Single-Stage Parallel Coupled Microstrip Line Bandpass Filter using Weak Coupling Technique

Jayaseelan Marimuthu, Student MIEEE, Mazlina Esa, SMIEEE and S-Kamilah Yusof, MIEEE

Telematics Research Group, Faculty of Electrical Engineering,
81310 UTM Skudai, Johor Darul Takzim, MALAYSIA. mazlina.esa@ieee.org

Abstract **-** The frequency–dispersive characteristic of a two-port parallel coupled microstrip line (PCML) can be obtained using equivalent *J*–inverter network parameters. The latter is obtained from its corresponding admittance parameters. Hence, the behaviour of transmission zero frequency, fundamental response frequency and harmonic response frequency of the PCML can be shown. The former is realigned by varying a centrally located single groove size to suppress the first spurious harmonic passband of the filter. Using the *J*–inverter parameters, the transmission zero of *J*-susceptance null of a PCML can be realigned by employing a single groove with specific dimension. This simultaneously cancels the first harmonic resonance. In this paper, the behaviour of the *J*–inverter parameters with varying coupling gaps is presented. The effect of having weak coupling characteristic is then presented. The proposed technique is then justified by two single-stage bandpass filters of PCML with weak coupling characteristic.

Keywords: Bandpass filter; harmonic suppression; transmission zero; J–inverter network, two port admittance network.

1. Introduction

The parallel-coupled microstrip line (PCML) structure has been used as coupling components in the design of bandpass filters [1], [2]. Though the filters are popular and simple to implement, the traditional design suffers from a fundamental limitation, i.e., the presence of spurious response at twice the frequency of the basic passband. This is mainly due to the velocity of the odd mode that travels faster than that of the even mode, whilst both modes concentrate at different edge of the PCML. Various techniques have been proposed to minimize the harmonic response by restructuring or redesigning the filter with new physical design parameters [3], [4] or reallocation of the transmission zero frequency [5].

A different method has been proposed which employs transmission zero frequency realignment that will simultaneously cancel the spurious response at the first harmonic frequency [6]-[9]. The PCML two port admittance parameters are first extracted by full wave analysis using commercially available *em* software such as Sonnet [10]. Then, for the equivalent *J*–inverter network of PCML, parameters such as *J*–susceptance and electrical line length, θ, are calculated by using extracted susceptance of PCML two–port admittance parameters. The equation proposed in this paper is for *J*–susceptance and electrical line length, θ, giving good agreement when compared with PCML *S* – parameters. The *J*–susceptance and electrical line length, θ, parameters are used as main tools, to obtain the transmission zero frequency, fundamental frequency and first harmonic response frequency of PCML which are unable to be identified by using any other methods. The *J*–inverter networks parameters, which were extracted from modified PCML, will identify the transmission zero frequency and first harmonic response frequency.

This paper presents a modified PCML by weak coupler (WCg). Initial work has been done by the tight coupler (TCg) method. After realignment of transmission zero frequency and first harmonic frequency, single-stage bandpass filter can be designed for both TCg and WCg. The single-stage TCg and WCg filters are able to demonstrate that the first harmonic resonance can be fully suppressed. Three-stage bandpass filter can then be designed by using the modified TCg and WCg structure. The response showed the full suppression of spurious response as predicted. This paper presents the investigation of PCML that is modified for WCg. A filter that has a combination of both TCg and WGg is then presented.

2. Modified PCML with Weak Coupling

The PCML geometry is shown in Figure 1. It is the basic unit of a Parallel Coupled Microstrip Bandpass Filter (PCMBF) with feeding impedance of Z_o. The PCML with length l, width w and coupling gap s, has the characteristic impedance and phase constant of even mode as Z_{even}, β_{even}, and odd mode as Z_{odd}, β_{odd}. The PCML structure is a reciprocal and lossless network. The corresponding equivalent circuit and J-inverter network are shown in Figures 2 and 3, respectively.

