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Compact Broadband PCML bandpass Filter with Broad Upper Stop Band

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Abstract – A simple broadband parallel coupled microstrip line (PCML) bandpass filter with compact design is proposed. A PCML structure with two feeding network of various widths is characterized by an equivalent J-inverter network. The extracted parameters indicate that the normalized J susceptance and equivalent electrical length are frequency dependent. A pair of PCML structure with middle resonator, without ground plane aperture at PCML structure and capacitive open-ended stub at the middle resonator, is proposed. The proposed design is further optimized by adjusting the length and width of the middle resonator. Three broadband bandpass filter with PCML structure of various coupling strengths have been designed. The simulated and measured insertion and return loss responses show good agreement with bandwidth of over 80%, return loss of better than -16dB and 250% broad upper stop-band.

Keywords: Broadband Bandpass Filter, PCML, Tight Coupler, J – inverter network.

1. Introduction

In recent years, compact broadband filters compatible with printed circuits board (PCB) are in demand 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. The filter bandwidth is mainly limited by the achievable maximum coupling between these resonators. Various compact resonator structures can be found in literature [1]-[4].

Parallel coupled microstrip line (PCML) structure has been used as coupling components in the design of bandpass filter [5]-[6]. A broadband bandpass filter of PCML structure can be realized by employing high coupling parallel coupled line. High coupling PCML structure can be achieved by using narrow width and gap of parallel microstrip line.

The enhancement of PCML structure tight coupling over the wide frequency range can also be realized by using feeding network with lower impedance. The coupling characteristic depends on the width of the feeding network.

In this paper, a simple broadband PCML structure similar to [7] has been designed by attaching a single line resonator of specific length and width between two PCML sections without having a backside aperture and pair of capacitive open-ended stubs. The overall filter performance such as insertion loss, return loss and suppression of harmonic response has been further improved by adjusting the length and width of the centre resonator. The centre resonator behaves as a main element in enhancing the bandwidth of the bandpass filter. The width of the centre resonator can be adjusted accordingly to improve the insertion loss and return loss performances. In addition, the length of the resonator can be adjusted for harmonic cancellation by transmission zero frequency. The overall performance shows that a simple PCML structure with centre resonator without ground plane aperture and a pair of capacitive open-ended stubs at the centre resonator can be used to design compact broadband bandpass filter.

2. PCML Structure

A simple PCML structure as shown in Figure 1, with various feeding network width as shown in Table 1, was designed and investigated for coupling factor in terms of normalized *J*-inverter susceptance $\bar{J}$ and equivalent electrical length $\theta/2$ [13]-[14].

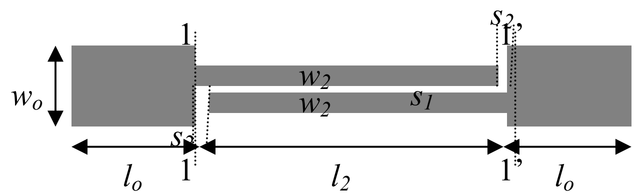

Figure 1: A PCML Structure

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Based on the physical parameters given in Table 1, for various feeding network widths, the normalized susceptance $\bar{J}$, varies in a periodic with frequency, showing the frequency dispersion behavior of the network. This result demonstrates that feeding network with smaller value of characteristic impedance or higher value of characteristic admittance of PCML structure is able to improve the coupling factor and also bandwidth. Figure 2 shows the electrical length $\theta/2$ linearly increase for smaller w_o and quasi linearly increase for bigger value of w_o with respect to frequency.

Table 1: PCML Tight Coupler with Varying w_o

$\varepsilon_r = 6.15$, $h = 1.27$ mm						
PCML Tight Coupler	w_o mm	w_2 mm	s_1 mm	s_2 mm	l_o mm	l_2 mm
1	1.3	0.6	0.1	0.2	4.0	7.0
2	1.9	0.6	0.1	0.2	4.0	7.0
3	2.5	0.6	0.1	0.2	4.0	7.0
4	3.1	0.6	0.1	0.2	4.0	7.0

