Harmonic Cancellation of Parallel-Coupled Bandpass Filter with Transmission Zero Realign Method

Jayaseelan Marimuthu[1] and Mazlina Esa[2]

[1] Faculty of Engineering
Multimedia University
Jalan Multimedia
Cyberjaya, Selangor Darul Ehsan

[2] Microwave/RF and Antenna Research Group
Department of Radio Communication Engineering
Faculty of Electrical Engineering
81310 UTM Skudai
Johor Darul Takzim, Malaysia
mazlina@fke.utm.my

Abstract--This paper presents the harmonic cancellation of a 3rd order Butterworth response parallel-coupled bandpass filter by introducing periodical grooves. The cancellation was obtained by aligning the transmission zero of the Tight Coupling (TCg) coupler with the harmonic of the Weak Coupling (WCg) coupler. The alignment of transmission zero and harmonic was carried out by introducing square grooves periodically at the TCg and WGc couplers. Various numbers of grooves were introduced at the TCg and WCg couplers. By varying the number of grooves at the TCg coupler, the first transmission zero was obtained. Then similar method was used to align the harmonics of the WCg coupler with transmission zero of the TCg coupler. When three stage bandpass filter design with transmission zero of the TCg coupler is aligned with the harmonic of the WCg coupler, the overall the performance of filter improved in terms of suppression of the harmonics and cutoff frequencies.

1. Introduction

Parallel coupled microstrip structure has been widely used as coupling components in the design of bandpass filters due to attractive features [1]. Although microstrip parallel-coupled bandpass (MPT) filter with uniform coupled microstrip line sections are popular and simple to be implemented, the conventional design suffers from the spurious passband at the harmonic response at second resonance frequency.

The presence of harmonic at second resonance frequency also worsens the performance of upper stopband and lead to degradation of the overall system performance. These effects are mainly due to the presence of even and odd mode at the parallel-coupled elements, with difference in their velocities. Odd mode travels faster than even mode and both modes concentrate at various parts of the parallel-coupled microstrip [2], [3]. Various techniques have been proposed to equalize the even and odd mode velocities of the parallel-coupled, which lead to minimization of harmonic response. All the techniques proposed above lead to the restructure or redesign of the filter with new physical design parameters [2], [3].

The technique discussed here does not require recalculation for new structure, but modification of the structure with same physical dimensions obtain from well-known equations by introducing square grooves in a periodical manner [4], [5]. The design frequency and operating bandwidth were f_o = 2.5 GHz and 10%, with Butterworth response. The chosen microwave laminate has permittivity, ε_r of 10.2 and substrate thickness, h of 0.64 mm. The design equations for the physical dimensions of a parallel-coupled bandpass filter were used, which is the most accurate design equation based on the modified equations from Sina Akhtarzad, Thomas R. Rowbotham and Peter B. Jones [5], [6], [7].

2. Physical Design Parameters

The 3rd order of Butterworth response was chosen to investigate the performance of the filter, with and without periodical square grooves (PSG). Table 1 shows the design parameters for a 3rd order Butterworth response MPT filter. Based on the design parameters, the filter was simulated in Ansoft Designer for filter responses, $|S_{11}|$ and $|S_{21}|$. Figure 1 shows the conventional design of a 3rd order MPT filter

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based on the physical dimension of Table 1 with f_o = 2.5 GHz and 10% FBW, w = 0.6 mm, l = 10 mm of the input and output ports (Z_o = 50 Ω). The corresponding simulated return and insertion losses responses for the 3rd order Butterworth response MPT filter are as depicted in Figure 2. The return and insertion losses responses clearly show that the first harmonic resonance frequency at 5 GHz is present heavily and the upper cutoff frequency was also affected, where the response is not symmetry at f_o.

