Design of a Compact Wide-Stopband Bandpass Filter Using Meandering Uniform-Impedance Resonators

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Abstract — A compact wide-stopband bandpass filter using meandering uniform-impedance resonators is proposed. The filter consists of a pair of uniform-impedance resonators and feeding lines. By bending the designated positions of resonators, the first harmonic and second harmonic can be suppressed to achieve a wide stopband. The proposed filter shows harmonic suppression to exceed \( 3f_0 \) for a rejection better than 22 dB, where \( f_0 \) is the fundamental frequency. Due to the multi-path effect between resonators and feeding lines, the attenuation poles are realized near the passband edges to improve the filter selectivity. The full-wave simulator IE3D is used to design the meandering structure of the proposed filter to suppress the first and second harmonics.

Index Terms — Bandpass filter, harmonic suppression, meandering structure.

I. INTRODUCTION

Microstrip lines have been widely used as coupling elements in the design of bandpass filters (BPFs) due to several attractive features such as compact size, low cost, and ease of integration with other passive and active microwave devices [1]–[2]. However, these microstrip BPFs with uniform-impedance resonators usually suffer from the spurious passbands at the multiple fundamental frequencies. Therefore, the spurious passbands will cause the upper stopband performance worse. To solve this problem, much effort has been made to suppress the spurious passbands [3]–[8]. Koch-curve-shaped microstrip coupled lines using multiple Koch orders are used to design BPFs with spurious suppression [3]. A traditional dual-mode filter is miniaturized to form the triangular loop structure [4]. By using these forms of resonators, the sizes of the filters are compact. In recent years, stepped-impedance resonators (SIRs) are applied to shift the higher-order mode, while some approaches also use the higher frequencies to suppress the harmonics [5]–[6]. By using suitable impedance and electrical length ratio, the higher order mode can be pushed to higher frequency [5]. An enhanced stepped-impedance combline BPF is with tapped-transformer coupling at input and output [6]. In addition, the wide-stopband BPF with quarter-wavelength SIRs has been proposed [7]. To improved stopband performance further, the resonators with embedded bandstop structures are used to suppress the lower spurious harmonics of SIRs [8].

In this study, a compact wide-stopband bandpass filter by bending the resonators to suppress harmonics is proposed. Each resonator of the proposed filter has two forms of meandering structure. The two forms of meandering structure can be realized to suppress the first and the second harmonic, individually. Because of the multi-path effect, attenuation poles are around the passband to improve the passband selectivity. The BPF realized on a printed circuit board occupies an area of only \( 24.7 \times 9.3 \text{ mm}^2 \).

II. DESIGN OF THE PROPOSED BPF

Fig. 1 shows the configuration of the proposed two-pole wide-stopband microstrip BPF using meandering structure. The circuit is fabricated on a RT/Duroid 5880 substrate with dielectric constant \( \varepsilon_r = 2.2 \), loss tangent \( \delta = 0.0009 \), and thickness \( h = 20 \text{ mil} \). The BPF mainly consists of a pair of uniform-impedance resonators (UIRs) and feeding lines. The width of the UIRs and the feeding lines are 0.4 mm. There are three positions of the UIRs to be bent to suppress the first and second harmonics. The fundamental frequency of the resonators with meandering structure is at 2.45 GHz. To improve the passband selectivity, the designed BPF assumes a multi-path structure to produce two attenuation poles near the passband edge. Each attenuation pole occurs because of the cancellation of the transmitted signals going through two different paths. The two signal paths incurred from this multi-path structure are indicated in Fig 2. Path 1 is indicated that
signal transmit from port 1 to port 2 through the feeding lines; path 2 is indicated that signal through the resonators. In order to decide the spacing $D_{12}$ between the resonators and the gap $b$ of the filter, the coupling coefficient and external quality factor need to be calculated. The design parameters of this proposed BPF are determined for the Chebyshev response with 0.1-dB ripple level. The coupling coefficient $M_{12}$ and the external quality factor $Q_e$ can be calculated by [2]
\[
M_{12} = \frac{FBW}{\sqrt{g_1 g_2}} = 0.027
\]
\[
Q_e = \frac{g_0 g_1}{FBW} = 42.15
\]
where $g$ are the element values of the lowpass prototype filter, and $FBW$ is the fractional bandwidth. The coupling coefficient can be used to determine the spacing $D_{12}$ between the resonators and the gap $b$ is dependent on the required $Q_e$. The fundamental frequency $f_0$ is 2.45 GHz, and $FBW$ is 2%. The lumped circuit element values for a Chebyshev filter with 0.1-dB ripple are found to be $g_0 = 1$, $g_1 = 0.8432$, $g_2 = 0.622$, and $g_3 = 1.3554$. Thus, by using the full-wave electromagnetic simulator IE3D [9], the coupling coefficient and external quality factor can be found as
\[
M = \frac{f_H^2 - f_L^2}{f_H^2 + f_L^2}
\]
\[
Q_e = \frac{f_0}{\Delta f_{\pm 90^\circ}}
\]
where $f_H$ is the higher one and $f_L$ is the lower one of the two resonant frequencies, $\Delta f_{\pm 90^\circ}$ is the bandwidth of the resonant frequency over which the phase varies from -90° to +90°. According to (1)-(4), the dimensions of the spacing $D_{12}$ and gap $b$ is 0.4 mm and 0.2 mm, respectively.

