Broadband PCML Bandpass Filter with Rectangular Middle Resonator

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1. Introduction

In recent years, compact broadband filters compatible with printed circuit boards (PCB) are required in many communication systems. The filter size is usually constrained by the number of resonators and size of the resonator structures employed in the design. Various techniques were proposed to design broadband bandpass filter [1]-[2]. One of the simplest and easiest methods to achieve broadband is by employing resonators with multiple poles within passband region [3]. In these studies multiple poles within passband were achieved by employing two types of resonators. One is a pair PCML with tight coupling factor and the other is rectangular middle resonator which connecting the both PCML structure. By varying the physical parameters of PCML and middle resonators multiple poles can be achieved which will lead to design of broad band bandpass filter. The filter bandwidth is mainly limited by the achievable maximum coupling between these resonators. A broadband bandpass filter of PCML structure can be realized by employing high coupling parallel coupled line of narrower width and gap. The overall PCML coupling factor can be further enhanced by using feeding network with small characteristics impedance.

In this paper, a simple broadband bandpass filter with PCML structure was designed by placing a rectangular single line resonator of specific length and width between two identical PCML sectors. Basically a simple PCML structure with high coupling factor can produce two poles near to each other. The enhancement of PCML structure coupling over the wide frequency range can be realized by using microstrip transmission line with narrow width and gap of the parallel structure. Due to fabrication constraint in real world, the microstrip line width and gap of the parallel structure as the minimum value which cannot be further reduce. In these studies, a technique was proposed by employing a feeding network with small value of characteristic impedance. This technique shows that the PCML structure coupling factor can be further enhanced and two poles can be achieved. In order to further increase the number of poles, a rectangular middle resonator between two PCML structures with specific dimension introduced. This will produce multiple poles in periodical at overall electrical length of 180°, 360° and etc. By carefully selecting the length and width of the resonator the poles at 180° and 360° can brought nearer to two poles of PCML structure. The overall filter performance such as insertion loss, return loss and suppression of harmonic response was further improved by adjusting the length and width of the middle resonator. The middle resonator width was adjusted accordingly to improve the insertion loss and return loss performance at passband response. The length of resonator was adjusted for harmonic cancellation by transmission zero frequency. Details of the compact broadband filter design are presented and measured results are given to demonstrate the performance of the proposed filter. The proposed design is further optimized by adjusting the length and width of the middle resonator. Overall the simulated and measured results of insertion and return loss show good agreement with BW > 80%, $|S_{11}| < -16$dB, $|S_{21}| > -0.1$dB and 200% wide upper stop-band.

2. Simple PCML structure

A simple PCML structure design as shown in Figure 1a with strip and slots widths w_1=0.2 mm, s_1=0.2 mm and the length l_1=7 mm ($\approx \lambda/4$ at 5.25 GHz). The PCML feeding network of fixed length l_o= 4 mm, width was adjusted accordingly to investigate the overall coupling factor. The design was constructed on RT/Duroid substrate with the relative permitivity ε_r = 6.15 and the thickness h = 1.27 mm. The two-port periodically non uniform coupled microstrip line with finite length is characterized as an equivalent J-inverter network, showing its frequency-dispersive coupling performance. The equivalent J-inverter network of the PCML parameters, such J-susceptance and electrical line length θ, are calculated by using admittance parameters components. The two – port admittance Y – matrix of PCML Figure 1a can be effectively extracted using full – wave analysis from *em* tools. The equivalent normalized $\overline{J}$ –susceptance of PCML structure calculated based on [4] by using the extracted Y – parameters. Since the J–inverter network with the susceptance (J) and two equal electrical lengths of θ/2 at the two sides can be modeled equivalent to PCML, the equivalent circuit of a two–port network admittance of PCML can be used to calculate the J-susceptance and electrical length (θ).

