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CPW bandpass filters with controllable passbands

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ABSTRACT

Defected coplanar waveguide (CPW) resonator has been analyzed, and multi-band bandpass filters with individually controllable passband have been developed. New dual-band and tri-band bandpass filters which center at 2.4/3.5/5.2 GHz have been designed, fabricated and measured. The measurements demonstrate the new presentations. The measured filter passband insertion losses are less than 2.7 dB. It has been noticed that the filter center frequencies can be individually controlled, and the bandwidths can be individually adjusted. Advantages of the new design are not only its simple and compact circuit topology, miniature circuit size, but also its less electromagnetic leakage.

1. Introduction

Coplanar waveguide circuits have important applications in microwave systems because of the outstanding virtues of easy integration with the lumped elements and other microwave components. In this research, it has been noticed that when there are etched patterns or slots in the CPW conductor strip, the electromagnetic field distributions may be changed, and resonances may be introduced when the electric field and the magnetic field keep balance. In order to control each passband of the multi-band bandpass filter independently, a design scheme is presented. In this scheme, (1) etched patterns with different length generate different resonances; (2) each pattern only needs generating a single resonance in order to control each passband effectively. It has been demonstrated that the individually controllable resonances can be easily obtained by the etched patterns, and the other assistance such as microstrip resonators or CPW ground resonators are not required. This is very useful for miniature multi-band filter design.

In this paper, coplanar waveguide bandpass filters with dual-band and tri-band have been proposed. Filter center frequency and bandwidth can be easily controlled only by controlling the corresponding etched pattern. Compared with the related reports [1–3], the new CPW filters meet the requirement of more flexible design, more controllable bands, and even smaller dimensions. Compared with the DGS coplanar waveguide bandpass filters [1,4,5], the new designs have less circuit complexity and less electromagnetic waves leakiness. CPW circuit is more immune than DGS from crosstalk and ground plane interference not only because the conductor strip and the ground are coplane but also because there is no manipulation on the ground plane. The proposed filter design scheme is helpful for multi-band microwave filters design.

2. Analysis of the defected CPW resonator

When there are etched slots/patterns in the CPW conductor strip, resonances can be produced. Fig. 1 shows the defected CPW resonator, where two identical L-shaped slots are etched in the conductor strip. Resonant frequency and bandwidth can be controlled by the etched slots. Equivalent transmission line model that ignores the inner couplings is plotted in Fig. 1(b). According to the transmission line and network theory, each parameter of the ABCD matrix can be expressed as

$$A = \cos\theta_e, \quad B = jZ_b \sin\theta_e \tag{1}$$

$$C = \frac{-jZ_a \cos\theta_a \sin^2\theta_e - 2Z_b \sin\theta_a \sin\theta_e \cos\theta_e}{Z_a Z_b \cos\theta_a \sin\theta_e} \tag{2}$$

$$D = \frac{Z_a \cos\theta_a \cos\theta_e - 2Z_b \sin\theta_a \sin\theta_e}{Z_a \cos\theta_a} \tag{3}$$

where Z_a, Z_b and Z_d are characteristic impedances of CPW with widths of w_a, w_b and w_d, respectively. Electric length can be expressed as $\theta_i = \omega l_i \sqrt{\varepsilon_{re_i}}/c$, $\theta_e = \theta_b + \theta_m$, $\theta_m = \arctan[Z_b/Z_d)\tan\theta_d]$. $i = a, b, d$; l_i is the physical length; c is the velocity of light in free

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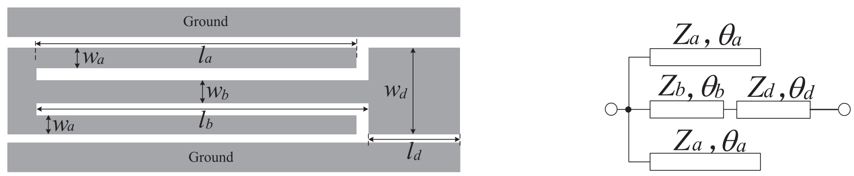

(a) Resonator topology (b) Equivalent transmission line model

Fig. 1. Defected CPW resonator.

space; ε_{re} is the effective permittivity. S_{21} can be expressed with ABCD as $S_{21} = 2/(A + B/Z_0 + CZ_0 + D)$ [6]. When S_{21} equals zero, frequency point of the transmission zero can be computed and predicted as

$$f_z = c(2n+1)/\left(4l_a\sqrt{\varepsilon_{rea}}\right), \quad n = 0, 1, 2\ldots \tag{4}$$

Resonant frequency of the CPW resonator can be obtained when S_{21} equals 1, from which the resonant condition can be expressed as

$$(P/Q)^2 + (P/R)^2 = 1 \tag{5}$$

where P, Q and R can be expressed as

$$P = 2Z_0Z_aZ_b\cos\theta_a\sin\theta_e \tag{6a}$$

$$Q = 2Z_0Z_b[sin\theta_e cos\theta_0(Z_a cos\theta_a - Z_0 \sin\theta_a) - Z_b \sin\theta_a \sin^2\theta_b] \tag{6b}$$

$$R = Z_aZ_b^2 cos\theta_a \sin^2\theta_e - Z_0^2 Z_a cos\theta_a \sin^2\theta_e \tag{6c}$$

When l_a = 10.8 mm, l_b = 11 mm, l_d = 2.5 mm, w_a = 0.3 mm, w_b = 1.2 mm, w_d = 2.2 mm, it can be calculated by Matlab that the transmission zero and resonant frequency are 2.96 GHz and 2.4 GHz, respectively, which approach to the simulated results of 2.74 GHz and 2.43 GHz.

