A Narrow-Band Two-Cavity Filter With Five Transmission Zeros

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Abstract

The presented filter has two transmission poles and five transmission zeros. The parallel coupling between two hairpin resonators, the open-circuited stubs result in three transmission zeros in the vicinity of the passband. The two stubs which share a common grounded via-hole contribute two additional transmission zeros in the upper stopband.The novel filter with 4.5% fractional bandwidth (FBW) has been designed and fabricated to verify the validity of the proposed method. Measured results are in good agreement with the electromagnetic simulation. The measured results show five transmission zeros in the stopband, located at 1.72GHz, 2.25GHz, 2.55 GHz, 3.17 GHz,4.33 GHz,respectively. The circuit size of proposed bandpass filter only occupies 20×17mm^2.

1. Introduction

Microwave bandpass filters with low insertion loss, compact size and high selectivity play more and more important roles in mobile communication systems and radio frequency (RF) front/end of the wireless communication systems [1-5].The out-of-band characteristics of a bandpass filter can be effectively improved by generating attenuation poles in the rejection band [1]. There are mainly three methods to achieve transmission zeros, such as cross-coupling, source-load coupling, and asymmetric input and output feed lines tapping on the first and last resonators [2].Recently, an alternative technique for the implementation of transmission zeros was proposed in [4].An important advantage of this method, is that transmission zeros can be easily shifted from one side of the passband to the other side.but the selectivity in the upper band is not very good.In addition, the transmission zeros are sensitive to different tapped positions, so that transmission zeros cannot be turned over a wide range.In [6][7], although two resonators sharing the same via hole grounding are proposed,the relationship between the length of resonators and the locations of the transmission zeros has not been given.

In this paper, we propose a simple design method for a bandpass filter with attenuation poles at desired frequencies. The relations between the three types of microstrip lines and transmission zeros are thoroughly analyzed. Because of the series resonance of the quarter-wavelength open stubs, parallel coupled-lines with symmetric feed structure by increasing the velocity ratio and quarter-wavelength microstrip lines with a via hole grounding, the proposed bandpass filter can create five transmission zeros. Finally, these structures are applied to the design of a two-pole hairpin microstrip filter. The simulated and experimental results of the designed filter are compared.

2. Analysis

2.1 Impact of the Tap-Lines Feeding Position L_3

The mixed coupling hairpin filter was described by [8-10],It is shown that three transmission zeros in the two-cavity hairpin filter can be resolved by utilizing open-circuited stubs and increasing the velocity ratio.However, the selectivity in the upper band is not very good. Fig. 1 illustrates the schematic layout of the proposed bandpass filter, which is composed of microstrip open-circuited stubs (l_2, l_3), parallel coupled-lines with open circuits at one end (l_1). All the resonators are around half-wavelength of its center frequency f0, and the lines have the identical characteristic impedance Z0. The filter is fabricated on a substrate with a thickness of $h = 0.635\ mm$ and a relative dielectric constant $\varepsilon_r = 9.6$. The coupling of lines is dominated by the mixed EM coupling,the ends of coupling lines realize strong electric coupling. Thus, desired transmission zero can be obtained by tuning the spacing g, coupling length L1 and the Tap-Lines Feeding Position L3.Here g=0.2mm, L1=9mm, and then the shift of transmission zeros at the lower stopband can be realized by changing L3. Meanwhile, L2 need to be adjusted to keep the total length of each resonator equal to half-wavelength. The even and odd modes which have different velocities in hairpin-comb filters create a pole of attenuation at fz1,but the tapping positions L3 of feed lines affect the even- and odd-mode input impedances between coupling lines L1 . Furthermore, when the tap-lines feeding position L3 is moved nearer to the coupling lines L1, the

shorter the average electrical length for a transmission zero is. In other words, the created transmission zero will move to a lower frequency. The effect of the tap-lines feeding position for a half-wavelength resonator is not only the realization of transmission zeros. but also control of the external Q. The position of transmission zero fz2 can be obtained from the quart-wavelength resonance of lengths L2, The upper frequency transmission zero fZ3 is almost unchanged because of the length of the open-circuited stub(l_1) is constant. fz3 is obtained by $f_{z3} = nc / 4l_1\sqrt{\varepsilon_{eff}}$, where ε_{eff} is the effective dielectric constant, n is the mode number, c is the speed of light in free space. When L3 = 10 mm, L3= 10.6mm, and L3 = 11.4 mm,the positions of transmission zeros are fZ11=1.67GHz, fZ21=2.32GHz,fZ12=1.97GHz,fZ22=2.37GHz, and fZ13=2.16GHz, fZ23=2.46GHz.