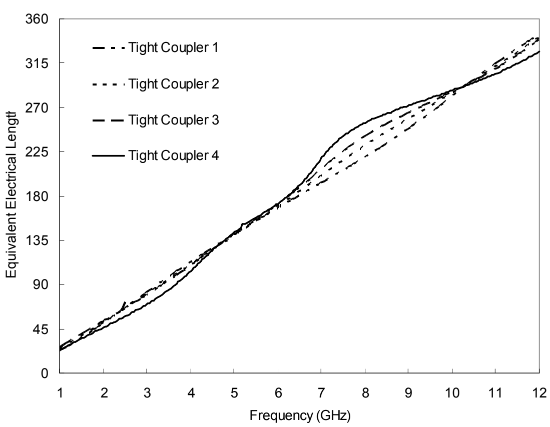

Figure 2: Frequency-Dispersive Electrical Line Length of Figure 1 with Varying w_o

Based on the J-inverter network, the return loss can be obtained as given below [13],

$$S_{11} = \frac{1 - \bar{J}^2}{1 + \bar{J}^2} \qquad (1)$$

It is clearly shown that S_{11} will be zero when $\bar{J} = 1$. The frequency of $\bar{J} = 1$, corresponds to the S_{11} pole location over the bandpass range. Figure 3 shows simulated return and insertion losses of the PCML structure with various feeding network widths.

The poles of the return loss appear at the same frequency as $\bar{J} = 1$ and the bandwidth between both poles increases with w_o. As the width increases, the separation between the two poles due to $\bar{J} = 1$ increases. The insertion loss within this frequency range reduces as the return loss increases. The results show that the coupling factor for any given PCML structure with specific width and gap can be enhanced by using a feeding network with lower characteristic impedance, comparatively.

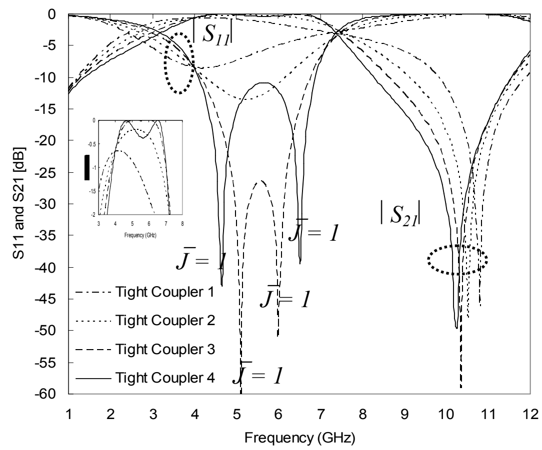

Figure 3: Insertion and Return loss of PCML Structure with Varying w_o

3. Bandpass Filter: Prototype Concept and Verification

A simple structure consists of microstrip line of Z_L (Y_L) characteristics impedance (characteristics admittance) is connected across two identical PCML sections as shown in Figure 4. The middle resonator is formulated to enhance the normalized J susceptance value and generate additional bandpass poles from its resonant modes as proposed in [13].

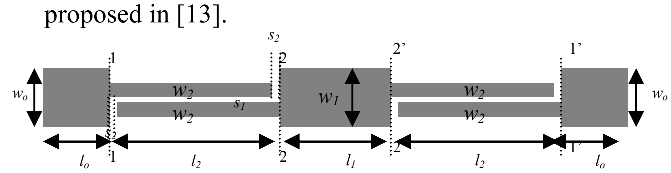

Figure 4: The Physical dimension of PCML broadband bandpass structure,

Prototype PCML broadband filter with various feeding networks and middle resonator width has been designed for center frequency at 5 GHz based on physical dimension stated in Table 2.

From Figure 5, multiple resonances present at various frequencies. It is clearly shown that the resonance frequencies very much depend on the feeding network and middle resonator width. The middle resonator width can be fine tuned to meet the requirement of its J-inverter susceptance in the optimization procedure of broadband PCML bandpass filter with extremely good passband response of insertion and return loss.

Table 2: Prototype PCML Filter with varying w_o

ε_r = 6.15 h = 1.27mm 50 Ω equal to 1.9mm width at 5 GHz								
PCML Filter	w_o mm	l_o mm	w_2 mm	l_2 mm	s_1 mm	s_2 mm	w_1 mm	l_1 mm
1	1.3	4.0	0.6	7.0	0.1	0.2	1.3	6.7
2	1.9	4.0	0.6	7.0	0.1	0.2	1.9	6.7
3	2.5	4.0	0.6	7.0	0.1	0.2	2.5	6.7
4	3.1	4.0	0.6	7.0	0.1	0.2	3.1	6.7

