Compact Wideband Parallel-Coupled Microstrip Line Bandpass Filter with In-Line Structure

Chuan Shao [1], Yang Li [1], Liang Wang [1], and Chen Jin [2]

[1] School of Electronics and Information
Jiangsu Vocational College of Business, 48 Jiangtong Road, Nantong, Jiangsu Province, P. R. China
ch_shao@126.com

[2] Xinglin College
Nantong University, 9 Seyuan Road, Nantong, 226019, Jiangsu Province, P. R. China
jc_uu@126.com

Abstract **─** A compact wideband microstrip bandpass filter constructed by a parallel-coupled microstrip line and a parallel-connected half-wavelength ($\lambda_g/2$) microstrip line is proposed in this letter. The proposed bandpass filter showcases wideband bandpass response with four transmission zeros within the operating bandwidth from DC to $2f_0$ (f_0 center frequency). The transmission zeros located at DC and $2f_0$ are inherently generated by the parallel-coupled microstrip line while the other two are realized by the parallel-connected $\lambda_g/2$ microstrip line. For validation, a wideband bandpass filter centered at 4.15 GHz with bandwidth of 3 GHz is designed, fabricated and measured. The size of the in-line bandpass filter is $0.27\lambda_g \times 0.045\lambda_g$, which features very compact size and can be integrated conveniently with other microwave components.

Index Terms **─** In-line structure, parallel-coupled microstrip line, transmission zero, wideband filter.

I. INTRODUCTION

Compact microwave wideband microstrip line bandpass filters are the most widely used filter structures, as they can be integrated with other passive or active microwave components conveniently, benefitting from the advantages of planar structure, easy fabrication and low cost. The parallel-coupled microstrip line (PCML) has been widely employed in the design of multistage bandpass filters [1-9]. Nevertheless, the conventional PCML filters may suffer from several disadvantages. One major disadvantage is that the occupied sizes of this kind of filters are too large, especially when the filter order becomes high to achieve good selectivity for the filter or other multi-functional microwave device [10]. Another disadvantage is that the first spurious passband of this type of bandpass filter appears at twice of the fundamental ($2f_0$), which is resulted from the unequal even and odd-mode phase velocities. These advantages may be the main limitation for the application of this type of filters.

In order to expand the application range for the PCML bandpass filters, several approaches have been adopted accordingly. In [1-2], meandered PCMLs and capacitive termination have been employed respectively to achieve size minimization. By taking these measures in [1-2], the reported PCML filters can achieve at least 25% size minimization compared with the conventional PCML filters of same order and specification. To reject the second harmonic response at $2f_0$, several methods have been reported [3-6]. In [3], the re-entrant coupling structure was applied in the design of parallel-coupled microstrip bandpass filter to realize a wide bandwidth and the suppression of spurious [3]. A certain height of substrate suspension [4] and grooved substrate [5] were used to equalize the even- and odd-mode phase velocities, and the second harmonic response can be rejected accordingly. In [6-9], defected ground structure (DGS) has been reported in designing microwave filter for rejecting spurious responses. However, filters employed DGS have etched patterns in the ground plane, which will cause a problem for package and lowering the reliability of the microwave systems.

In this letter, a compact wideband bandpass filter realized by PCML and a parallel-connected half-wavelength ($\lambda_g/2$) microstrip line is proposed. The PCML is used to provide wideband bandpass response while the $\lambda_g/2$ microstrip line is employed to generate two more transmission zeros and enhance the bandwidth of the proposed bandpass filter. In order to adjust the bandwidth of the filter for different kind of practical applications, the $\lambda_g/2$ microstrip line has been folded to form a parallel-connected coupled line. And the bandwidth of the bandpass filter can be shifted by changing the coupling coefficient of the parallel-connected coupled line. In addition, as the parallel-connected coupled line was compact, and it could be placed into the 50Ω

Submitted On: September 18, 2016
Accepted On: December 24, 2016

microstrip line and a wideband bandpass filter with in-line structure was realized. Owing to this in-line structure, the size of the bandpass filter is only 12mm×1.9mm, which corresponds to $0.27\lambda_g \times 0.045\lambda_g$ in electrical size.