2.2 parallel coupled-lines with a via hole grounding.

Figure 3 shows a kind of coupled-lines with a via hole grounding and the equivalent circuit, z_{0e} and z_{0o} are the even- and odd-mode characteristic impedances for the coupled line sections. z_1 and z_2 are the identical characteristic impedance, l is the length of coupled-lines with a via hole grounding, $\theta = \beta l$. β is the propagation constant.S21 of the circuit can then be calculated from the transmission matrix and is expressed as

$$S_{21} = \frac{2}{[j\sin\theta[Z_1 + Z_2 + \frac{1}{Z_1}] - \frac{Z_2}{Z_1}\tan\theta\sin\theta + 2\cos\theta]} \quad (1)$$

Since the numerator of S21 is not equal to zero, the necessary and sufficient condition for the existence of the transmission zero is $\tan\theta \approx \infty$,The positions of the transmission zeros are

$$f = nc / 4l \sqrt{\varepsilon_{eff}} \quad (2)$$

The filter is fabricated on a substrate with a thickness of $h = 0.635\ mm$ and a relative dielectric constant $\varepsilon_r = 9.6$.

3.Filter design

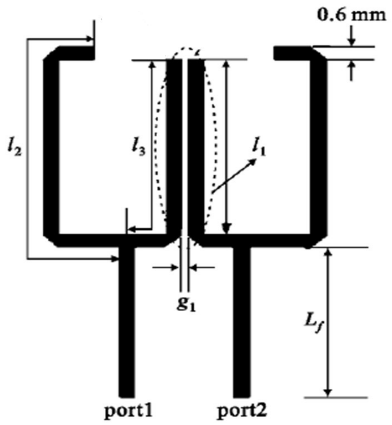
Based on the above analyse, the mixed coupling hairpin filter generate transmission zeros by the open-circuited stubs,and the parallel coupled line filter with symmetric feed structure can yield tuned transmission zero by increasing the velocity ratio vo / ve or reducing the impedance ratio Z0e / Z0o .Coupled-lines with a via hole grounding can be obtain transmission zero.These structures are applied to the design of a novel two-cavity microstrip hairpin filter.Fig. 3 illustrates the schematic layout of the proposed bandpass filter, which is composed of $\lambda / 4$ microstrip open-circuited stubs (l_2 , l_3), parallel coupled-lines with open circuits at one end (l_1) and two $\lambda / 4$ resonators (l_4 , l_5) sharing the same via hole grounding. The filter is designed at the fundamental frequency of 2.4 GHz with bandwidth of 2%. The filter is fabricated on a substrate with a thickness of $h = 0.635\ mm$ and a relative dielectric constant $\varepsilon_r = 9.6$. The proposed filter is designed in the aim of the in-band return loss of 15 dB, and a minimum out-band loss of 25 dB in the lower band, 15 dB in the upper band. The dimensions of the filter are shown as follows: the length of the line $l_1 = 9\ mm$, $l_2 = 13.9\ mm$, $l_3 = 10.8\ mm$, $l_4 = 9.6\ mm$, $l_5 = 6.4\ mm$, the total length is $L = l_2 + l_3 = \lambda_{go} / 2$, where λ_{go} is the guided wavelength of the fundamental mode at the resonant frequency; the width of the line: $W_1 = 0.6\ mm$, $W_2 = 0.2\ mm$; coupling gap: $g_1 = 0.27\ mm$, $g_2 = 0.13\ mm$; the diameter of the via hole: $D = 0.6\ mm$. As a result, the total size of the filter is about $20mm \times 17mm$, and a compact filter has been implemented.

