Designing A Miniaturized T-shaped Non-Orthogonal Feed Input/Output Dual-Mode Bandpass Filter

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Abstract

Dual-mode filters with differently structured resonator were designed on Al₂O₃ substrate for pattern minimization and better properties. Al₂O₃ substrate with a permittivity of 9.8 is easily integrated with RF circuits. For the proposed filter, two open stubs, one perturbation patch, and one meandering loop ring were investigated to achieve the same purpose with smaller size. To improve the coupling effect, two additional stubs were used to form the T-shaped microstrip coupling lines. The proposed filter showed a size reduction compared with the published filters, and it also provided deep transmission zeros on both sides of the passband.

1. Introduction

Recently, the dual-mode resonators are widely used for microwave bandpass filter in wireless local area network (WLAN) applications and mobile communications systems. Compact size, wide bandwidth, small insertion loss, and high out-of-band rejection are requisite properties, and because dual-mode filters meet these demands they have attracted interest in the investigation of bandpass filters (BPFs) [1]. The dual-mode microstrip filters are composed of one or more dual-mode resonators, which are usually in the form of patch or ring with a square, triangular or circular shape. Various types of the dual-mode microstrip filters with patch or ring resonators have been proposed in theory and experiment [2-5]. However, most of dual-mode filters construct the input/output microstrip lines at orthogonal (equal to 90°) and few filters construct at an angle between 90° and 180° to excite two degenerate modes with closer frequency in the resonators. In this way, the bandwidth of dual-mode filter is improved, but the complexity of layout arrangement connecting with other RF devices is increased.

In this paper, one new design of dual-mode BPFs is investigated. The proposed filter uses two open stubs, one perturbation patch, and one meandering loop ring to generate two degenerate modes but with a smaller pattern size than the dual-mode filters published before. Notably, the input/output microstrip lines are arranged in a straight line, making the designed filter easy to connect with other RF circuits. To promote a coupling effect between the input/output and the resonator, two additional coupling stubs are used to form modified T-shaped microstrip coupling lines. Finally, the proposed filters are fabricated using a printing method that generates minimal environmental pollution, and are verified by simulation and measurement.

2. Design of T-Shaped Square Ring Dual-Mode Bandpass Filter

The proposed T-shaped square ring dual-mode filter was based on a resonator with the length of 1λg. According to the εᵣ (9.4) of the Al₂O₃ ceramic substrate, the approximate fundamental guided wavelength of the 2.4 GHz 1λg square ring resonator was calculated using Eq. (1) [1]:

\[ V = \frac{C}{\sqrt{\varepsilon_r}} = f\lambda_g \]  

yielding a value of 40.77 mm. To investigate the degenerate modes of the resonator, even and odd modes were used for modeling. The typical equivalent resonant functions with impedance (Z) and electrical length (θ) can be expressed as
follows [1]:

(a) even mode:

\[
Z_{\text{in,even}} = \frac{Z_1 (-Z_p j \cot \theta_p) + Z_j j \tan \theta_p}{Z_1 + (-Z_p j \cot \theta_p) j \tan \theta_p} = \infty
\]

\[Z_1 + (-Z_p j \cot \theta_p) j \tan \theta_p = 0\]  \hspace{1cm} (2)

\[R \tan \theta_\text{le} + \tan \theta_\text{pe} = 0\]  \hspace{1cm} (3)

(b) odd mode:

\[
Z_{\text{in,odd}} = \frac{Z_1 (Z_p j \tan \theta_p) + Z_j j \tan \theta_p}{Z_1 + (Z_p j \tan \theta_p) j \tan \theta_p} = 0
\]

\[Z_1 j \tan \theta_\text{pe} + (Z_p j \tan \theta_p) = 0\]  \hspace{1cm} (5)

\[\tan \theta_\text{pe} + R \tan \theta_\text{pe} = 0\]  \hspace{1cm} (6)

where \( R = Z_p / Z_1\), \( Z_1 \) is the impedance of the ring resonator, \( Z_p \) is the impedance of the perturbation, \( \theta_1 \) is the electrical length of the resonator (without perturbation), and \( \theta_p \) is the electrical length of the perturbation. The degenerate modes were excited and coupled to each other when \( R \neq 1 \). The dual-mode resonator demonstrated an elliptic response at \( R < 1 \) and a Chebyshev response at \( R > 1 \) [1]. In this study, \( R < 1 \) was chosen because the elliptic response exhibited deeper transmission zeros. According to circuit theory, one line with characteristic impedance \( Z_0 \) was divided into two lines with characteristic impedance \( 2Z_0 \) using a shunt connection [6]. The coupling sections of the T-shape structure were halved for impedance matching, and the filter structure was modified as shown in Fig. 1, with thinner C and H values.