Figure 2 shows the normalized J-inverter susceptance $\overline{J}$ and S -parameters of a PCML structure Figure 1a, with various feeding network widths. It can be observed that $\overline{J}$ varies in a periodic manner with frequency for various feeding network widths. These indicate the frequency dispersion behavior of the network. When w_o= 1.4 mm, $\overline{J}$ has the peak value which less than 1, shows the moderate coupling factor of the PCML structure. But the coupling factor improve further when w_o= 1.9 mm, with peak value $\overline{J}$ =1.15, which gives $\overline{J}$ =1 at f = 4.5 GHz and f = 6.0 GHz. Further investigation was carried out by using w_o= 2.4 mm, shows excellent improvement of coupling factor over broad bandwidth with peak value $\overline{J}$ =1.4, which gives $\overline{J}$ =1 at f = 4.2 GHz and f = 6.4 GHz. Overall it shows an increase in w_o from 1.4 mm to 2.4 mm, the $\overline{J}$ peak value increases from 0.9 to 1.4 and also the bandwidth between first frequency to second frequency of $\overline{J}$ =1 also increases. The peak value of $\overline{J}$ also shifted to a higher frequency as w_o increases. This result demonstrates that feeding network with smaller value of characteristic impedance of PCML structure is able to improve the coupling factor and also the bandwidth. From the Figure 2 also, S_{11} pole appear when $\overline{J}$ =1. For PCML with w_o=1.9 mm and w_o=2.4 mm, the corresponding S_{11} pole frequency is the same as the frequency for $\overline{J}$ = 1 and the bandwidth between both poles increase as the w_o increase. It shows poles can be achieved when $\overline{J}$ =1. As the width increases the separation between two poles due to $\overline{J}$ =1 increase and insertion loss within this frequency range reduce as the return loss increase. The results shows clearly feeding network with smaller characteristics impedance can easily improve the coupling factor of the PCML structure leading to producing multiple poles. The conclusion, coupling factor for any given PCML structure can be enhanced by using a feeding network with lower characteristics impedance without further reducing the strip width and parallel strip separation. The proposed PCML structure with feeding network, maximum can produce only two poles with good bandwidth separation. This method can be applied to design a simple PCML broadband bandpass filter.

3. Broadband PCML-RMR filter structure

In order to obtain broadband bandpass filter of good bandwidth with multiple poles and sharp-rejection stopbands a prototype layout was proposed with a pair of PCML structure separated by rectangular resonator as shown in Figure 1(b). It is named PCML-RMR filter. PCML strip and slot widths are set as given above in order to achieve a broad bandwidth of tight coupling degree and a relaxed fabrication tolerance. Meanwhile, the middle resonator is formed with l_2 and w_2 in order to achieve a length of slightly greater $\lambda/4$ at 5.25 GHz. The feeding network of width w_o=1.9 mm and length l_o=4 mm for the input and output port is designed. Figure 3 shows the simulated results of S_{11} and S_{21} of a broadband filter over the wide frequency range (1.0 to 12.0 GHz) with respect to the three different middle resonator lengths (l_2=4.0 mm to 7.0 mm) under the fixed width. It shows four poles separated well at various frequencies. Poles at frequency f_1 = 4.65 GHz and f_2 = 5.95 GHz are mainly due to $\overline{J}$ = 1 with respect to feeding network of width w_o=1.9 mm. The other two poles present within the operating bandwidth of broadband at f_3 and f_4 are mainly due to rectangular middle between the PCML structures. The f_3 and f_4 are due to electrical length 180° and 360° of middle resonator, due to periodicity f_5 present due to electrical length of 540° as harmonic at out of non operating band. When the middle resonator length l_2 of the filter varies the f_1 and f_2 remain at respective frequencies without change but f_3 and f_4 frequencies change effectively. After a few simulations of various lengths as shown in Figure 3, the optimum length of l_2=5.7 mm is obtained with harmonics cancellation of f_5 by transmission zero frequency and improves passband response of insertion and return loss with well separated f_1, f_2, f_3 and f_4 . Figure 4 shows the simulated results of S_{11} and S_{21} with respect to the three different middle resonator widths (w_2=1.1 mm to 2.7 mm) under the fixed length. It shows overall middle resonator width also influencing the coupling factor of PCML structure of the filter. When w_2=1.1 mm, no effective poles present within the operating band. But, when w_2=1.9 mm the resonant frequencies are well equally spaced. It produces S_{21} – magnitude with an almost flat frequency response near the 0dB line over the desired passband. Again by increasing the w_2=2.7 mm, due to over coupling the poles due to $\bar{J} = 1$ overlapping with poles due to middle resonator electrical length which worsen the overall operating passband. Good PCML broadband bandpass filter operating at 5.25 GHz, having bandwidth of 4 GHz (or 87%), with passband insertion loss response of less than -0.2 dB and less than -13 dB return loss has been successfully obtained. The main draw back is the harmonic picked up again. Hence, fine tuning was employed at the centre resonator length to suppress the harmonic. Based on these findings and approach, an optimized broadband PCML bandpass filter has been fabricated and measured for the insertion and return losses performances.