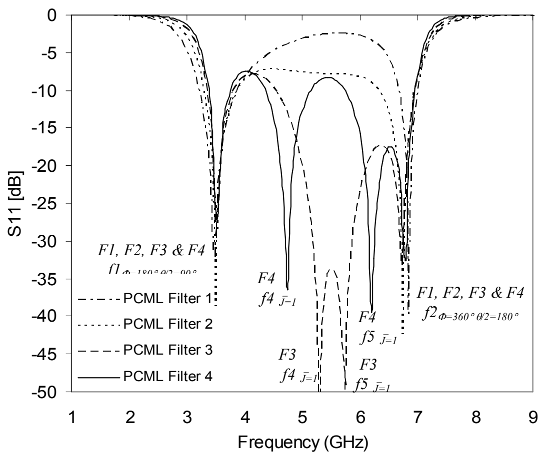

Figure 5: Returns loss of PCML Broadband Filter with various w_o and w_1

Based on the findings, an optimized broadband PCML bandpass filter with low return loss and high insertion loss over the passband can be designed. The physical parameters of PCML Filter 2 from Table 2 are used.

For the above PCML Filter, multiple resonances present at various frequencies; first resonance frequency at f_1 = 3.5 GHz, second resonance frequency at f_2 = 6.75 GHz and third resonance frequency at $f_3 = f_h$ =10.1 GHz. The first and second resonance frequencies become passband frequencies with centre frequency at 5 GHz, and third resonance frequencies become first harmonic frequency. Transmission zero frequency is at f_z = 10.5 GHz.

4. Bandpass Filter: Improved, optimized design and measurements

Broad upper stopband achieved by canceling the harmonics appear near to the passband frequency. The simplest way to perform harmonic cancellation is by transmission zero frequency realignment method [11]-[12] which can be achieved by adjusting the length of the middle resonator l_1.

As the length of l_1 varies, the passband response of the insertion and return losses of the design also vary. The insertion loss response in Figure 6 shows that as l_1 changes the transmission zero frequency always remain at 10.5 GHz. When l_1 = 6 mm, the transmission zero frequency and first harmonic frequency were realigned and cancel the first harmonic frequency. The main draw back is the passband response for insertion loss of approximately -1 dB. The passband response decreases mainly due to the coupling effects of PCML structure. As the length of middle resonator l_1 decreases, the overall coupling coefficient decreased.

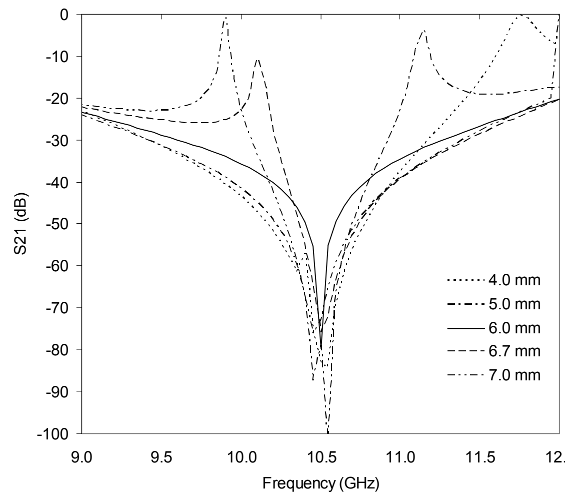

Figure 6: Insertion Loss (S21 (dB)) for varying lengths of middle resonator. Width w_1 = 1.9 mm (50 Ω line)

In order to improve the coupling of two tight couplers the characteristic impedance of middle resonator was varied by changing the width w_1.

Figure 7 and 8, shows clearly as the width of middle resonator increase w_1 (or the characteristics impedance reduce), the return and insertion loss shows much improvement. For w_1 = 2.7mm, the passband response of insertion loss -0.22 dB with much flatten response. The return loss also shows good improvement at passband response about -13 dB with flatten response.

Good PCML broadband bandpass filter is observed at 5 GHz, with bandwidth of 4.35 GHz (87%), and passband response of less than -0.2 dB for insertion loss and less than -13 dB return loss. The main draw back is the harmonic picked up again. Hence, fine tune is performed at the middle resonator length to suppress the harmonic.