### 3. Simulated and Measured Results

According to Ref. [7], open stubs connected to a square ring resonator asymmetrically increase the resonant path and shift the resonant frequency to lower value. To keep the resonant frequency unchanged, the length of the square ring resonator was reduced and the pattern size was decreased. It is known that a square ring resonator can be curved into a meandering loop resonator for pattern miniaturization. In this study, both open stubs and a meandering loop were adopted to design a new modified dual-mode BPF, as shown in Fig. 1.

![Fig. 1 The modified meandering loop T-shaped non-orthogonal input/output dual-mode bandpass filter with open stubs.](image)

Fig. 2 Simulated results as a function of R and S.

![Fig. 3 Simulated results as a function of T1.](image)
The operating frequency was easily tuned using the different parameters in the designed filter, including the lengths of the open stub and of the meandering loop. Figs. 2-5 show the simulated results as a function of R, S, T₁, N, and M values, respectively. As the values of R and S increased (Fig.2), the bandwidth of designed filter increased, so did the ripple in the passband. R=4mm and S=2mm were the optimal parameters because the filter designed at those parameters had less ripple and lowest insertion loss in the passband and the optimal shape factor. Similar, the increase in the value of T₁ also increased the bandwidth of designed filter and the ripple in the passband (Fig.3), and T₁=3mm was chosen because of less ripple and lowest insertion loss in the passband and better shape factor. As the values of N (Fig.4) and S (Fig.5) were changed, the bandwidths of designed filters and the ripples in the passband had no apparent variations. However, the F value had apparent effect on the shape factor. Also, N=1 mm and F=8.1mm were chosen because the filter designed at those parameters had the optimal shape factor and less ripple in the passband.

![Simulated results as a function of N.](image1)

![Simulated results as a function of F.](image2)

The current distributions of the proposed filter at the frequencies of the two degenerate modes are simulated and shown in Fig. 6. At 2.26 GHz, the maximum current distribution zones were to the left and right of the meandering loop resonator, where the maximum magnetic field was generated. The maximum electrical field and voltage were phase shifted 90° from the maximum magnetic field, existing at the top and bottom of the square ring. The phenomenon was inverted at 2.55 GHz and the two degenerate modes also had a 90° phase difference. Because these modes resonated close together, at 2.26 GHz and 2.55 GHz, the bandwidth in the proposed dual-mode filter was enhanced.

![Current distributions of the proposed type-B filter at (a) 2.26 GHz and (b) 2.55 GHz.](image3)

![Simulated and measured results for the proposed filter.](image4)
After optimal tuning, the proposed filter (21.4 mm × 9.1 mm, without SMA) showed a size reduction of 42% compared with the size of filter we published before (25.4 mm × 13.1 mm, without SMA) [3]. The optimal parameters for the proposed filter are $A = 10.2$ mm, $B = I = N = 1$ mm, $C = H = 0.5$ mm, $D = 6.5$ mm, $J = 10$ mm, $E = 8.5$ mm, $P = M = 5.5$ mm, $K = 12$ mm, $F = 8.1$ mm, $L = 5.6$ mm, $Q = T_1 = 3$ mm, $S = 2$ mm, $R = 4$ W = 4 mm, and $G_1 = G_2 = G_3 = 0.1$ mm. Fig. 7 compares the simulated and measured results for the proposed filters. For the proposed filter, the simulated results are $S_{21} = 1.15$ dB and $BW = 610$ MHz (24.71%) at 2.47 GHz, and the measured results are $S_{21} = 2.26$ dB and $BW = 650$ MHz (26.97%) at 2.41 GHz. The simulated out-of-band rejections are 30.75 dB at 2.16 GHz and 42.09 dB at 3.63 GHz. The measured out-of-band rejections are 29.26 dB at 2.14 GHz and 43.81 dB at 3.69 GHz.

4. Conclusion

In this study, dual-mode filters with meandering loop ring structured resonators were investigated. The proposed filter had a 26.97% bandwidth at a center resonant frequency of 2.41 GHz. Two transmission zeros with insertion losses of 29.26 dB and 43.81 dB were present on both sides. The proposed filter was 21.4 mm × 9.1 mm (without SMA). This study demonstrated that the proposed filter had a smaller size and wider bandwidth in the passband than the most dual-mode filters proposed in other researches.

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6. References


