Harmonic Suppressed Single Groove PCML Bandpass Filter

[1]Jayaseelan Marimuthu and [2]Mazlina Esa

Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia.

[1]`jayaseelan.marimuthu@yahoo.com`

[2]`mazlina.esa@ieee.org`

Abstract— **This paper presents the design of single grooved parallel-coupled microstrip bandpass filter with improved passband response and first harmonic suppression. The undesired first harmonic spurious response is suppressed through transmission zero frequency realignment method. A single groove is located at the center of the parallel-coupled line. It is employed for the realignment of the transmission zero and first harmonic frequencies. Two three–stage bandpass filters of different operating bandwidths were designed and implemented with optimized groove. The measured results validate real harmonics suppression performance with controllable single groove dimensions.**

I. INTRODUCTION

Parallel-Coupled Microstrip Bandpass Filters (PCMBF) are widely employed in many microwave systems. Designs of PCMBF used the Parallel-Coupled Microstrip Line (PCML) structure as the main coupling component [1]. An undesirable disadvantage is the existence of the first spurious passband at twice the basic passband frequency, and the worse rejection of the upper stopband than the lower stopband. The inequality of the even and odd mode phase velocities of coupled lines in each stage causes the phenomenon as described in the behavior of a PCML structure [2].

Recently, various techniques have been proposed. These include sinusoidal modulation on the widths of two strip conductors [3] and the corrugated coupled-slot structure [4], [5] that extend the actual odd-mode traveling path towards its even-mode counterpart at the first-harmonic passband. Similarly, the square grooves are periodically and symmetrically etched out at both sides of the coupled lines [6]. Without knowing the even- and odd-mode characteristic impedances and phase velocities of these periodically non-uniform coupled microstrip lines, all the filters can only be designed optimally. Frequency-dispersive coupling performance of periodically non-uniform coupled microstrip lines is comprehensively investigated and the two-port periodically non-uniform coupled microstrip line with finite length is characterized as an equivalent *J*-inverter network [7]. The work involves reallocating the transmission zero towards suppressing the first harmonic passband of coupled microstrip-line filters.

In this paper, the suppression of harmonic response was carried out by transmission zero realignment method by using a simple modification via a single groove at the center of a PCML structure [8]-[9]. A single groove placed at the center of a PCML can be used to relocate the transmission zero frequency and first harmonic frequency. PCML structure with various coupling factors are investigated for single groove. Since the purpose of this work is to demonstrate the effectiveness of PCML single groove on elimination of unwanted harmonic, the low loss RT/Duroid RT6006 board of relative permittivity $\varepsilon_r = 6.15$ and substrate thickness $h = 1.27$ mm has been adopted. Detail studies about even and odd mode impedance and electrical length performance which describe the harmonic suppression by using transmission zero realign method utilizing a single optimized groove are presented next.

II. INVESTIGATION OF TRANSMISSION ZERO AND HARMONIC FREQUENCY ON PCML STRUCTURES

Fig. 1 shows the layout of a PCML structure of width (w), gap (s) and length (l), with and without groove. H and W are the height and width of the single groove. For a given bandwidth, operating frequency and passband response, the width w, gap size s and length l of each structure can be calculated by using even mode impedance Z_{oe}, and electrical length θ_e, odd mode impedance Z_{oo}, and electrical length θ_o [1].

To investigate the cancellation of harmonic on PCML stage, the behaviors of transmission zero frequency and harmonic frequency are investigated in detail. The transmission zero frequency of PCML must be accurately allocated at $2f_o$, so that the entire circuit is free of spurious at this frequency. The two-port impedance parameters [Z] of the open–circuit PCML structure Fig. 1a, with Z_o as the input and output impedances are given as [1]:

$$Z_{11} = Z_{22} = \frac{-j}{2}\left(\frac{Z_{oe}\cos(\theta_e)\sin(\theta_o) + Z_{oo}\cos(\theta_o)\sin(\theta_e)}{\sin(\theta_e)\sin(\theta_o)}\right) \quad (1)$$

$$Z_{21} = Z_{12} = \frac{-j}{2}\left(\frac{Z_{oe}\sin(\theta_o) - Z_{oo}\sin(\theta_e)}{\sin(\theta_e)\sin(\theta_o)}\right) \quad (2)$$

$$\alpha = Z_{oe}\cos(\theta_e)\sin(\theta_o) + Z_{oo}\cos(\theta_o)\sin(\theta_e) = 0 \quad (3)$$

$$\beta = Z_{oe}\sin(\theta_o) - Z_{oo}\sin(\theta_e) = 0 \quad (4)$$

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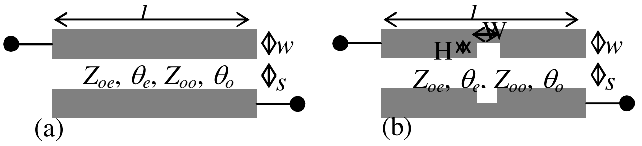

Fig. 1 PCML structure (a) PCMLng (b) PCMLwg.