Table 1: Physical parameter for the 3rd order Butterworth response MPT filter centered at 2.5 GHz with a 10% FBW, w = 0.6 mm, l = 10 mm of the input and output ports (Z_o = 50Ω)

ε_r = 10.2 h = 0.64 mm (RO30010)							
n	Z_{oe}(Ω)	Z_{oo}(Ω)	w_n/h	s_n/h	w_n mm	s_n mm	L mm
1	77.6706	38.0373	0.6548	0.2322	0.4191	0.1486	11.528
2	56.1705	45.0632	0.9381	1.1294	0.6003	0.7228	11.204
3	56.1705	45.0632	0.9381	1.1294	0.6003	0.7228	11.204
4	77.6706	38.0373	0.6548	0.2322	0.4191	0.1486	11.528

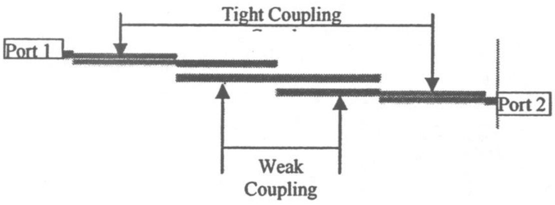


Figure 1: The design of a 3rd order Butterworth response MPT Filter.

To further investigate the presence of first harmonic response, the 3rd order filters coupled regions were separated. The 3rd order MPT filter has two coupling regions as shown in Figure 1. One is Tight Coupling (TCg) coupler (Figure 3) and the other is Weak Coupling (WCg) coupler (Figure 5). Both couplers have different responses with respect to frequencies, as illustrated in Figures 4 and 5. The coupling region was investigated separately for transmission zero and harmonic response.

The investigation shows that the first harmonic was also present in TCg coupler at f^{h}_{T} = 5.10 GHz and WCg coupler at f^{h}_{W} = 5.5 GHz. The transmission zero located at f^{0}_{T} = 5.88 GHz for TCg coupler and f^{0}_{T} = 6.7 GHz for WCg coupler.

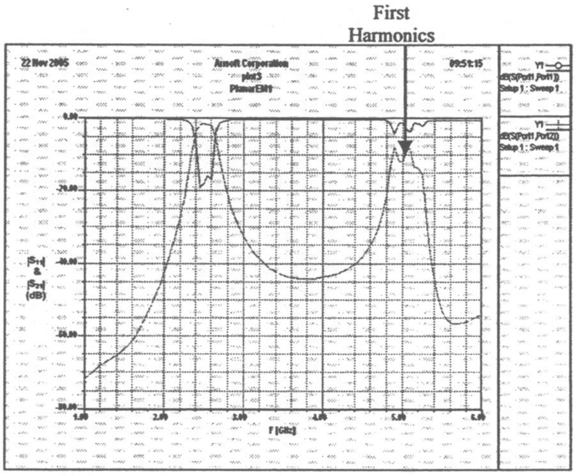


Figure 2: Simulated responses for the 3rd order MPT filter.

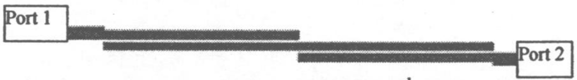


Figure 3: The design of TCg Coupler of a 3rd order Butterworth response MPT Filter.

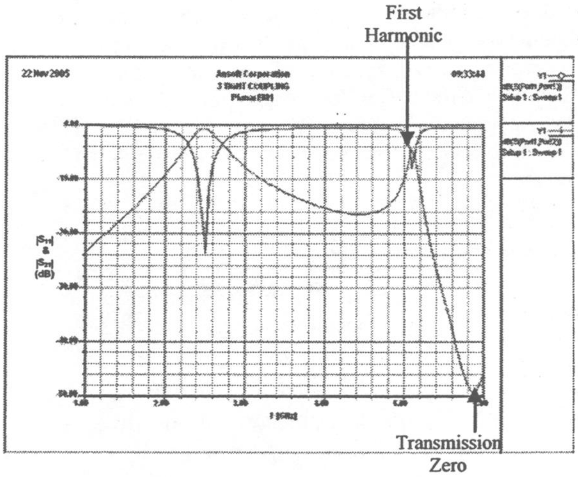


Figure 4: The response of TCg Coupler of the 3rd order MPT filter.

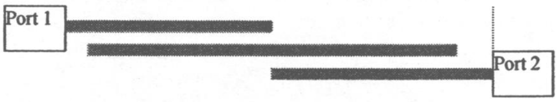


Figure 5: The design of WCg Coupler of a 3rd order Butterworth response MPT Filter.