II. ANALYSIS OF THE PARALLEL-COUPLED MICROSTRIP BANDPASS FILTER

The ideal circuit for the traditional PCML is shown in Fig. 1. In this figure, Z_{oe} and Z_{oo} are the even-mode and odd-mode characteristic impedances of the PCML and θ is the electrical length. The ideal responses for the circuit under different coupling coefficient K ($K=(Z_{oe}-Z_{oo})/(Z_{oe}+Z_{oo})$) in Fig. 1 are presented in Fig. 2. As we may see from this figure, the transmission poles will move away from the center frequency f_0 as the coupling coefficient K of the PCML increases. Therefore, the bandwidth of this structure can be controlled accordingly. There is a pair of transmission zeros located at DC and $2f_0$ within the operating bandwidth, however, the selectivity of the bandpass filter is not good enough. Therefore, a parallel-connected half-wavelength ($\lambda_g/2$) microstrip line is added to generate another two transmission zeros.

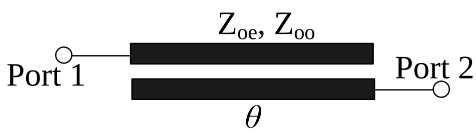

Fig. 1. Ideal circuit for the PCML.

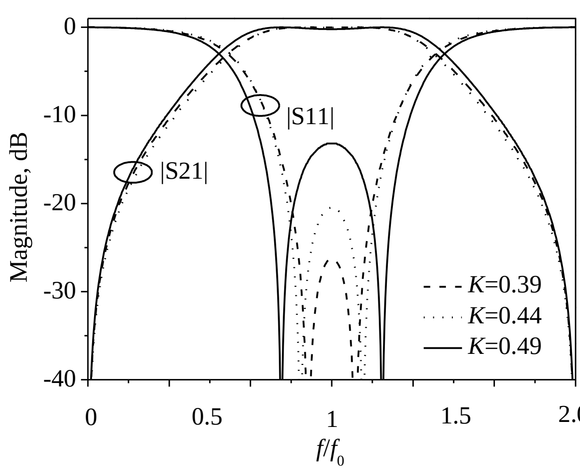

Fig. 2. Simulated responses for the traditional PCML under different coupling coefficient K.

A. Analysis of the transmission zeros

The ideal circuit for the proposed parallel-coupled filter with a parallel-connected $\lambda_g/2$ microstrip line is presented in Fig. 3. The ideal responses for the circuits in Fig. 1 and Fig. 3 are compared and plotted in Fig .4. According to Fig. 4, a pair of transmission has been added for the proposed wideband bandpass filter.

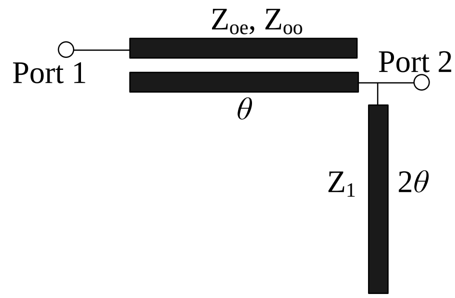

Fig. 3. Proposed PCML filter with a parallel-connected $\lambda_g/2$ microstrip line.

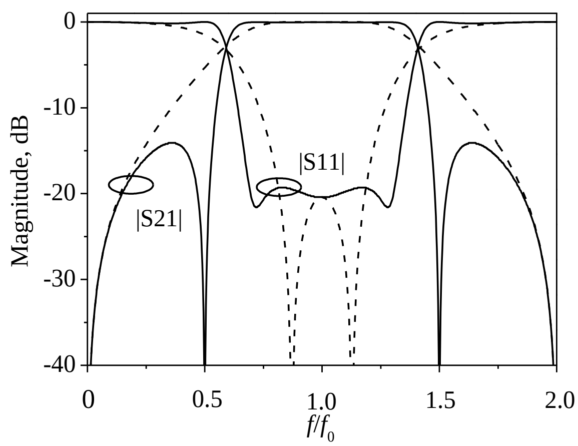

Fig. 4. Simulated responses for the circuits in Fig. 1 and Fig. 3 (Z_{oe}=180Ω, Z_{oo}=70Ω, Z_1=100Ω).

