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A NOVEL CPW DUAL PASSBAND FILTER USING THE SPLIT-MODES OF LOADED STUB SQUARE LOOP RESONATORS

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Abstract—This paper presents a novel coplanar waveguide (CPW) dual passband filter using the split-modes of the loaded stub square loop resonators. With the CPW feeding line, two microstrip stub resonators built on the rear sides are used to suppress the first even resonance. The modes splitting characteristics of the proposed structure are analyzed. A dual passband filter covering center frequencies of 4.8 GHz and 6 GHz is fabricated to verify the validity of the methodology. Good agreement between simulated and measured results is demonstrated.

1. INTRODUCTION

In modem wireless and mobile communication systems, filter with multiple passband have become one of the essential elements [1, 2]. For the initial investigations, dual passband filter has been taken much more attention. Several design approaches have been proposed [3–6]. In [3, 4], dual passband filters are obtained by combining two bandpass filters with different center frequencies. However, this configuration increases the size of the circuit. Another dual mode dual passband filter has been realized by using a stacked structure and an air-bridge [5, 6]. Due to their configuration, these kinds of filters are not easy to be fabricated.

In this paper, a novel CPW dual passband filter is designed by using the split-modes of the loaded stub square loop resonators. CPW

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has been taken more and more attention for its advantages such as easy connections in series and shunt without via hole, insensitivity to substrate thickness, and low dispersion effect in the designed of microwave and millimeter wave circuits [7, 8]. By loading an open stub in the proposed CPW square loop resonator, two degenerated modes could be simultaneously excited and they are split to produce two resonance frequencies. And then when two CPW square loop resonators are putting together with proper coupling, a dual passband filter would be achieved. Besides, in order to broaden the stopband and improve the selection of the proposed dual passband filter, two microstrip stubs resonators are introduced. They are built on the rear side of the CPW structure [9]. The characteristics of the proposed loaded stub CPW square loop resonator are analyzed. And a validation filter of this type has been fabricated based on the center frequencies of 4.8 GHz and 6 GHz. The EM simulated and the measured results are offered to demonstrate the characteristics of the proposed dual passband filter.

2. CPW SQUARE LOOP RESONATOR WITH LOADED STUB

Figure 1 shows the configuration of the proposed CPW square loop resonator with loaded stub. With a CPW feeding line, the structure is consisted of a CPW square loop and a loaded stub. Such a square loop resonator will resonate if its electrical length is an integral multiple of the guided wavelength. When a discontinuity is introduced into the loop, each resonance degenerates into two distinct modes.

In references [10] and [11], the field solutions for the two degenerate modes of the square loop resonator are given by

$$\begin{aligned} E_z &= \{AJ_n(kr) + BN_n(kr)\}\cos(n\phi) \\ H_r &= \frac{n}{j\omega\mu_0 r}\{AJ_n(kr) + BN_n(kr)\}\sin(n\phi) \\ H_\phi &= \frac{k}{j\omega\mu_0}\{AJ'_n(kr) + BN'_n(kr)\}\cos(n\phi) \end{aligned} \tag{1}$$

and

$$\begin{aligned} E_z &= \{AJ_n(kr) + BN_n(kr)\}\sin(n\phi) \\ H_r &= \frac{-n}{j\omega\mu_0 r}\{AJ_n(kr) + BN_n(kr)\}\cos(n\phi) \\ H_\phi &= \frac{k}{j\omega\mu_0}\{AJ'_n(kr) + BN'_n(kr)\}\sin(n\phi) \end{aligned} \tag{2}$$

where A and B are constants, J_n is the Bessel function of order n, N_n is the Neumann function of order n, and k is the wavenumber.

By adding an open loading stub to the square loop, resonance splitting of the degenerate modes would be observed. As the analysis in the reference [10], it illustrates that when $\phi = 0$, one of the two degenerate solutions goes to zero, and the phenomenon of resonance splitting would not achieve in the odd or even modes. However, when $\phi = \pi/4$, the odd modes will split yet the even modes are not affected. That is due to for odd n both solutions exist and the resonances split, while for even n one of the solutions goes to zero and hence the resonances split do not appear.

Figure 2 depicts the simulated results of the square loop resonator which is driven through capacitive weak coupling with the loading stub l set to be 0 and $\lambda_g/4$. Here the parameter of the square loop are $a = 4\,\text{mm}$ and $b = 19\,\text{mm}$. It shows that when $l = 0\,\text{mm}$, just the same as the situation of $\phi = 0$, there is no resonance splitting. However,

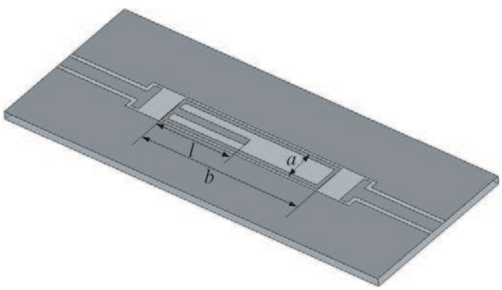


Figure 1. Configuration of the proposed CPW square loop resonator with loaded stub.