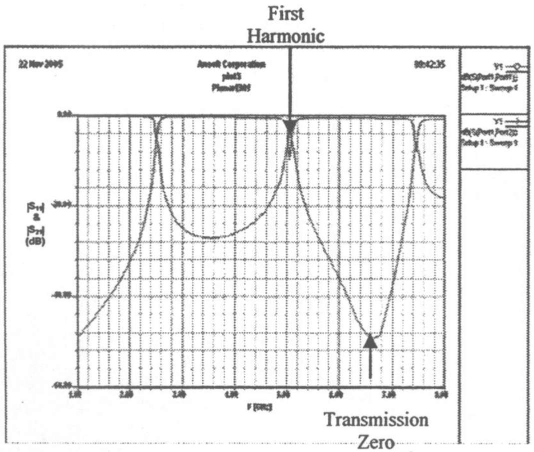


Figure 6: The response of WCg Coupler of 3rd order MPT.

From the investigations, it can be concluded that the first harmonic in the 3rd order Butterworth response are mainly contributed by the first harmonic in TCg coupler and WCg coupler. If steps are taken to align the first harmonic and transmission zero of TCg coupler and WCg coupler at $f^{0} = f^{h}$ frequency, the harmonic in 3rd order filter can be suppressed. Multiple grooves periodically introduced at parallel- coupled region give good option to control the movement of the frequencies. As *n* increases, the center frequency effectively shifted. The PSGs as in Figure 7 were used as the main option to control the movement of f^{0} and f^{h} in order to realign $f^{0} = f^{h}$ at the TCg coupler and WCg coupler.

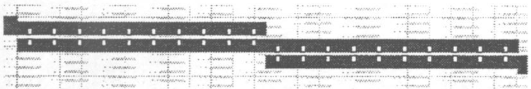


Figure 7: Ten square grooves were introduced periodically.

3. Tight Coupling Coupler: Harmonic & Transmission Zero Frequency Realign

Various *n* were introduced as listed in Table 2 and illustrated as shown in Figure 7. Initially, it shows that $f^{0}_{T} > f^{h}_{T}$ as n increases. The transmission zero frequency and first harmonic frequency getting closer ($f^{0}_{T} = f^{h}_{T}$) at $n = 8$, and when n > 8, $f^{0}_{T} < f^{h}_{T}$. The results are summarized as follows: $f^{0}_{T} > f^{h}_{T}$ when $0 < n < 8$, $f^{0}_{T} = f^{h}_{T}$ when n = 8 and $f^{0}_{T} < f^{h}_{T}$ when n > 8. For TCg coupler, transmission zero frequency equals to first harmonic response $f^{0}_{T} = f^{h}_{T}$ when $n = 8$. This clearly shows that the first harmonic frequency can be cancelled via the transmission zero realign technique.

Table 2: Transmission Zero and First Harmonic Response Frequency versus Finite Square Grooves (*w/2*) for Tight Coupled with Fixed Coupling Length (*L*) $L = 11.528$ mm $w = 0.4191$ mm and $s = 0.1481$ mm.

Number of Grooves	Transmission Zero Frequency, f^{0}_{T}	First Harmonic Frequency, f^{h}_{T}
0	5.88	5.10
1	5.72	5.02
2	5.71	5.01
3	5.68	5.00
4	5.39	4.91
5	5.36	4.90
6	5.34	4.86
7	5.16	4.80
8	4.67	4.67
9	4.47	4.60
10	4.15	4.56

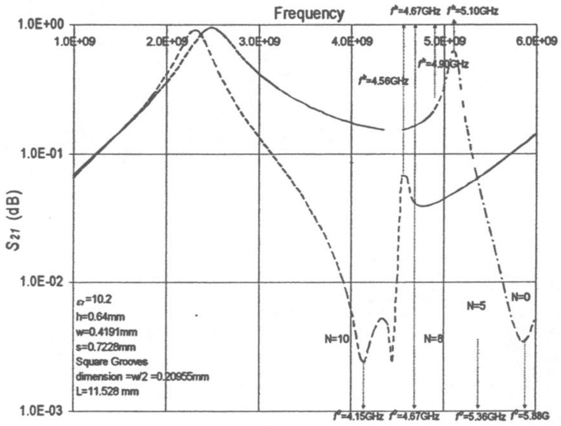


Figure 8: Frequency response of Tight Coupling coupler of 3rd order Butterworth response filter for various *n* and fixed *L*.