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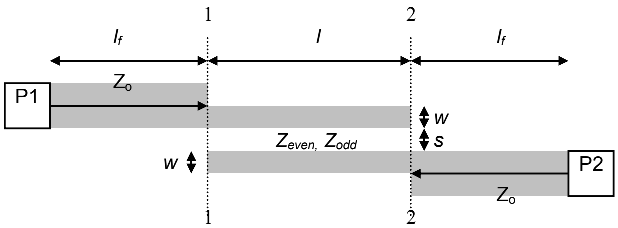

Figure 1: Physical Layout of Parallel Coupled Microstrip Line (PCML) with Z_o feeding.

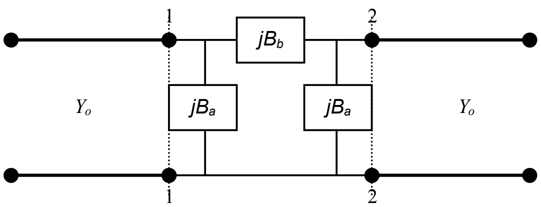

Figure 2: Equivalent Circuits for Reciprocal Two Port Network Admittance for Lossless PCML

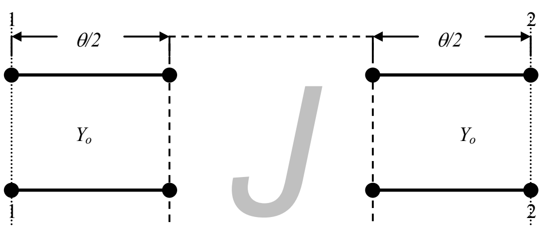

Figure 3: Equivalent *J* – Inverter Network with Susceptance *J*

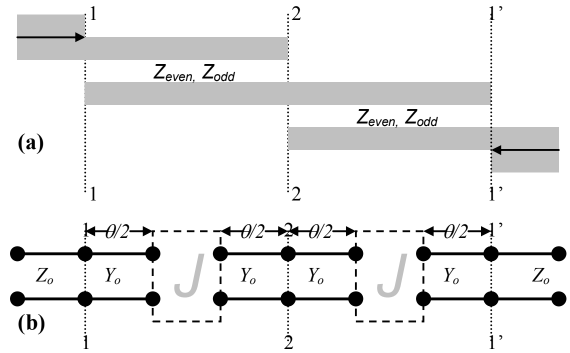

Figure 4: Single–Stage PCMBF (a) Physical Layout and (b) Equivalent *J*–Inverter Circuit

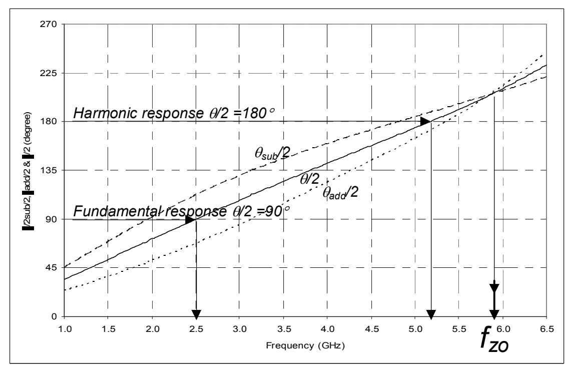

Figure 5: Frequency–Dispersive Electrical Line Length of Equivalent *J*–Inverter Network of PCML.

The PCML has been shown as a single–stage PCMBF in Figure 4 with its equivalent *J*–network. From the equivalent *J*–network of two PCMLs, the middle transmission-line resonator is actually formed by cascading two identical electrical lengths of $\theta/2$, where its overall length become θ. The transmission– line resonator resonates at the frequencies of $\theta = 180°$, 360°, 540°, etc. The first resonance occurs at $\theta = 180°$ [$\theta/2 = 90°$ at $f_o = 2.52$ GHz in Figure 5], and is usually utilized to make up the dominant passband in the design of a bandpass filter. The second resonance at $\theta = 360°$ [$\theta/2 = 180°$ at $f = 5.18$ GHz in Figure 5] contributes to the first–harmonic spurious passband.