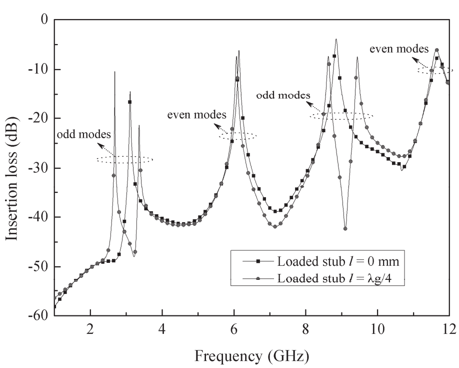


Figure 2. Simulated results of the square loop resonator with loaded stub $l = 0\,\text{mm}$ and $\lambda g/4$.

when $l = 10.5\,\text{mm}$, which corresponding to $\lambda_g/4$, then as explained above, the odd modes split and without any effect on the even modes.

3. CPW DUAL PASSBAND FILTER DESIGN

From the basic of the analysis illustrated above, using the split modes of the proposed loaded stub square loop resonator, a dual passband filter could be achieved by taking two loaded square loop resonators closely with suitable coupling. Figure 3 shows the layout of the proposed CPW dual passband filter. It is consisted of two loaded square loop resonators with capacitive coupling to the CPW feeding line. Besides, in order to suppress the first even resonance, two microstrip stub resonators are introduced. They are on the other layer of the CPW structure with capacitive coupling to the CPW feeding line.

Following the general theory of couplings, the respective parameter could be designed. Its external quality factor is controlled by adjusting the width s_1 of the coupling gap, while the coupling coefficient of the two neighboring resonators is tuned by varying the distance s between the two square loops. And the corresponding fitting curve could be obtained by using the method demonstrated in references [12] and [13].

The center frequencies and bandwidth of the dual passband are affected by the square loop resonators and the loaded stubs. Here the model of proposed dual passband filter without adding the microstrip stubs is simulated using the Ansoft HFSS. Figure 4 depicts the center frequencies against the length b of the square loop varying from 9.5 to 11.5 mm, while the loaded stub l, which corresponding to $\lambda_g/4$, varying from 5.75 to 6.25 mm. and the other parameters are $a = 3\,\text{mm}$, $s = 1.6\,\text{mm}$, $w_1 = 0.5\,\text{mm}$, $w_2 = w_4 = 1\,\text{mm}$ and $s_1 = 0.15\,\text{mm}$. When the length b increases, the center frequencies of the dual passband slows down smoothly with rarely influence on the bandwidth of each

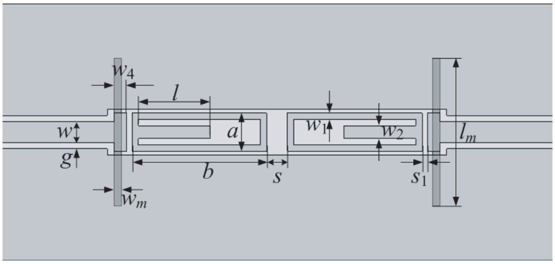


Figure 3. Layout of the proposed dual passband filter.

passband. However, as is shown in the Figure 5, when the length b of square loop keeps constant, the bandwidth of each passband would be adjusted by varying the length l of the loaded stub.

From the simulated results in Figures 4 and 5, it shows that not enough suppression at the higher frequency of the second passband is achieved. The reason is that it is influenced by the first even mode resonance. For broadening the stopband of the proposed filter and improving the selection of the second passband, two microstrip stubs at the bottom layer with capacitive coupling to the top CPW structure are introduced. Figure 6 illustrates the insertion losses with the microstrip stub l_m changing from 11.5 to 13.5 mm, and the simulated result of $l_m = 0$ mm is added for comparison. Here $b = 9.5$ mm, $l = 6.2$ mm,

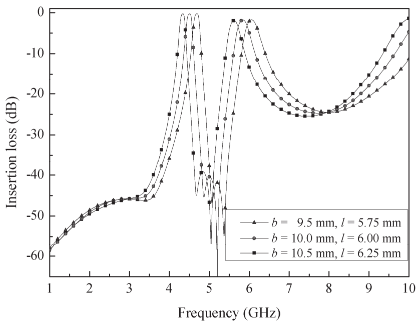


Figure 4. Insertion losses against the length b of the square loop and the loaded stub l.

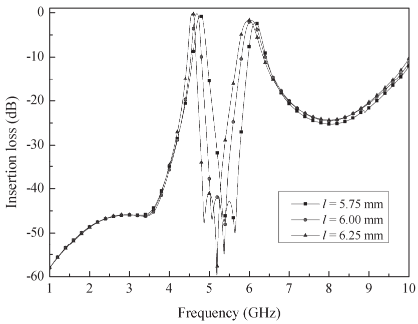


Figure 5. Insertion losses against the loaded stub l with the length $b = 10.5$ mm.