3. Single band CPW bandpass filter

CPW bandpass filter can be constructed by coupling CPW resonators with wavelength of $\lambda/4$. Defected slots have been introduced in order to control passband effectively, as Fig. 2 shows. Where the four identical L-shaped slots determine the filter center frequency and bandwidth. When designed with second-order (n = 2) Chebyshev response with 0.15 dB ripple, the element values of the low-pass prototype are g_0 = 1, g_1 = 0.93, g_2 = 0.65, and g_3 = 1.43. The bandpass filter is designed centering at 2.4 GHz with fractional bandwidth (FBW) of 9%. The external quality factor can be obtained as Q_e = 10.87. Filter dimensions can be estimated from expressions (5) and (6), the required FBW, and the resonator coupling coefficient, and then are optimized with EM simulator as: l_1 = 11 mm, a_1 = 0.2 mm, d_1 = 0.5 mm, w = 0.96 mm, g = 0.4 mm, w_a = 0.3 mm, w_b = 1.2 mm, w_d = 2.2 mm. The coupling scheme including the source and load can be formulated by coupling matrix as

$$M = \begin{bmatrix} 0 & -0.0674 & 0 & 0 \\ -0.0674 & 0 & -0.0873 & 0 \\ 0 & -0.0873 & 0 & 0.0623 \\ 0 & 0 & 0.0623 & 0 \end{bmatrix} \tag{7}$$

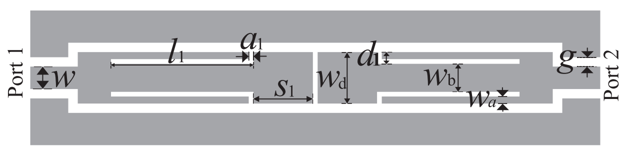

Fig. 2. Topology of the CPW BPF.

The research results on filter center frequency and fractional bandwidth (FBW) variations are illustrated in Tables 1 and 2. The external quality factor can be obtained from $Q_e = f_0/\Delta f_{3dB}$. It indicates that filter center frequency is mainly determined by parameter l_1, while, bandwidth can be adjusted mainly by etched slot width. Center frequency decreases with l_1 increasing, while, 3 dB bandwidth may increase when slot width increases. Simulated filter frequency responses comparison with l_1 and d_1 are plotted in Fig. 3(a) and (b), respectively, the simulations demonstrate the centre frequency and bandwidth variation rules. Fig. 3(c) shows the comparison of the coupling matrix result and the simulation, the simulated result is similar to the theoretical prediction.

Transmission zeros are attributed to the mixed electromagnetic coupling. It has also been noticed that a longer etched slot can introduce more resonances in a certain frequency band, for which brings more effective capacitance and inductance. But for this case, the required resonances are difficult to control because these resonances are relevancy each other, which limits the multi-band applications. So, individually controlled slots have been introduced for multi-band BPF design in order to obtain individually controllable passbands.

The proposed CPW bandpass filter is different from the traditional CPW filter because the filter performance can be controlled by the etched slots. Simulated electromagnetic field distributions of the CPW bandpass filter are illustrated in Fig. 4(a) and (b). It is seen that the electric field and the magnetic field concentrate on the edge of etched slots with different part, the electric field has stronger magnitude. The current path of the CPW bandpass filter is plotted in Fig. 4(c). The inner coupling of the CPW resonator with etched slots is mixed electromagnetic coupling (MEMC), while, the coupling between neighboring CPW resonators is electric coupling. In this paper, the designs have used ceramic dielectric substrate with a relative permittivity of 10.2 and a thickness of 1.27 mm.

4. Multi-band CPW bandpass filters

4.1. Dual-band CPW BPF

A dual-band CPW bandpass filter with individually controllable passband is proposed. The filter centers at 2.4 GHz and 3.5 GHz with fractional bandwidth of 14.8% and 6.6%, respectively. The passband insertion loss is less than 2 dB. The design procedures: (1) calculate the width of CPW conductor strip, and the width of air gap which is between the conductor strip and the ground, feed lines are set with 50 ohm. (2) Estimate the dimensions of etched slots to meet the desired frequencies. For example, a longer slot

Table 1
Filter performance variation versus l_1, a_1 = 0.2 mm, d_1 = 0.5 mm, s_1 = 2.5 mm.

l_1 (mm)	f_0 (GHz)	FBW (%)	Q_e
9.0	2.97	11.4	8.74
10	2.69	10	9.96
11	2.42	9.5	10.87