Fig. 4 illustrates the simulated and measured two-port *S*-parameters of the optimized broadband filter. Both the measured and simulated results are found to have reasonably good agreement with each other. The measured result shows that in-band performance of the proposed filter stays almost the same as the predicted results, including small insertion loss and return loss variation. It shows, a cost effective compact broadband PCML bandpass filter with excellent passband response can be designed and fabricated.

4. Conclusion

Based on these studies it shows that for any given PCML structure, the coupling factor can be enhanced by employing feeding network of smaller characteristics impedance. A simple PCML structure with both input and output feeding network of characteristics impedance $Z_c << Z_o$, shows two poles when $\bar{J}>1$. The multi pole shows filtering characteristics of PCML structure. This idea leads to design an improved version of PCML broadband bandpass filter without ground plane aperture. By modifying the middle resonator width and length, an improved broadband PCML bandpass filter can be design. The technique proposed in this study is the easiest and the simplest in designing the broadband compact PCML bandpass filter. The optimized design shows excellent broadband characteristics with bandwidth > 80%, insertion loss > -0.1 dB and return loss < -16 dB at passband. Overall the proposed filter exhibited excellent broadband bandpass performance in operation band. The experimental results are in good agreement with the simulated responses, validating the theory and design method.

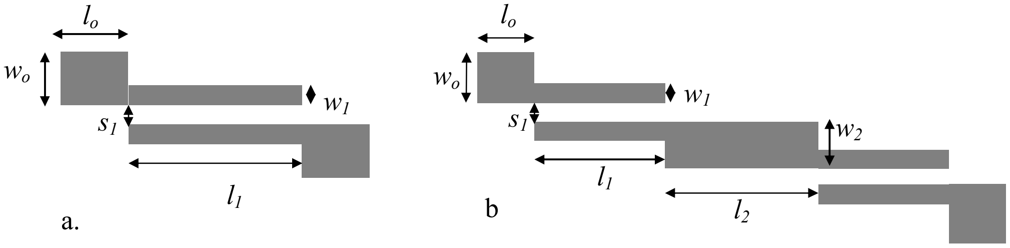

Figure 1: Proposed design: a) Simple PCML Structure, b) Compact Broadband Bandpass Filter with Rectangular Middle Resonator, PCML-RMR.

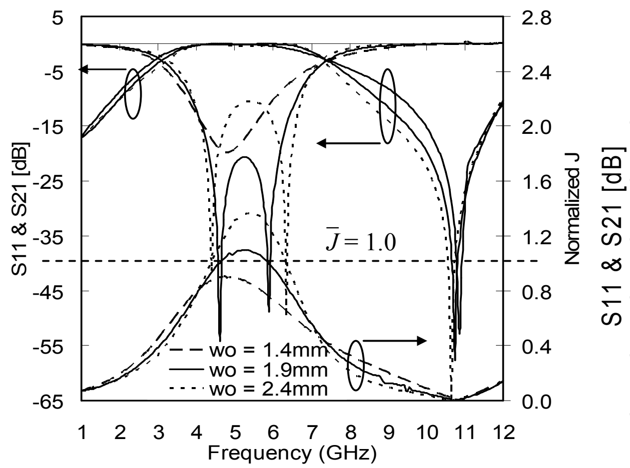

Figure 2: Predicted S-parameters and normalized *J* susceptance results of Simple PCML structure Figure 1(a).