The *ABCD* matrices of the PCML and the parallel-connected $\lambda_g/2$ microstrip line are given as [11]:

$$M_p = \begin{bmatrix} A_p & B_p \\ C_p & D_p \end{bmatrix} = \begin{bmatrix} \dfrac{Z_{oe}+Z_{oo}}{Z_{oe}-Z_{oo}}\cos\theta & j\dfrac{(Z_{oe}-Z_{oo})^2-(Z_{oe}+Z_{oo})^2\cos^2\theta}{2(Z_{oe}+Z_{oo})\sin\theta} \\ j\dfrac{2\sin\theta}{Z_{oe}-Z_{oo}} & \dfrac{Z_{oe}+Z_{oo}}{Z_{oe}-Z_{oo}}\cos\theta \end{bmatrix}, \quad (1)$$

$$M_s = \begin{bmatrix} A_s & B_s \\ C_s & D_s \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ j\dfrac{\tan 2\theta}{Z_1} & 1 \end{bmatrix}. \quad (2)$$

For the proposed bandpass filter, the *ABCD* matrices is $M_p \times M_s$, then the *S*-parameters of the wideband bandpass filter can be illustrated as [12]:

$$S_{11} = \frac{A+B/Z_0-CZ_0-D}{A+B/Z_0+CZ_0+D}, \quad (3)$$

$$S_{21} = \frac{2}{A + B/Z_0 + CZ_0 + D}. \quad (4)$$

When S_{21}=0, two transmission zeroes can be obtained as:

$$\theta_{z1}=\pi/4, \quad (5)$$

$$\theta_{z2}=3\pi/4. \quad (6)$$

Moreover, three transmission poles reflect that S_{11}=0 has three real solutions when the values of Z_{oe}, Z_{oo} and Z_1 are properly selected.

B. Analysis of the parallel-connected λ_g/2 microstrip line

In Fig. 5, simulated transmission coefficient for the proposed bandpass filter versus Z_1 is presented. Bandwidth of the proposed bandpass filter will increase when the value of Z_1 decreases. Nevertheless, the out-of-band rejection level becomes bad while the bandwidth increases. Therefore, large value of Z_1 has been adopted in this design. In order to adjust the bandwidth even further, the parallel- parallel-connected half-wavelength (λ_g/2) microstrip line has been folded to form a parallel-connected coupled line as depicted in Fig. 6. The bandwidth of the proposed bandpass filter can be adjusted by changing the coupling coefficient K_1 (K_1=(Z_{oe1}-Z_{oo1})/(Z_{oe1}+Z_{oo1})) of the parallel-connected coupled line, as shown in Fig. 7.

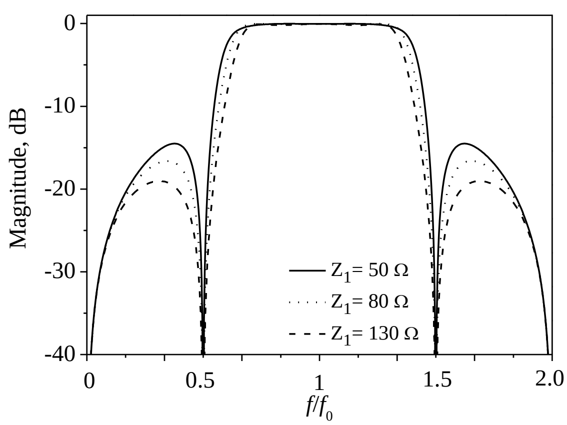

Fig. 5. Simulated transmission coefficients for the circuit in Fig. 3 versus Z_1 (Z_{oe}=180Ω, Z_{oo}=70Ω).

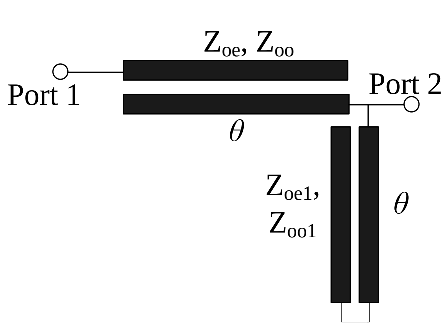

Fig. 6. Ideal circuit for the proposed PCML filter with a parallel-connected coupled line.