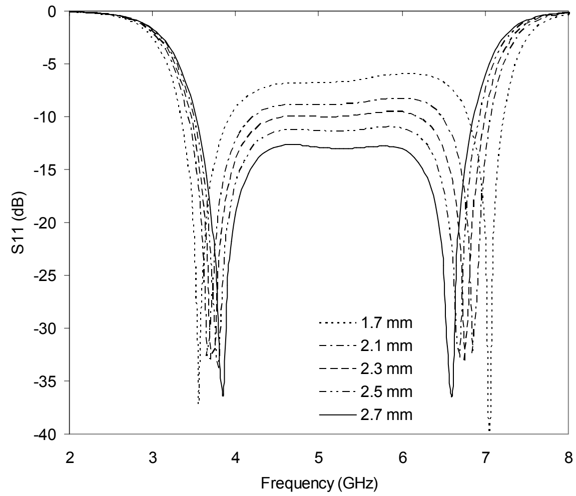

Figure 7: Return Loss (S11 (dB)) for varying widths of the middle resonator. Length l_1 = 6 mm.

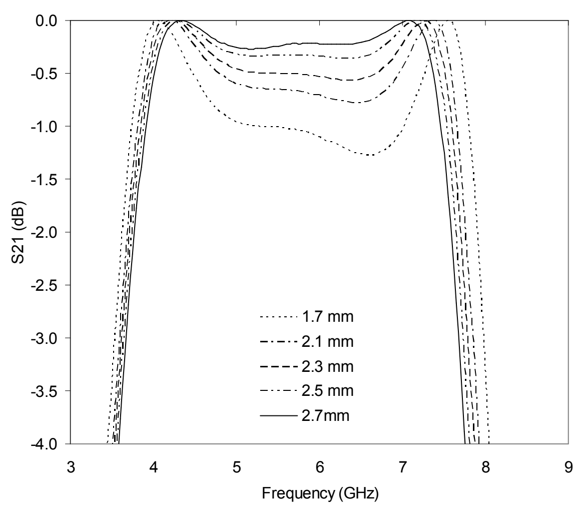

Figure 8: Insertion Loss (S21 (dB)) for varying widths of the middle resonator. Length l_1 = 6 mm.

Based on the findings and approach, an optimized broadband PCML bandpass filter of varying coupling factor is designed, fabricated and measured.

Figures 9 to 11 show simulated and measured frequency response for three optimized PCML filters with various coupling factors. It can be seen that the simulated and measured insertion and return loss responses agree well with each other. The summary of the results are given in Table 3. It can be concluded that a cost effective compact broadband PCML bandpass filter with excellent passband response can be designed and fabricated.

Table 3: Summary of simulated and measured results of the optimized filters

PCML Filter	Simulated			Measured			Dimension
	BW %	S11 dB	S21 dB	BW %	S11 dB	S21 dB	Length (mm)× width (mm)
1	87	< -13	> -0.2	85	< -13	> -0.5	27.9 × 10
2	96	< -22	> -0.03	93	< -20	> -0.3	28.2 × 10
3	82	< -15	> -0.1	80	< -12	> -0.3	28.2 × 10

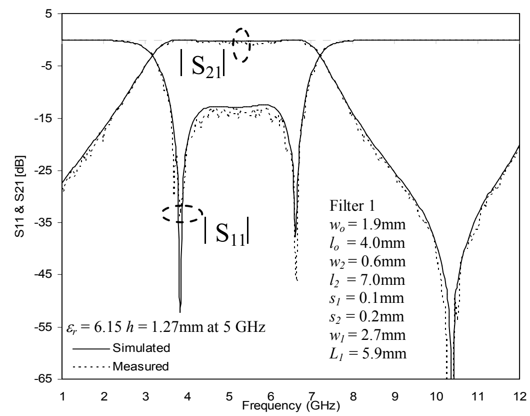

Figure 9: Simulated and Measured Responses of Filter 1.

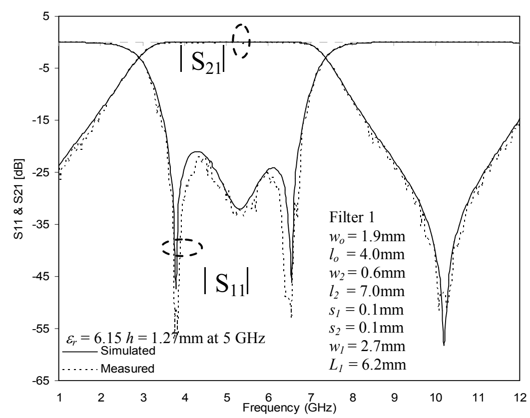

Figure 10: Simulated and Measured Responses of Filter 2.