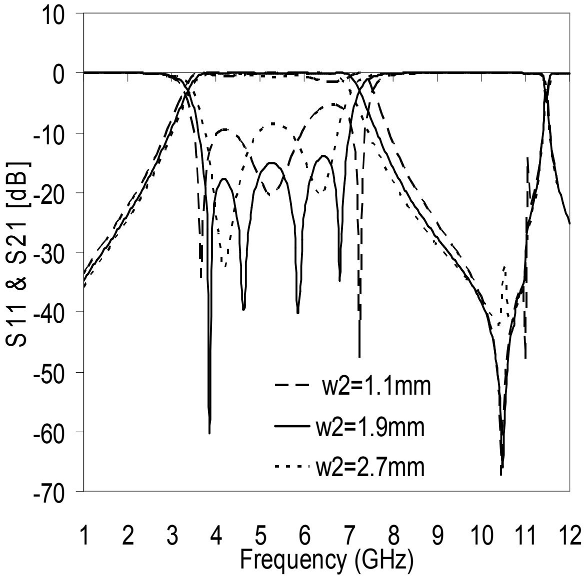

Figure 4: Predicted S_{11} and S_{21} for various width w_2 of middle rectangular resonator

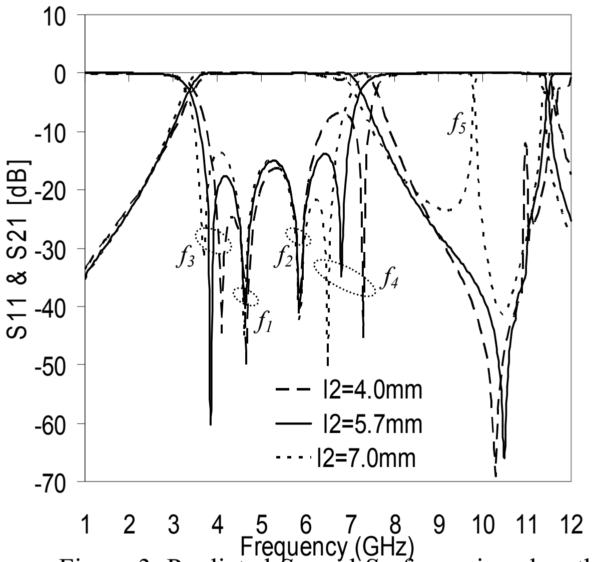

Figure 3: Predicted S_{11} and S_{21} for various length l_2 of middle rectangular resonator

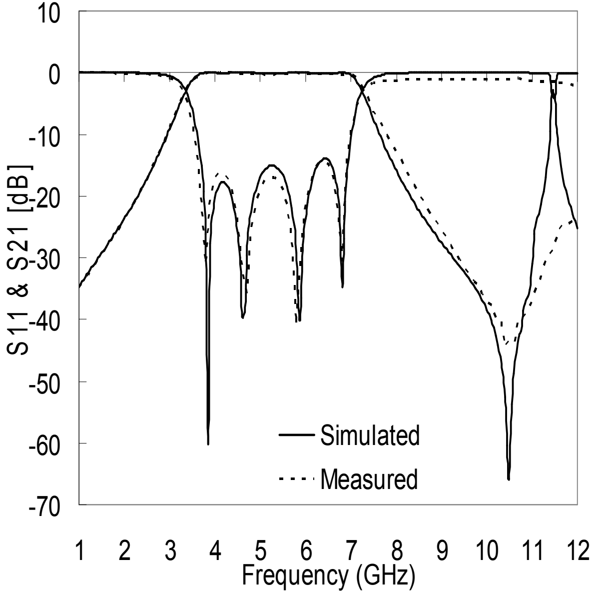

Figure 4: Simulated and measured results of the optimized PCML-RMR filter.

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