Figure 6 shows the simulated responses from the full–wave analysis of single-stage PCMBF. It can be seen that the fundamental response or first resonance occurs at $f_o = 2.52$ GHz and the second resonance or first harmonic spurious passband at $f_h = 5.18$ GHz with transmission zero at $f_{zo} = 5.86$ GHz. It can be concluded that the *J*–network analysis method can be used as a main tool for designing PCMBFs.

The effect of groove has been investigated for PCML with coupling gap $s = 0.2$ mm (Tight Coupler, TCg) and $s = 0.6$ mm (Weak Coupler, WCg). This paper reports on the latter.

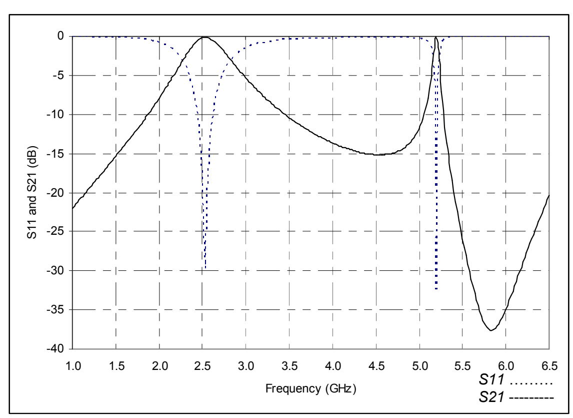

Figure 6: Simulated responses of PCMBF.

3. Harmonic Response and Transmission Zero for WCg

Optimization of groove size was performed by adjusting the groove width (W) and height (H). Figure 7 shows the transmission zero frequency and harmonic response frequency for groove of fixed height (H=1mm), and different W. It can be seen that $f_{zo} > f_h$ when 0 < W < 2.4 mm and $f_{zo} < f_h$ when W > 2.4 mm, for H = 1.0 mm. It is observed that $f_{zo} = f_h$ = 4.68 GHz when W = 2.4 mm. It can be concluded that when H = 1.0 mm and W = 2.4 mm, the transmission zero frequency equals the first harmonic response and able to cancel the first harmonic response. The effects of normalized J susceptance maximum value versus W are given in Figure 8. Its shows as the W increase normalized J susceptance maximum value drop at higher rate for 0 < W < 0.4 mm and slower rate for W > 0.4 mm. At W = 2.4 mm, when $f_{zo} = f_h$ = 4.68 GHz, J susceptance maximum value drops 15% compared with no W.

Further optimization of the single groove for WCg was carried out by adjusting H for fixed W. The performance showed that for W = 1.2 mm, as H increases, the transmission zero and first harmonic frequency in Figure 7 reduces quasi-linearly to smaller value.

In Figure 7, $f_{zo} > f_h$ when 0 < H < 1.4 mm and $f_{zo} < f_h$ when H > 1.4 mm, for W = 1.2 mm. It is observed that $f_{zo} = f_h$ = 4.62 GHz when H = 1.4 mm. It can be concluded when W = 1.2 mm and H = 1.4 mm, the transmission zero frequency equal to the first harmonic response and this able to cancel the first harmonic response. The effects of normalized J susceptance maximum value versus W are given in Figure 8. Its shows as the W increase normalized J susceptance maximum values drop at quasi linearly. For H = 1.4 mm, when $f_{zo} = f_h$ = 4.62 GHz, J susceptance maximum value drops 12% compared with no H.