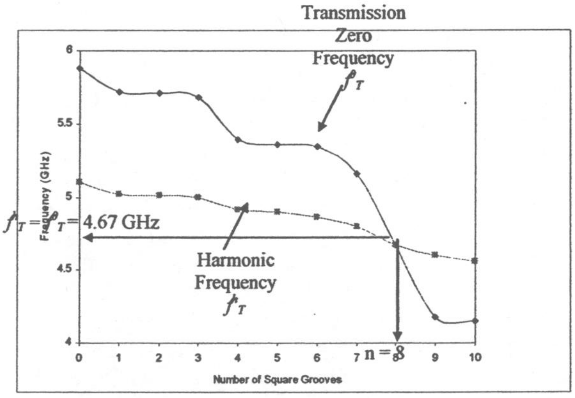


Figure 9: Frequency of Transmission Zero and the First Harmonic as the number of grooves increases.

4. Weak Coupling Coupler: Harmonic and Transmission Zero Frequency Realign

Table 3 and Figure 10 show that as *n* increases, the rate of decaying of harmonic frequency f^{h}_{W} and transmission zero frequency f^{θ}_{W} for WCg coupler is slower. Both did not meet at one frequency. It can be inferred that $f^{\theta}_{W} > f^{h}_{W}$ for any value of *n*. However, as *n* increases, f^{θ}_{W} and f^{h}_{W} decreased. Hence, the harmonic of WCg coupler f^{h}_{W} can be aligned to transmission zero of f^{θ}_{T} of the TCg coupler.

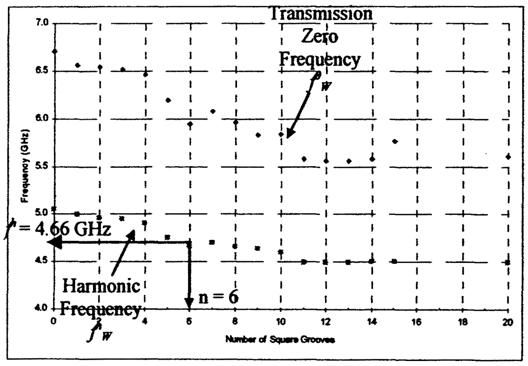


Figure 10: Frequency of Transmission Zero and First Harmonic as *n* increases.

5. Improved Design of MPT Filter

From the above investigations, it has been shown that for a TCg coupler, the first harmonic f^{h}_{T} and the transmission zero f^{θ}_{T} frequency can be aligned at the respective frequency to cancel out the spurious response. But for the WCg coupler, the first harmonic f^{h}_{W} and the transmission zero f^{θ}_{W} frequency cannot be aligned at the respective frequency, hence the spurious response is not cancelled out. The 3rd order MPT filter with TCg and WCg couplers with various *n* were brought together in one design to suppress the harmonic response.

The TCg coupler exhibits harmonic suppression by bringing the $f^{\theta}_{T} = f^{h}_{T} = 4.67$ GHz when $n = 8$, with the PSG dimension $w/2 = 0.20955$ mm. This configuration was used to design the TCg coupler for 3rd order Butterworth response MPT filter with center frequency $f_o = 2.5$ GHz. Next, the WCg coupler does not exhibit harmonic suppression, but shows the movement of harmonic response f^{h}_{W} and the transmission zero f^{θ}_{T} frequency as *n* increases. In order to cancel out the harmonic response of the 3rd order MPT filter, the f^{h}_{W} of the WCg coupler were chosen from 4.65 to 4.75 GHz, which coincides with $f^{\theta}_{T} = f^{h}_{T} = 4.67$ of the TCg coupler's frequency. This means that the transmission zero of the TCg coupler will cancel out the harmonic response of the WCg coupler. Hence, based on the above assumption, the WCg coupler with $n =$ 5, 6 and 7, with PSG dimension of $w/2 = 0.30015$ were chosen from Table 3 to incorporate as the WCg coupler for the 3rd order MPT filter.