The insertion loss of the PCMLng structure is given by

$$S_{21} = \frac{2\left(Z_{oe}\sin(\theta_o) - Z_{oo}\sin(\theta_e)\right)Z_o}{\left[Z_{11}^2 + Z_{11}Z_o + Z_{22}Z_o + Z_o^2 - Z_{21}^2\right]*(\sin(\theta_e)\sin(\theta_o))} \qquad (5)$$

Equation (5) shows that the zeros can be obtained by obeying equation (4). It can be concluded that the transmission zero for a simple PCML structure exists due to condition (4) which depends on even mode impedance Z_{oe}, and electrical length θ_e, odd mode impedance Z_{oo}, and electrical length θ_o.

To further investigate the behavior of higher order PCML structure, a single–stage bandpass filter is designed with a cascade of two PCML stages. The insertion loss S_{21} for the single–stage PCMBF is:

$$\frac{1}{S_{21}} = \frac{j\left(\frac{\alpha}{2Z_o}\right)\left[\beta^2 - \alpha^2 + 4Z_o^2\chi^2\right]}{\beta^2} - \frac{\chi\left(\beta^2 - 2\alpha^2\right)}{\beta^2} \qquad (6)$$

$$\chi = \sin\theta_o \sin\theta_e \qquad (7)$$

For $|S_{21}|$, the first pole (or resonant frequency) is mainly due to $\beta^2 - 2\alpha^2 = 0$, and second pole (harmonic frequency) due to $\alpha = 0$. f_z for $|S_{21}|$ is obtained by setting a condition $\beta = 0$ based on equation (4). It shows that f_z for a simple PCML structure and single–stage PCMBF based on cascaded PCML structure obey the condition (4). Meanwhile, f_h presence in a single–stage PCMBF is due to (3).

The above findings show that the harmonic presence in a single-stage PCMBF is due to $\alpha = 0$ and the transmission zero f_z is due to $\beta = 0$. Hence, for harmonic cancellation via transmission zero, $f_z = f_h$ is possible when $\beta = 0$, $\alpha = 0$ appear simultaneously. Based on these conditions [10],

$$\cos(\theta_e) + \cos(\theta_o) = 0 \qquad (8)$$

and hence it can be solved as

$$\theta_o = n\pi \pm \theta_e \quad n=1,2,3....... \qquad (9)$$

For first f_h and harmonic cancellation by f_z, $n = 1$,

$$\theta_o = \pi - \theta_e \qquad (10)$$

$$Z_{oo} = Z_{oe} \qquad (11)$$

This shows that f_h of a single–stage PCMBF can be cancelled by f_z if electrical length and characteristic impedance of odd mode obey conditions (10) and (11). This can be effectively achieved by using a simple optimized groove at the centre of a PCML structure.

III. SINGLE GROOVE PCML STRUCTURE

To control the transmission zero frequency which depends on even and odd mode parameters, a single groove is introduced at the center of PCML structure as shown in Fig. 1(b). For given any PCML structure, along the coupled lines in Fig. 1(a), the odd mode propagates faster than the even mode. By introducing a groove, it is possible to make these two modes obey the conditions (10) and (11) when the size is properly chosen.

Fig. 2 shows the behavior of even and odd mode parameters for various groove sizes for PCMLwg with w = 1.0 mm and s = 0.2 mm. It shows that for groove of W = 1.0 mm and increasing H, Z_{oo} increases at a higher rate compared to Z_{oe}, and f_{odd} decreases at a higher rate compared to f_{even}. This means that θ_o increases at a higher rate compared to θ_e. Thus, a single groove at the center of PCML effectively increases Z_{oo} and θ_o compared to Z_{oe} and θ_e. Hence, it can be used to shift f_z to the required position based on condition (4).