Two different sets of single-stage bandpass filter are designed by using two identical WCg coupler with single groove of H = 1.0 mm but different W, and W = 1.2 mm but different H. The corresponding frequency responses are depicted in Figures 9 to 10. As discussed, single-stage bandpass filter with WCg of groove H = 1.0 mm and W = 3.0 mm (WCg A) shows that the cancellation of first harmonic response compared to other WCg with groove configuration for fixed H as shown in Figure 11. In Figure 12, a single-stage bandpass filter with WCg of groove H = 1.4 mm and W = 1.2 mm (WCg B) shows the cancellation of first harmonic response compared to other WCg with groove configuration for fixed W. The two single-stage bandpass filter of two identical WCg with groove of H = 1.0 mm, W = 3.0 mm (WCg A) and H =1.4 mm, W = 1.2 mm (WCg B) are compared. The single-stage bandpass filter of WCg B shows better response.

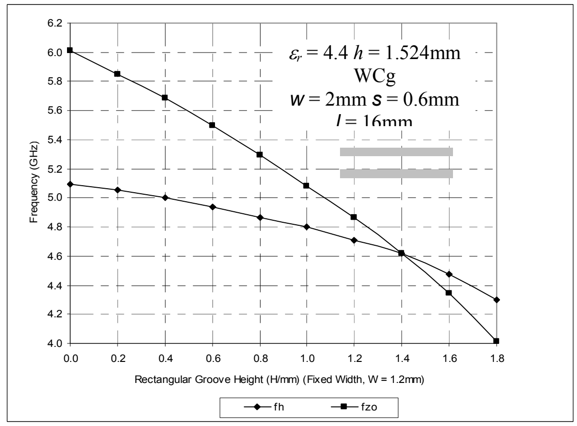

Figure 7: Frequency of Transmission Zero and harmonic resonance for Single Groove with H = 1 mm and different W for WCg

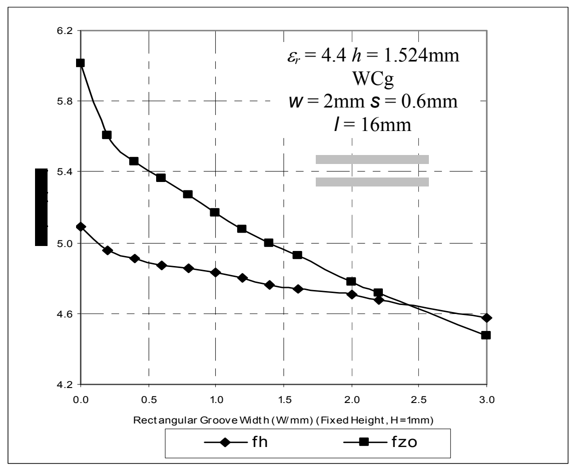

Figure 8: Normalized J Susceptance maximum value for Single Groove with H = 1 mm and different W for WCg

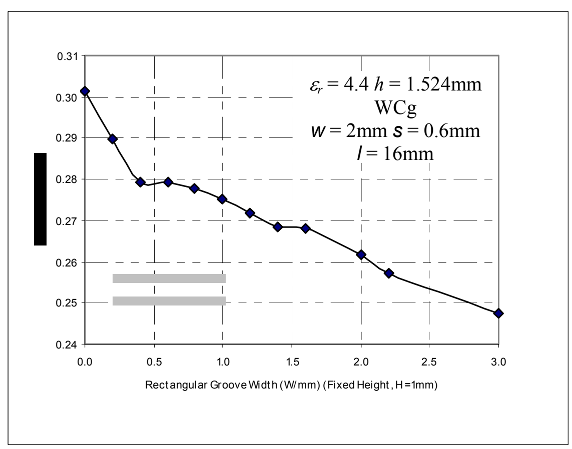

Figure 9: Frequency of Transmission Zero and harmonic resonance for Single Groove with W = 1.2 mm and different H for WCg

