Miniaturization of Harmonics-suppressed Filter with Folded Loop Structure

Han-Nien Lin¹, Wen-Lung Huang², and Jer-Long Chen³

¹Department of Communications Engineering, Feng-Chia University, Taiwan, R.O.C.
²Department of Electrical Engineering, Feng-Chia University, Taiwan, R.O.C.
³Department of Electrical Engineering, National Taiwan Ocean University, Taiwan, R.O.C.

Abstract—In this paper we utilize a basic loop resonator to design and realize the bandpass filter, and then use the quarter-wavelength open stub to suppress the second and third harmonics. Electric and magnetic coupling in this filter will be realized by a narrow coupled gap and grounded via to achieve the transmission zeros in either the lower or upper stopband. Since the prototype of the original bandpass filter is a resonator-based one wavelength structure, it is slightly larger compared with the other proposed structures. We therefore utilize the folding loop structure of the circuit to achieve miniaturization. The 30% reduction of the circuit size is achieved. The circuit with folded structure not only can reduce the size but also can maintain the performance as original structure with only slight degradation on the third harmonic. The result of the measurement and simulation is in good agreement to provide an experimental verification on the compact filter design.

1. INTRODUCTION

Microwave/RF filters are the key components in RF front-ends, so the performance of filter is important to the modern wireless communications. In the past, the design rules in many type of filters were quite complete, therefore the future research in filter design will be focused on high selectivity or harmonics suppression capability. Besides the fundamental resonance of unwanted signal, the similar resonance can also be generated on second, third, or even higher order harmonic frequencies, but those higher order resonances might pass the filter and cause the electromagnetic interference. Therefore many literatures have been proposed to suppress the harmonics with quarter-wavelength open stub [1], spurline [2], step impedance resonator [3, 4]; With quarter-wavelength open stub and spurline being used as bandstop filter to filter the unwanted signal, and step impedance resonator being used to shift the harmonic frequency to higher frequencies.

Recently, the higher performance requirement in communication-system was demanded, and the noise control scheme was also become more strictly. If the filter can be designed to improve selectivity, then the noise will be filtered out effectively and provide the better signal to noise ratio. In the past, the most filters were originally designed to provide the selectivity by using the higher order elliptic filter [5], or later by using the cross coupled (electric coupling, magnetic coupling and mixed coupling) to achieved the transmission zeros generated in lower, upper stop or even in both bands [6]. However, the two methodologies above have the disadvantage of their large sizes. The filter in [7] achieved high selectivity by using separate electric and magnetic coupling without any size reduction of filter. In order to reduce physical dimension of the filter, lumped elements [8], capacitive termination [9], aperture coupled [10] or folded structure [11] are frequently used in miniaturizing RF/microwave filters. However the lumped element method is known to have very poor quality factors for the insertion loss and out-of-band rejection. Therefore many miniaturization design techniques are still under investigation.

The filter we proposed in this paper, not only can suppress the second and third harmonics with quarter-wavelength resonators, but also improve the selectivity with narrow coupled gap and grounded vias to generate the transmission zeros in both lower and upper stopbands. Finally, we utilize the folding loop for the filter circuit to achieve the miniaturization.

2. LOOP FILTER

In this paper, a filter configuration (see Fig. 1). The FR-4 dielectric substrate with permittivity of $\varepsilon_r = 4.4$ and thickness of 1.6 mm.

The prototype filter was based on a loop resonator, where the resonant condition occurs when the length of microstrip line equals to one guided wavelength of the resonance frequency. The
feeding line in this filter (see Fig. 1) is different from the other filters. This feed type can improve the coupling energy and reduce the insertion loss as used in [8], for the particular structure with \( l_1 \) and \( l_2 \) being used as quarter-wavelength open stubs, where different lengths are used to achieve harmonics suppression. The two quarter-wavelength stubs were close to each other. When we made the length of \( l_2 \) longer, the electric coupling can then be realized by utilizing the coupling gap to generate an additional transmission zero at the upper stopband. When the signal is injected to the transmission line, the current distribution can be determined and show the maximal magnitude near the quarter-wavelength of the transmission line (the current distribution can be seen clearly in Fig. 2). Based on this principle, magnetic coupling can also be introduced by a grounded via to generate an additional transmission zero at the lower stopband. After adjusting the filter configuration shown in Fig. 3, the real circuit size (see Fig. 1) can be reduced to about 31.5 mm \( \times \) 12 mm.

In this paper, commercial EM software IE3D version 10.0 and PNA network analyzer Agilent E8362B are used in simulation and measurement respectively. To meet the design goal, we first utilize the principle of quarter-wavelength transmission line by adjusting the length of \( l_1 \) and \( l_2 \) to suppress the second and third harmonics. However, the lengths of \( l_1 \) and \( l_2 \) are different, because the \( l_1 \) and \( l_2 \) are both the tightly adjacent paths of the loop resonator with the parasitic effect introduced by the gap between the lines. It thus affects the original quarter-wavelength long open stubs. The resulting effect of different \( l_1 \) and \( l_2 \) is shown in Fig. 5. We finally obtained the
optimum length with $l_1 = 5\,\text{mm}$ and $l_2 = 15.5\,\text{mm}$ with the second and third harmonics being suppressed $-30\,\text{dB}$ and $-15\,\text{dB}$ respectively. Although the quarter-wavelength open stubs have good harmonics suppression performance, but the lower frequency response tends to rise up and degrade performance as shown in Fig. 5. Therefore, the grounded via is introduced to achieve magnetic coupling and thus generate an additional transmission zero at the lower stopband. Up to this point, our filter design not only can compensate the effect of different $l_1$ and $l_2$, but also can improve the selectivity and therefore enhance the system performance. As to the determination of grounded via location, the maximum magnitude of the current distribution should occur near the quarter-wavelength position of the transmission line (see Fig. 2) from the transmission line effect. Therefore the location of grounded via was chosen at quarter-wavelength distance away from the feed point (see Fig. 3).