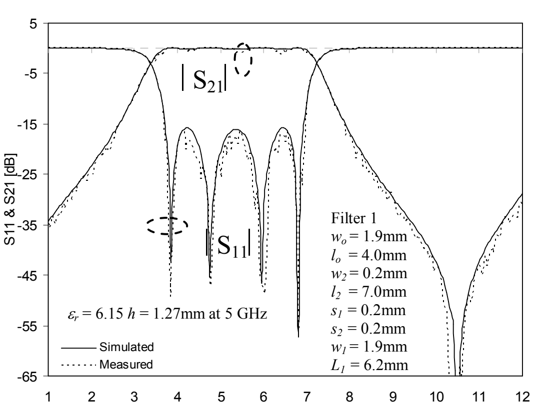

Figure 11: Simulated and Measured Responses of Filter 3.

5. Conclusion

It has been shown that for given any PCML structure, the coupling factor can be enhanced by employing feeding network of smaller characteristic impedance. A simple PCML structure with both feeding networks of characteristic impedance $Z_c << Z_o$, shows two poles when J>1. The multi pole show filtering characteristics of PCML structure. By modifying the middle resonator width and length, an improved broadband PCML bandpass filter can be designed. The technique proposed in the paper is easiest and simplest for designing broadband compact PCML bandpass filter.

Three PCML broadband bandpass filters have been designed. All show excellent broadband characteristics with bandwidth of over 80%, insertion loss of better than -0.2 dB at pass band, and return loss of better than -13 dB. The proposed filter exhibit excellent broadband bandpass performance in operation band. The experiment results are in good agreement with the simulated responses, validating the theory and design methods.

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References

[1] G. L. Matthei, L. Young, and E. M. T. Jones, *Microwave Filters Impedance–Matching Networks and Coupling Structures*. Norwood: Artech House 1980.

[2] E. Cristal and S. Frankel, "Hairpin-line and hybrid hairpin-line/half-wave parallel-coupled-line filters," *IEEE Trans. Microwave. Theory Tech*., vol. MTT-20, no. 11, pp. 719-728, Nov. 1972.

[3] C.-Y. Chang, C.-C. Chen, and H.-J. Huang, "Folded quarter-wave resonator filters with Chebyshev, flat group delay, or quasi-elliptical function response," *IEEE MTT-S Int. Microw. Symp. Dig*., Jun. 2-7, 2002, vol. 3, pp. 1609-1612.

[4] K. Chang, *Microwave Ring Circuits and Antennas*. New York: Wiley, 1996, ch. 3, 7, and 12.

[5] David M. Pozar, *Microwave Engineering* 3rd Edition, Chap. 8, Wiley: New York, 2005.

[6] J. S. Hong and M. J. Lancaster, *Microstrip Filters for RF/Microwave Applications*, Chap. 5, Wiley, New York 2001.

[7] L. Zhu, H. Bu, and K. Wu, "Broadband and compact multi-pole microstrip bandpass filters using ground plane aperture technique," *IEE Proc.-Microw. Antenna* Propag. vol 149, no. 1, Feb. 2002.

[8] Sonnet 10.51-Lite Plus User's Guide, Sonnet Software Inc. USA.

[9] Ansoft Designer version 1.0, Ansoft corporation. USA.

[10] Jayaseelan Marimuthu and Mazlina Esa, "Equivalent J – Inverter Network Parameters Analysis and Cancellation of Spurious Response of Parallel Coupled Microstrip Line," *IEEE Proceedings of 2006 International RF and Microwave Conference*. September 2006.

[11] Jayaseelan Marimuthu and Mazlina Esa, "Harmonic Cancellation of Parallel - Coupled Bandpass Filter with Transmission Zero Realign Method," *IEEE Proceedings of Asia-Pacific Conference on Applied Electromagnetics*, December 2005, pp. 227-231

[12] Jayaseelan Marimuthu and Mazlina Esa, "Wideband and Harmonic Suppressed Method of Parallel Coupled Microstrip Bandpass Filter using Centred Single Groove", *IEEE 2007 14th International Conference on Telecommunication Proceedings* May 14-17, 2007.

[13] Jayaseelan Marimuthu and Mazlina Esa, "Three Element Compact Broadband Parallel-Coupled Microstrip Bandpass Filter of Simple Configuration" *IEEE Proceedings of Asia-Pacific Conference on Applied Electromagnetics*, December 2007, 4 pp.

[14] Mazlina Esa, Jayaseelan Marimuthu and S. Kamilah Syed-Yusof, "Broadband and Compact Simple Ladder PCML Filter with Rectangular Center Resonator" *Proceedings of Int. Symp. on Antennas and Propagation (ISAP 2008)*, October 2008, 4 pp.