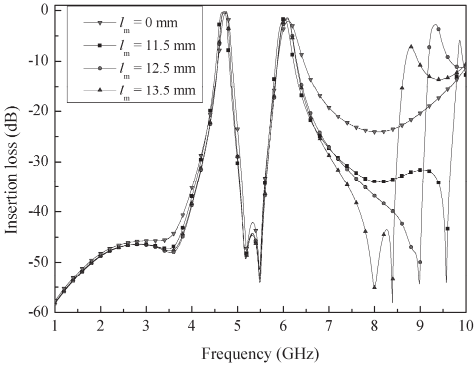


Figure 6. Insertion losses against the length l_m of microstrip stub

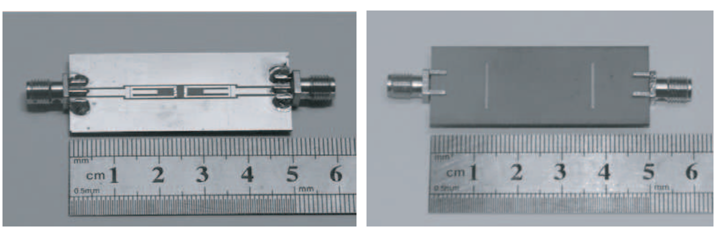
$w_m = 0.5\,\mathrm{mm}$ and the other parameters are the same as above. It shows that an attenuation pole is obtained and it is controlled by the length l_m of the microstrip stub. And the introduced microstrip stubs have slightly affected on the other characteristics of the proposed filter. With an appropriate length of the microstrip stub, a dual passband filter with wider stopband and higher selection would be obtained.

4. EXPERIMENTS AND MEASUREMENT

In order to validate the above design approach, a dual passband filter is fabricated on a substrate with a relative dielectric of 9.6 and a thickness of 1 mm. the input/output impedance of the feeding line is identical to $50\,\Omega$ corresponding to the coplanar waveguide which has a central strip width $w = 1.6\,\mathrm{mm}$ and a slot width $g = 0.5\,\mathrm{mm}$.

Using the commercial software Ansoft HFSS based on the finite element method, the desired physical dimensions of the proposed filter are determined. After simulation, the final optimized parameters of the filter are as follows: $a = 3\,\mathrm{mm}$, $b = 10.5\,\mathrm{mm}$, $l = 5.8\,\mathrm{mm}$, $s = 1.6\,\mathrm{mm}$, $s_1 = 0.15\,\mathrm{mm}$, $l_m = 11.5\,\mathrm{mm}$, $w_m = 0.5\,\mathrm{mm}$, $w_1 = 0.5\,\mathrm{mm}$, $w_2 = 1\,\mathrm{mm}$, and $w_3 = 0.58\,\mathrm{mm}$. Figure 7 shows the photograph of the fabricated CPW dual passband filter with dimensions of $20 \times 50\,\mathrm{mm}^2$.

The experimental results are obtained from Agilent vector network analyzer of N5230A. The measured and EM simulated results of the CPW dual passband filter are illustrated in Figure 8. It demonstrates that the dual passband filter has center frequencies of 4.8 GHz and 6 GHz, and the 3-dB FBW of 4.2% and 3.8%, respectively. The measured insertion losses at the passbands are approximately 1.68 dB and 1.97 dB. And the return losses are better than 24 dB and 20 dB at its respective passband. Comparison between simulated and measured results indicates a good agreement.



(a) Top view (b) Bottom view

Figure 7. Photograph of the fabricated dual passband filter. (a) Top view. (b) Bottom view.

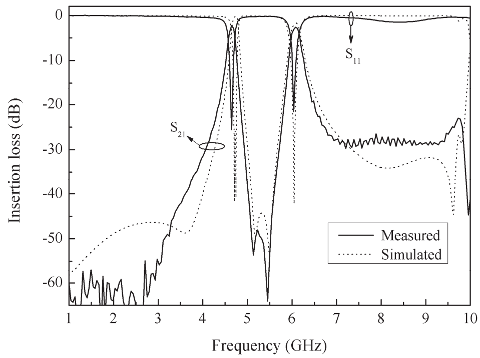


Figure 8. The measured and simulated frequency responses for the dual passband filter.

5. CONCLUSION

In this paper, a novel CPW dual passband filter using the split-modes of loaded square loop resonators is modeled in the theory and verified by the experiment. And two microstrip stub resonators are applied to suppress the higher resonance. The modes splitting characteristics of the CPW loaded square loop resonator are analyzed. A dual passband filter covering center frequencies of 4.8 GHz and 6 GHz is fabricated for validation. The measured results have shown good agreement with the theoretical results. We believe dual passband filter designed with the characteristic of split-modes is useful for multi-bands wireless transmitting system.

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