![Figure 5](image1)

Figure 5: The frequency response of different length with $l_1$ and $l_2$.

The frequency response with or without grounded via can be seen clearly from Fig. 6, where an additional transmission zero is generated at about $1.7\,\text{GHz}$ with a $-46\,\text{dB}$ dip. On the other hand, the electric coupling will generate an additional transmission zero at the upper side of the passband by a narrow gap between two open stubs. Fig. 7 shows the cases with different gap spacing $g$ ($0.2\,\text{mm} \sim 0.7\,\text{mm}$), the smaller the spacing $g$ the closer the transmission zero to the passband and therefore the larger capacitance. For the purpose of suppressing second harmonic, the $g = 0.4\,\text{mm}$ is considered the optimum value. The Fig. 8 shows the transmission coefficient of the proposed filter with excellent selectivity and good rejection performance in out-of-band.

![Figure 6](image2)

Figure 6: The frequency response with or without grounded via.

![Figure 7](image3)

Figure 7: The frequency response of different coupled gap.

![Figure 8](image4)

Figure 8: The frequency response of prototype filter.
3. COMPACT SIZE FILTER

In the previous section, we have designed the bandpass filter that not only can suppress the second and third harmonics, but also can improve the selectivity in the same time. However, since the structure of the filter is based on one wavelength resonant condition of a loop, it’s dimension is usually larger than others. Therefore, we try to make filter smaller size by folding the prototype structure. The proposed filter structure is shown in the Fig. 9, where the folded structure was used in the resonant loop path and internal quarter-wavelength open stub. The proposed filter is divided into two parts from the symmetrical plane with the spacing n controlling the coupling between two separate parts. The smaller the spacing n, the more coupling will occur between two separate partitions. Therefore, the spacing should be carefully decided. In order to maintain the performance of the selectivity, we double the number of grounded via for more magnetic coupling and to make the transmission zero much closer to the passband. While electric coupling is made by the gap between internal open stubs, it is a little different from the prototype but the same performance is kept.

![Symmetrical plane](image)

Figure 9: Proposed filter structure. (L = 1.7 mm; m = 0.2 mm; n = 0.9 mm; j = 0.5 mm; g1 = 0.2 mm).

![Transmission coefficient](image)

Figure 10: The frequency response compared with proposed and prototype filter.

The transmission coefficients of the proposed filter and original prototype filter were compared in Fig. 10, the transmission zeros of the proposed filter are found located farther away than the prototype because of the effect from folded structure. Meanwhile, the effect of magnetic and electric coupling was also decreased. The second harmonic was found below −30 dB, but the third harmonic was only reduced by −6.5 dB probably because of the open stub bending. The proposed filter was fabricated with a small size 23.5 mm × 11.5 mm, it is smaller than the original prototype (31.5 mm × 12 mm) with size reduction up to about 30%.

4. SIMULATION AND MEASUREMENT

The simulated and measured results of $S_{11}$ and $S_{21}$ are illustrated in Figs. 8 and 9 respectively. From the plot of $S_{21}$, the trend is found to be approximately close to each other. The second and third harmonics suppression is achieved about −25 dB and −17 dB, respectively. The discrepancies in
transmission zeros between the measurement and simulation might come from the dimension error of the structure due to inaccurate fabrication of grounded via and narrow coupling gap. While the discrepancies in $S_{11}$ between the measurement and simulation at 7.18 GHz might be due to the
material loss. To verify the effect, we use the perfect material characteristics in simulation from the beginning and found the discrepancy around 7.18 GHz is large. However, when we take the material loss into account, the results of simulation and measurement was in good agreement at 7.18 GHz. In order to improve the agreement for high frequency, we modified the bending corner of the structure to different angles for investigation. After modifying the bending corner to the bevel angle, the material loss effect was improved. From the result of Fig. 16, the modified corner technique not only makes the material loss effect reduced from $-40 \text{ dB}$ to $-7 \text{ dB}$, but also proves that the bevel angle corner is necessary for the high frequency implementation.

![Figure 17: Different angle of the corner.](image1)

![Figure 18: The photograph of the prototype filter.](image2)

5. CONCLUSIONS

In this paper, the original prototype filter can obtain the transmission zeros in both the lower and upper stopbands, and also can suppress the second and third harmonics. It is different from the past filter design that must use the higher order to realize the elliptical filter. Furthermore, the proposed folded-loop structure of the circuit not only can achieve miniaturization with size reduction about 30%, but also can maintain the same excellent performance as original structure with only a slight degradation on the third harmonic suppression. Finally, we have modified the angle of the bending corner to reduce the material loss effect and avoid electromagnetic interference problem.

REFERENCES