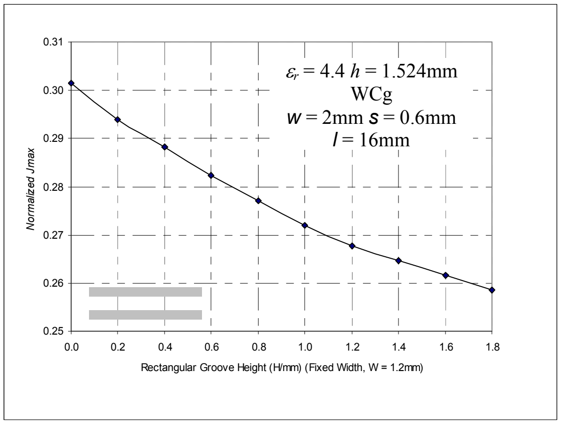

Figure 10: Normalized *J* Susceptance maximum value for Single Groove with W = 1.2mm and different H for WCg

The single groove is able to realign the transmission zero frequency to cancel first harmonic frequency of the single-stage bandpass filter. Harmonic suppression is hence possible with a groove.

4. Filter Implementation

With this idea, by using coupled microstrip line with single groove at the center, a multistage bandpass filter can be designed with harmonic suppression. It has been found that TCg B and WCg B with groove are optimum couplers which are able to cancel the presence of spurious response by realigning the transmission zero frequency. A three stage bandpass filter (*G*-PCMBF) has been design with TCg B and WCg B, as shown in Figure 14. The optimum tight couplers (TCg B) are arranged at the input and output of the filter. The optimum weak couplers (WCg B) are put at the middle section of the filter.

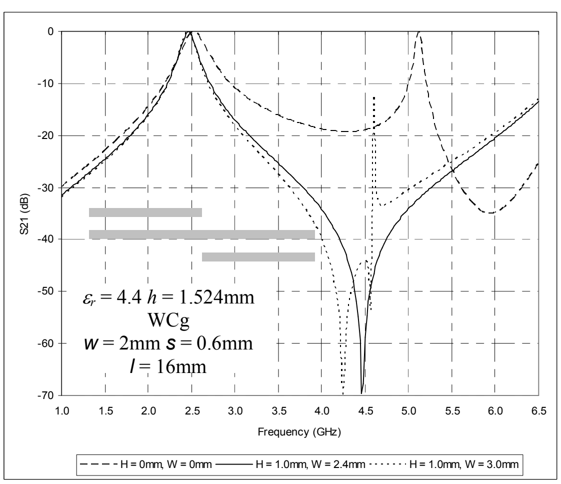

Figure 11: Frequency Response of single-stage bandpass filter with single groove of H = 1.0 mm and different W for WCg.

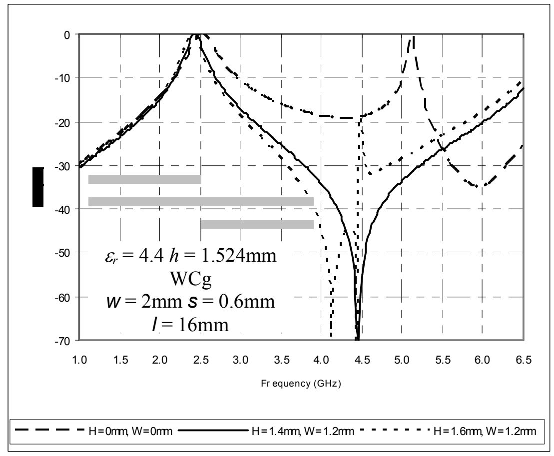

Figure 12: Frequency Response of one-stage bandpass filter with single groove of W = 1.2mm and different H for WCg.

Figure 13 shows the predicted *S*-parameters for the same filter without groove with TCg and WCg (PCMBF). The response of PCMBF shows spurious response at first harmonic frequency. The response of *G*-PCMBF shows that, the spurious response as in In Figure 13, the first harmonic frequency for PCMBF is completely suppressed. The performances of the filter improved in terms of harmonic suppression and symmetrical response center at 2.45 GHz. The insertion loss is higher than 60 dB at the first harmonic passband located around 4.9 to 5.0 GHz. The predicted *S*-parameters of *G*-PCMBF are shown in Figure 14.