In this study, the proposed BPF has spurious suppressions of first and second harmonics by bending the designated positions of resonators. The bending positions can be used to suppress the first or second harmonic, individually. Fig. 3(a) shows the schematic circuit to suppress the first harmonic. The bending position is located at the center of the UIR. The meandering structure is constructed of U-type microstrip tuned by using two scales of $L_1$ and $W_1$. Fig. 3(b) shows the simulated results if $L_1 = 2.8$ mm with $W_1 = 1, 2, \text{and } 3$ mm. In the case, the first harmonic can be suppressed stage by stage. Especially the case of $L_1 = 2.8$ mm with $W_1 = 1$ mm, the stopband rejection at 4.9 GHz is achieved as 28 dB. By using the scale, the electrical coupling and magnetic coupling at the first harmonic frequency cancel each other. Fig. 3 (c) and (d) shows the cases of simulated result of $L_1 = 3.8$ mm with $W_1 = 1, 2, \text{and } 3$ mm and $L_1 = 2.8$ mm with $W_1 = 1, 2, \text{and } 3$ mm.

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Fig. 3. Simulated frequency responses of the proposed BPF as $L_2 = W_2 = 0$. (a) the simulated circuit (b) $L_1 = 2.8$ with $W_1 = 1, 2, \text{and } 3$. (c) $L_1 = 3.8$ with $W_1 = 1, 2, \text{and } 3$. (d) $L_1 = 2.8$ with $W_1 = 1, 2, \text{and } 3$. All are in mm.
Fig. 5. Simulated frequency responses of the proposed and the traditional microstrip BPFs.

The first harmonic is excited and not to be suppressed. Furthermore, because of meandering structures with self-coupled effect, the fundamental frequency is shifted slightly. In order to preserve the same fundamental frequency, the electrical length of microstrip lines needs to be optimized. Fig. 4(a) shows the schematic circuit of the filter with meandering structures for suppressing the second harmonic. There are two positions used to bend at the one third from the open end of the UIR. The structure is constructed of U-type microstrip tuned by using two scales of $L_2$ and $W_2$. By using different cases of $L_2$ and $W_2$, the second harmonic can be tuned to achieve the good rejection level. Fig. 4(b) shows the simulated results of $W_2 = 1.4$ mm with $L_2 = 1, 2, \text{ and } 3$ mm. The insertion loss increases slightly as $L_2$ decreases. Fig. 4(c) has the same tendency in the scales of $L_2$ in the simulated results. In these cases of Fig. 4(d), the second harmonic can be suppressed obviously if $W_2 = 3.4$ mm with $L_2 = 1$ mm. By using the scale, the electrical coupling and magnetic coupling of the second harmonic cancel each other. Because of the coupled structures in the U-type microstrip, the electrical length of the UIRs needs to be tuned to compensate the bending effect.

Fig. 5 shows the simulated results of the proposed filter and a conventional filter from dc to 8 GHz. The two filters are designed to achieve the same fundamental responses. The proposed filter shows a better stopband performance. The first and second harmonics of the conventional BPF are suppressed. The proposed filter achieves a 22-dB rejection to exceed $3f_0$. Meanwhile, it should be mentioned that the proposed filter has a circuit size reduction about 33% in comparison to the conventional filter.

### III. DESIGN AND MEASURED RESULTS

The designed BPF with meandering structures to suppress spurious passbands is optimized by using a full wave EM simulation [9] and then is fabricated on the substrate of Duroid 5880. Photograph of the fabricated BPF is shown in Fig. 6(a). The overall size of the proposed BPF is about 24.7 mm × 9.3 mm, approximately $0.26 \lambda_g$ by $0.1 \lambda_g$, where $\lambda_g$ is...
IV. CONCLUSION

A compact wide-stopband microstrip BPF using meandering structures is proposed to suppress harmonics located at $2f_0$ and $3f_0$ GHz. By using the meandering structures, the harmonic suppression can be achieved without additional circuits. The attenuation poles around the two passband edges can be resulted from the multi-paths propagation mode between resonators and feeding line.

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