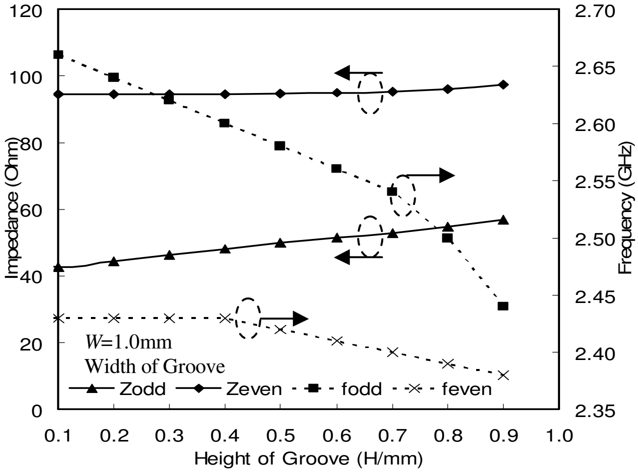

Fig. 2 Behavior of even and odd mode parameters for a single groove of W=1.0 mm and various H at center of PCMLng w = 1.0 mm and s = 0.2 mm.

By placing such a single groove, f_z can be effectively shifted to the required frequency. A similar study was carried out for a single–stage PCMBF by placing a single groove to investigate the shifting of f_z and f_h.

The vertical axis of Fig. 3 is frequency normalized with respect to f_o = 2.45 GHz. For a single–stage PCMLng, the harmonic frequency f_h = 2.06f_o and f_z = 2.3f_o. As the single groove is placed at the center of PCMLng, the normalized f_z (β = 0) shifts to a lower value at higher rate compared to normalized f_h (α = 0) as H increases for W = 1.0 mm. The effects are mainly due to changes in odd mode parameters as H increases with fixed W. For a single groove with W = 1.0 mm, when $H < 0.7$, $f_h < f_z$ and when $H > 0.7$, $f_h > f_z$. When H = 0.7 mm, f_z (β = 0) = f_h (α = 0) = 1.87f_o obeyed. This will lead to accurately placing transmission zero at 1.87f_o which is important for extending the upper stopband as shown in Figs. 4 and 5.This shows that f_h of a single–stage PCMBF can be cancelled by f_z if electrical length and characteristic impedances of odd mode and even mode obey conditions (10) and (11). This can be effectively achieved by using a simple optimized groove at the centre of a PCML structure.

Fig. 4 shows the shifting of transmission zero frequency from $2.3f_o$ to $1.87f_o$ when the single groove of $W = 1.0$ mm and $H = 0.7$ mm placed at the center of PCMLng. Generally it shows that a simple single groove will lead to shifting of transmission zero frequency to respective frequency. There are degrees of freedom to tune the PCML transmission zero frequency at a respective harmonic frequency.

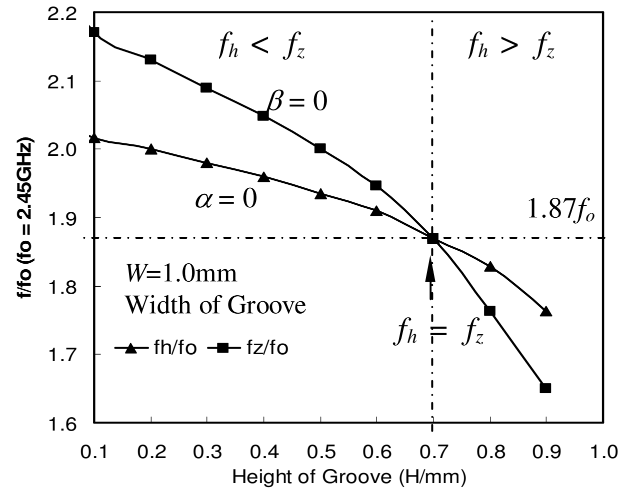

Fig. 3 Behavior of f_z and f_h for a single groove of W=1.0 mm and various H at center of PCMLng with w = 1.0 mm and s = 0.2 mm of a single-stage PCMBF.