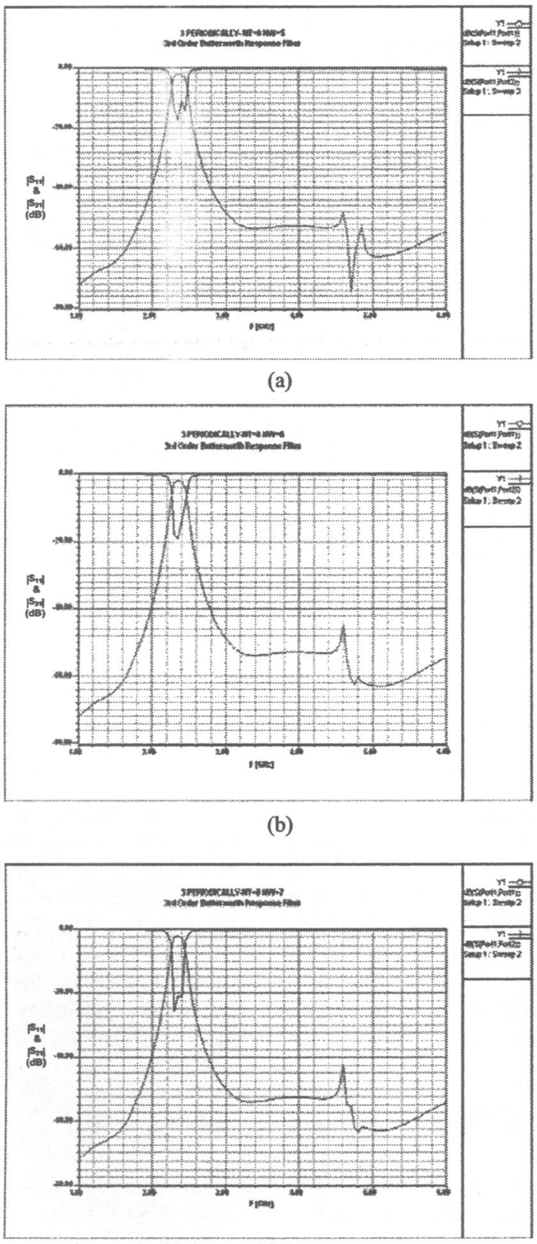
Table 3: Transmission Zero and First Harmonic Response Frequency versus Finite Square Grooves (*w/2*) for Weak Coupled with Fixed Coupling Length (*L*) $L = 11.204$ mm, $w = 0.6003$ mm and $s = 0.7228$ mm.

Number of Grooves	Transmission Zero Frequency, f^{θ}_{W}	First Harmonic Frequency f^{h}_{W}
0	6.70	5.05
1	6.56	4.99
2	6.54	4.96
3	6.52	4.95
4	6.46	4.90
5	6.19	4.75
6	5.94	4.66
7	6.08	4.70
8	5.96	4.65
9	5.83	4.64
10	5.84	4.60
11	5.58	4.49
12	5.56	4.49
13	5.56	4.49
14	5.58	4.50
15	5.60	4.49
20	5.76	4.56

It can be concluded that the 3rd order Butterworth response filter with composite number of PSGs at TCg and WCg couplers can effectively suppress the harmonic response of the resonance frequency. The idea of equalizing the transmission zero frequency of the TCg coupler with harmonic frequency of WCg coupler with various *n* is very effective. It can be seen that the filter response improves tremendously the suppression of the harmonic and upper cutoff frequencies.

6. Further Discussions and Conclusion

On the whole, the MPT filter generates high signal level at the harmonic resonance. For the 2.5 GHz filter, it appears at 5.0 GHz. The harmonic response suppression of the MPT filter was done by investigating the performance of TCg and WCg couplers with various *n*. It shows that the cancellation of harmonic response can be obtained by realigning the transmission zero of the TCg coupler with the harmonic of the WCg coupler. Good agreements were obtained by using NT = 8 grooves for TCg coupler and NW = 5 grooves for WCg coupler.



(a)

(b)

(c)

Figure 11: Filter response of 3rd order Butterworth response MPT filter based on design parameters of Table 1. (a) NT = 8, NW = 5, (b) NT = 8, NW = 6 and (c) NT = 8, NW = 7. (NT = number of PSGs at TCg Coupler and NW = number of PSGs at WCg Coupler).

It can be concluded that the proposed modified design has improved greatly the performance of the MPT filter. No recalculation of the physical dimensions is required. It involves only the introduction of periodically square grooves at equal distances within the coupled region. Compared to the improvement of the time spent for the design, this method is the cheapest method to improve the performance of the MPT filter.

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