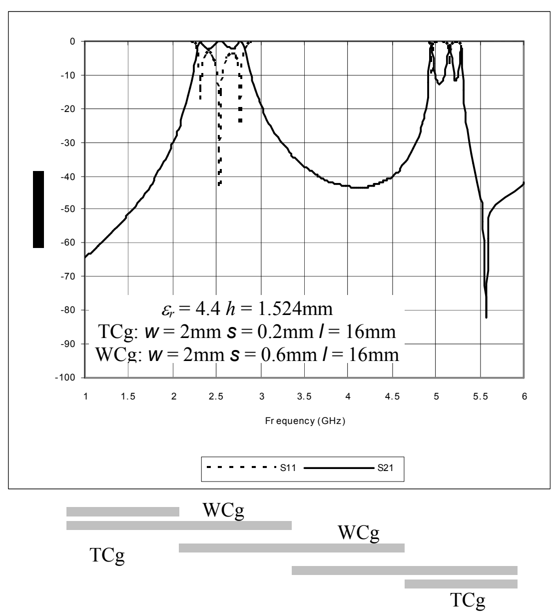

Figure 13: Predicted *S*-Parameters of Three Stage Bandpass Filter without Groove (PCMBF)

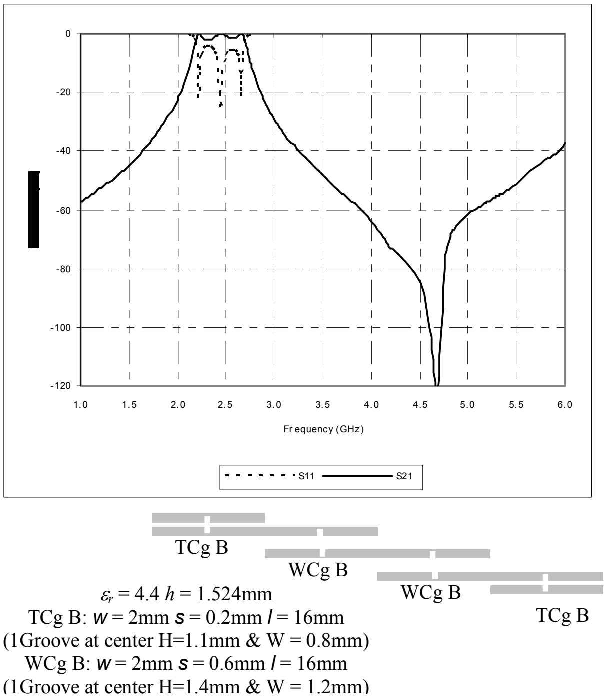

Figure 14: Predicted *S* – Parameters of Three Stage Bandpass Filter with Groove (*G*-PCMBF)

5. Conclusion

Generallly, two port admittance network parameters of a PCML structure are obtained from commercial *em* software. These can be used to calculate the J-inverter parameters of equivalent J- inverter network of PCML, such as normalized susceptance J and electrical line length θ. The J-inverter network parameters are precise tools for transmission zero realign techniques for cancellation of spurious response of PCMBF. Detail studies carried out show the behavior of J-inverter parameters for various PCML configurations. A technique was identified by using J-inverter parameters to cancel the spurious response. It has been shown that the transmission zero of J susceptance null of the PCML can be realigned to cancel the first harmonic resonance. This was done by using a single groove with specific dimension. The proposed technique was justified by two single-stage bandpass filter of PCML with TCg and WCg coupler. Finally a three stage bandpass filter was designed by using optimal TCg and WCg coupler, which shows the suppression of spurious response at first harmonic.

Acknowledgement

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