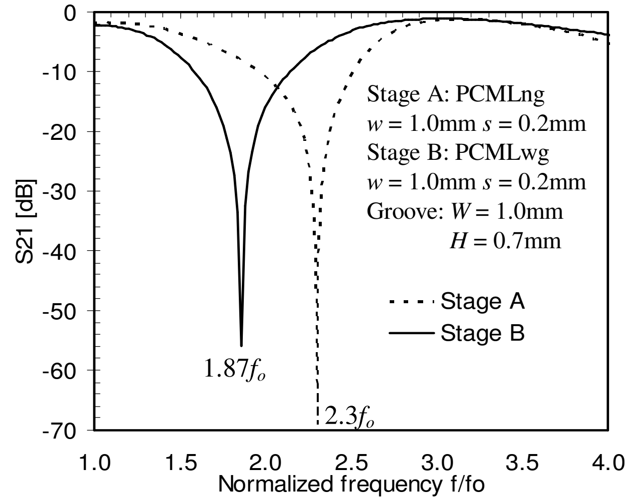

Fig. 4 $|S_{21}|$ for the PCML structure without and with optimum size groove

The response for a single–stage PCML cascade A (two stage A, no groove) and cascade B (two stage B) in vicinity of ~$2.0f_o$, are shown in Fig. 5. Both cascades exhibit the same zeroes as in Fig. 4. For cascade A, there is a 0 dB spurious peak at $2.06f_o$ and transmission zero at $2.3f_o$. For cascade B with $W = 1.0$ mm and $H = 0.7$ mm, no peak is present near ~$2.0f_o$, as expected, which is fully suppressed by the transmission zero at $1.87f_o$. For further demonstration, the response of cascade C with $W = 1.0$ mm and $H = 0.9$ mm is also plotted. The spurious peak locates at approximately $1.76f_o$ and its level is -10 dB while transmission zero is at $1.65f_o$.

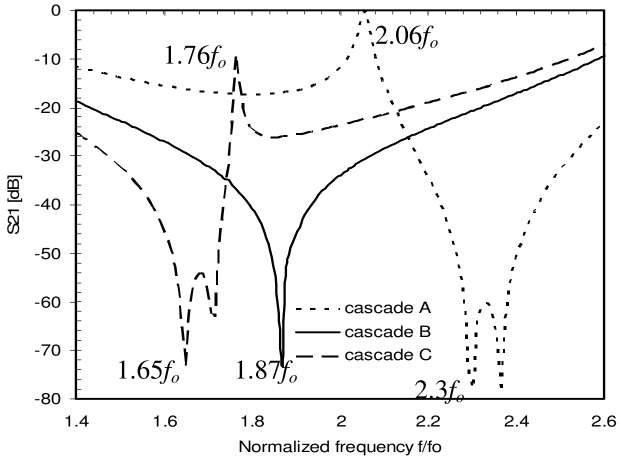

Fig. 5 $|S_{21}|$ for the single – stage PCML w = 1.0 mm and s = 0.2 mm without and with optimum size groove. Cascade A: No Groove, Cascade B: W = 1.0 mm H = 0.7 mm and Cascade C: W = 1.0 mm H = 0.9 mm

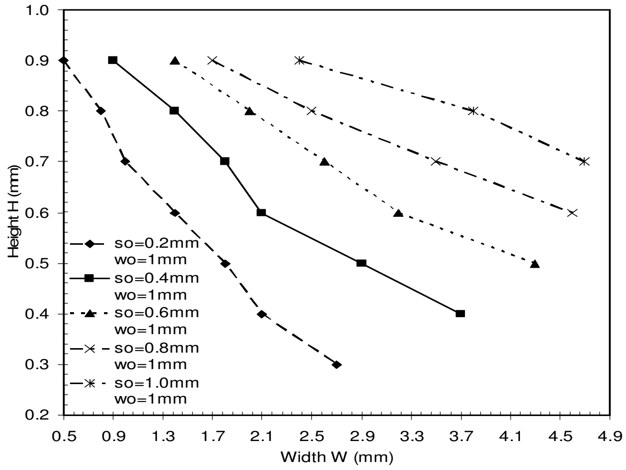

Fig. 6 Geometry parameters for a optimized single groove with zeros simultaneously tuned at ~$2.0f_o$.

Fig. 6 presents the geometric parameters of a single groove in PCMLwg for simultaneously tuning zeros at ~$2.0f_o$ harmonic suppression for various PCML structures. The results of optimized single groove dimensions for various PCML structures with w = 1.0 mm, and s = 0.2 mm, 0.4 mm, 0.6 mm, 0.8 mm and 1.0 mm are given in Fig. 6. When s in increased, respective harmonic suppression groove of larger size is required. This is because, for the odd mode propagation with increasing s, the coupling between the two strips decreases and hence the wave travels faster. The groove width is then increased to compensate or slow down its phase velocity. Based on the data in Fig. 6 which shows optimized groove for various PCML structures, three–stage PCMBFwg filters were designed with different operating bandwidths.