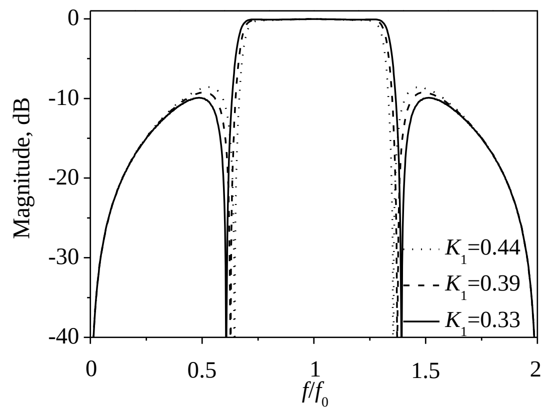

Fig. 7. Simulated transmission coefficients for the circuit in Fig. 6 versus K_1 (Z_{oe}=180Ω, Z_{oo}=70Ω).

III. FILTER DESIGN AND RESULTS

Based on the analysis given above, the final parameters for the circuit in Fig. 6 are obtained as follows: Z_{oe}=180Ω, Z_{oo}=70Ω, Z_{oe1}=160Ω, Z_{oo1}=80Ω, f_0=4.15 GHz, θ=90°. One prototype of the proposed PCML bandpass filter is fabricated on a RO4003c substrate with ε_r = 3.55, h = 32mil, and tanδ = 0.0027. The layout of the filter and the photograph of the fabricated filter are shown in Fig. 8, while the ideal, simulated and measured S-parameters and group delay are depicted in Fig. 9.

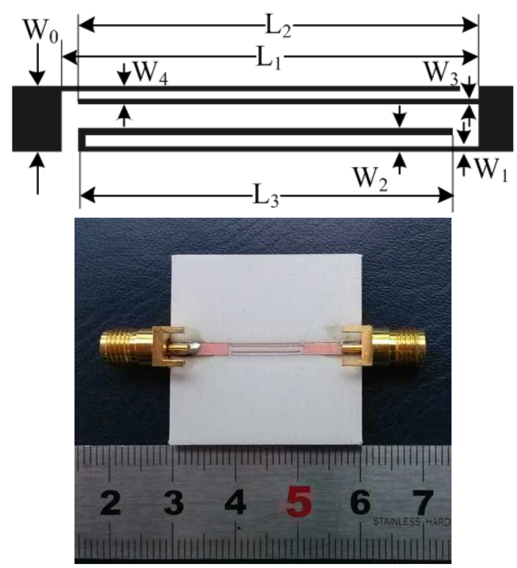

Fig. 8. Layout and photography of the fabricated in-line bandpass filter (L_1=12mm, L_2=11.5mm, L_3=11mm, W_0=1.9mm, W_1=0.2 mm, W_2=0.8mm, W_3=0.15mm, W_4=0.5mm).

As can be seen from Fig. 9, the results match with each other very well. The proposed wideband bandpass filter is centered at 4.15 GHz with 3-dB bandwidth of

3 GHz, which corresponds to 72.3% fractional bandwidth. Two transmission zeros generated by parallel-connected coupled line are located at 2.5 GHz and 5.8 GHz, which have greatly improved the selectivity of the bandpass filter. The minimum insertion loss is less than 0.55 dB while the return loss is over 10 dB within the passband. The ideal, simulated and measured group delay of this wideband bandpass filter are flat and less than 0.50 ns across the entire passband. As a result of the in-line structure, the total size of the proposed bandpass filter is $0.27\lambda_g \times 0.045\lambda_g$.

To further demonstrate the performance of the proposed bandpass filter, comparison between the proposed bandpass filter in this letter and previously reported filter structures are listed in Table 1. As can be seen from Table 1, the insertion loss of the proposed bandpass filter is much lower than most of the reported structures. Besides, the proposed bandpass filter is free of the spurious passband at $2f_0$ and possesses the most compact size.

