. The proposed method is applied for a specified coupler. Both couplers are numerically investigated by HFSS software. Results show that the directivity bandwidth is improved from 0.6 GHz in case of without filter up to 3 GHz for the coupler with low pass filter. It is shown also that, coupling bandwidth of the new coupler is greatly enhanced. These advantages are obtained without changing in size and other parameters of the coupler. The proposed method can be utilized on all couplers with poor directivity and isolation bandwidth.

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