The simulation is accomplished using an ensemble electromagnetic simulator based on the method of moment (MoM). Measurements are carried out on an Agilent Technologies N5230A network analyzer. As exhibited in Fig. 4, the measured results are consistent with the simulated results. The filter has a minimum insertion loss of 2.9 dB at 2.38 GHz. Due to the conductor loss, dielectric loss and non-ideal microstrip/coaxial line transitions, the insertion loss in the measurement is a little higher than that in simulation. The return loss is greater than 10 dB from 2.35 GHz to 2.42 GHz. Five transmission zeros, which are Zp1 to Zp5 from low frequency to high frequency shown in Fig. 2, are generated by

microstrip lines l_1, l_2, l_1, l_4, l_5, respectively. The 3 dB fractional bandwidth of the filter is 4.5% at 2.38 GHz.It shows that at Zp3 the simulated and measured results are consistent, both of which are only 0.2 GHz larger than the analytic ones. At Zp5, the analytic and simulated results are close to each other and the maximum difference is only 0.3 GHz between analytic and measured results. At other points, the analytic results and simulated results agree fairly well with measured results and the discrepancies are acceptable. Adjusting the length of l_5 can suppress the spurious response at twice of the center frequency, which is larger than 12 dB at 4.8 GHz. Though the result includes a little disagreement in stop-band due to discontinuity of permittivity and insufficient accuracy of fabrication, these responses almost agree with the method described, thus demonstrating the validity of the design method.

4.Conclusion

A novel compact two-pole microstrip bandpass filter with five transmission zeros have been proposed. By utilizing open circuited stubs, parallel coupled-lines and quarter-wavelength resonators with a via hole grounding, the proposed filter produces five transmission zeros at lower and upper stopbands. The locations of these transmission zeros can be adjusted to realize excellent out-of-band characteristics. There are good agreements among the analytic, simulated and measured results.



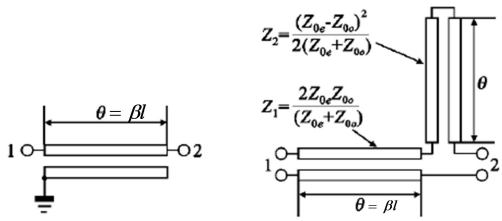
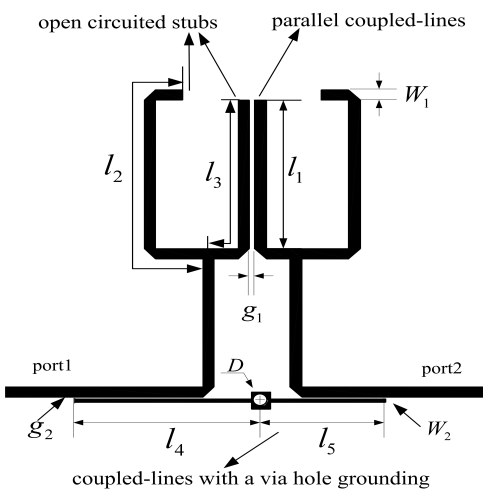


Fig. 1 Schematic layout of a mixed coupling hairpin filter

Fig. 2Coupled-lines with a via hole grounding and the equivalent circuit Fig. 4 Simulated results



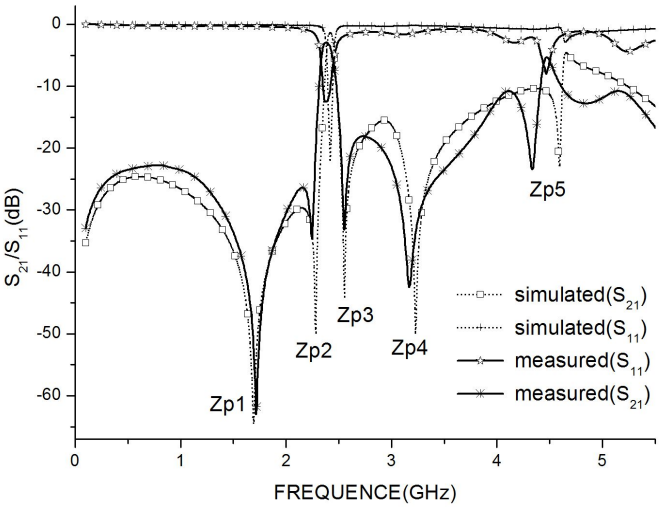


Fig. 3Schematic layout of novel bandpass filter

Fig. 4 Measured and simulated results of bandpass filter

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