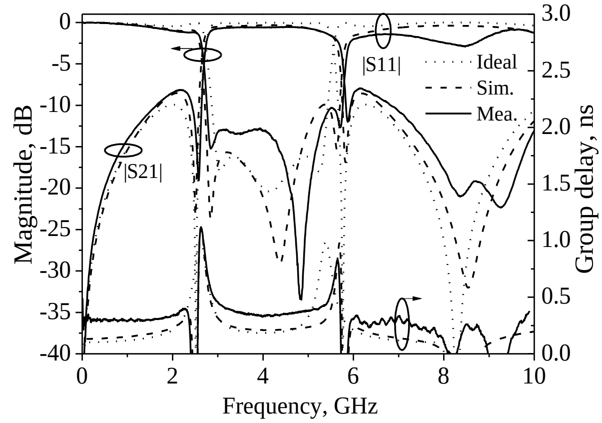

Fig. 9. Ideal, simulated and measured S-parameters and group delay of the proposed bandpass filter.

Table 1: Performance comparison with previously reported PCML filters

Ref.	f_0 (GHz)	3-dB Bandwidth	Insertion Loss (dB)	Transmission Zeros (DC to $2f_0$)	First Spurious Passband	Size ($\lambda_g \times \lambda_g$)
[1]	1.0	50%	NA	3	$>2f_0$	0.19×0.14
[2]	0.9	10%	1.0	2	$>3f_0$	0.8×0.06
[3]	5.0	70%	0.9	3	$>2f_0$	0.88×0.31
[4]	2.45	10%	NA	2	$3f_0$	1.33×0.17
[5]	1	20%	2	2	$3f_0$	NA
[6]	3	10%	1.0	3	$>2f_0$	NA
This work	4.15	>70%	0.53	4	$3f_0$	0.27×0.045

Where λ_g is the guided wavelength at the center frequency of the bandpass filters.

IV. CONCLUSION

In this letter, a compact PCML bandpass filter with in-line structure has been presented. Based on the traditional PCML, a parallel-connected half-wavelength ($\lambda_g/2$) microstrip line was added to realize two extra transmission zeroes, which have not only improved the selectivity of the filter but also enhanced the bandwidth. In addition, the parallel-connected $\lambda_g/2$ was folded and placed into the 50Ω microstrip line forming an in-line bandpass filter while the bandwidth of the filter can be tuned by changing the coupling coefficient of the parallel-connected coupled line. Compact size and good selectivity are realized for this wideband bandpass filter, which indicates a good candidate for modern wideband microwave communication applications.

ACKNOWLEDGMENT

The work was supported by the Nantong Science and Technology Project under Grants No. GY12015037.

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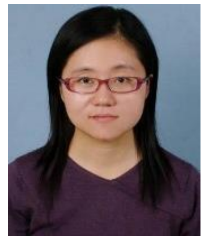
Chuan Shao was born in Tengzhou Shandong Province, China in 1988. He received B.E. and M.S. degree in Nantong University, Jiangsu Province, China, in 2012 and 2015 respectively. His research interests include microwave passive components, etc.

Shao is Reviewer of ACES Journal and International Journal of Microwave and Wireless Technologies.



Yang Li was born in Yichang Hubei Province, China in 1980. She received B.E. degree in Central China Normal University, Hubei Province, China, in 2002. She received M.S. and Ph.D degree in Hefei University of Technology, Anhui Province, China, in 2007 and 2013 respectively. Her main research interests include VLSI design and test, circuit aging, embedded system, built-in self-test, etc.

Wang Liang was born in Nantong Jiangsu Province, China in 1978. He received B. E. degree in Nantong University, Jiangsu Province, China, in 2000. He received M.E. degree in Jiangsu University, Jiangsu Province, China, in 2010. His main research interests include the application of Internet of thing, RFID, and network security technology.

Chen Jin received the B.E. degree and M.S. degree in from Nanjing University of Posts and Telecommunications, Nanjing, China, in 2011 and Nantong University, Jiangsu Province, China, in 2015 respectively. Since 2015, she has been with Xinglin College, Nantong University, Jiangsu Province, China. Her research interests include microwave filters and antennas.