V. HARMONIC SUPPRESSED THREE – STAGE PCMBF

Three–stage PCMBFwg were designed with various combinations of single–stage PCMBF with optimized groove for harmonic suppression at different operating bandwidths. Fig. 7 shows a three–stage PCMBF formed by cascading of two various coupling gap single–stage PCMBF with optimized groove. The optimized filters were then fabricated and measured. Both measured and simulated results in Fig. 8 agree well with each other, showing full suppression of harmonic response for various bandwidths. The filters show excellent performance in terms of harmonic suppression with sharp-rejection stopbands but the return and insertion losses are unable to improve due to the single groove which reduces the coupling factor. Filter 1 shows response of bandwidth ~ 11% while Filter 2 shows response of > 18%.

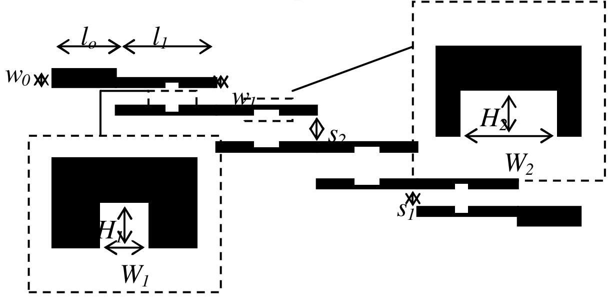

Fig. 7 Layout of Three–Stage PCMBF with Single Groove at Center of PCML.

VI. CONCLUSION

Detailed investigations on harmonics cancellation by using f_z realign method is presented. This can be done by using specific single groove located at the center of a PCML structure. Then, a simple three–stage PCMBF is demonstrated for different operating bandwidths. Various operating filter bands with sharp-rejection stopbands and excellent rejection of first harmonic spurious response can be achieved. For validation, two 2.45 GHz of various operating bands in a three-stage PCMBF prototype, useful in full-duplex Local Area Network (LAN) communication, have been demonstrated. The resulting agreement between measurements and simulations has confirmed the experimental viability of the filter topology.

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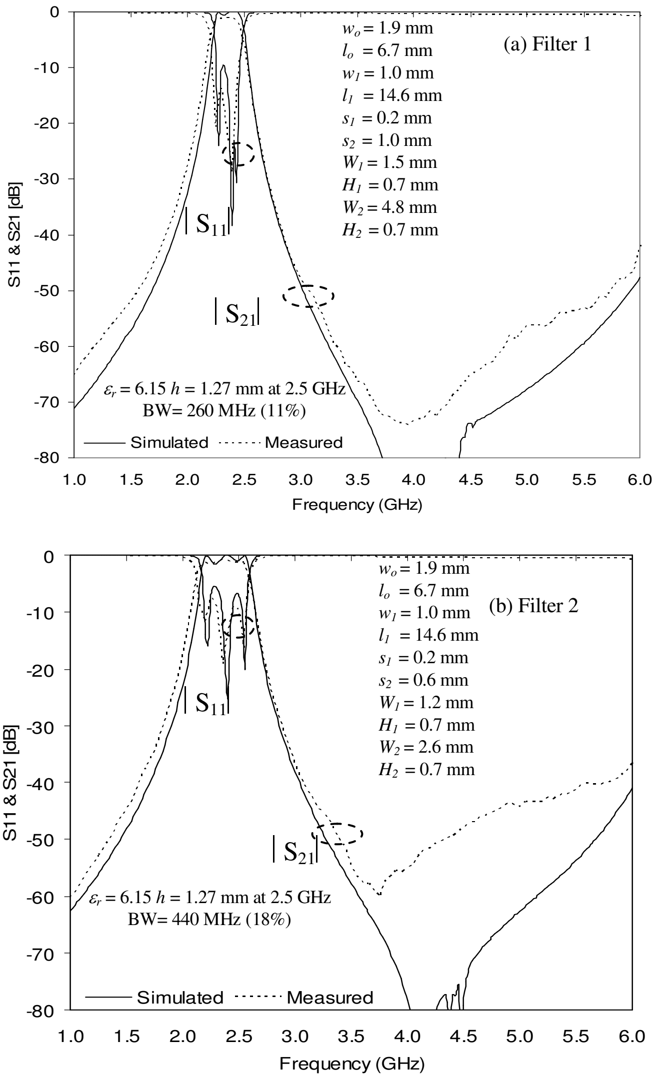

Fig. 8 Performances of various three–stage single grooved PCMBFs.