Design of a Quasi-Millimeter-Wave UWB Bandpass Filter Using Microstrip Dual-Mode Ring Resonator and Half-Wavelength Resonators

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Abstract

In this work, a novel quasi-millimeter-wave ultra wideband (UWB) bandpass filter (BPF) is designed by using a microstrip dual-mode square ring resonator and two folded half-wavelength stepped-impedance resonators. The transmission line equivalent circuit of the filter is analyzed first based on the even- and odd-mode method, and design formulas are derived for determining the frequencies of reflection zeros in the passband and transmission zeros in the stopband, as well as the 3dB edge-frequencies. Then by using the obtained formulas and circuit simulators, variations of the frequency response of the filter versus the circuit parameters are investigated. Finally, a compact UWB microstrip BPF with a midband frequency of 25.5 GHZ and a fractional bandwidth of 22% is designed, and the desired wide passband, sharp skirt property, and wide stopband are realized simultaneously. The FCC's UWB spectrum mask is met quite well.

1. Introduction

After the Federal Communications Commission (FCC) authorized the unlicensed civil use of 3.1-10.6GHz for ultra-wideband (UWB) communications, and 22-29GHz for automotive radar systems in 2002 [1], a large number of works on UWB bandpass filters (BPFs) operating over 3-10GHz have been reported [2-10]. Meanwhile, for the quasi-millimeter-wave 22-29 GHz frequency band, few papers on UWB filters are available. Compared with the 3-10GHz UWB BPFs, the quasi-millimeter-wave UWB BPFs require smaller fractional passband bandwidth, but much steeper passband skirt and larger attenuations in the stopband according to the FCC's spectrum mask for UWB applications. This requirement is found difficult to be met when we try to use typical 3-10GHz UWB BPF structures reported in recent years , include those designed using microstrip stub-loaded ring resonators [2-5], filters employing microstrip multi-mode step-impedance resonators [6-8], and filters consisting of other types of multi-mode resonators [9, 10], etc. Therefore, it is strongly demanded to develop quasi-millimeter-wave wideband BPFs having a sharp roll-off of attenuations near the passband and large attenuations over a very wide frequency range in the stopband.

In this paper, we try to develop a novel 26GHz UWB BPF for vehicular radar applications by using a microstrip dual-mode square ring resonator and two folded half-wavelength stepped-impedance resonators (SIRs). The microstrip dual-mode square ring resonator has a relatively small size, large unloaded Q-value and low losses. It exhibits a wide passband with a sharp passband skirt because of two transmission zeroes located closely near the passband [11, 12]. The folded half-wavelength resonators are added to increase attenuations in the stopband of the filter. The filter is analyzed by using its transmission line equivalent circuit and the even- and odd-mode method [5, 13, 14]. Design formulas are derived for determining the frequencies of reflection zeroes in the passband and transmission zeroes in the stopband, as well as the 3dB edge-frequencies of the passband of the filter. These formulas are proved accurate and easy to use by numerical results obtained from both a circuit simulator and an electromagnetic simulator. Then by using the obtained formulas and circuit simulators, variations of the frequency response of the filter versus the circuit parameters are investigated. Finally, a compact microstrip UWB BPF with a midband frequency of 25.5 GHz and a fractional bandwidth of 22% is designed, and the desired wide passband, low reflection loss in the passband, sharp skirt property, and wide stopband are realized simultaneously.

2. Structure, Design, and Performance of a Microstrip UWB Bandpass Filter

The configuration of the proposed UWB bandpass filter is shown in Fig.1. It consists of a microstrip dual-mode square ring resonator. Each side of the ring has an electrical length of θ, and is about one quarter-wavelength long at its fundamental resonant frequency. The vertical and horizontal strips of the ring are designed with different widths, w_1 and w_r, respectively, so that the ring resonator becomes a dual-mode resonator [11, 12]. The horizontal strips of width w_r have a characteristic impedance of Z_r. The vertical sides of the ring are parallel-coupled with the folded half-wavelength resonators through parallel-coupled lines having a width of w_1, a length of L_1, and a coupling gap-width of S_1. The even- and odd-mode characteristic impedances of the vertical coupled lines are expressed by Z_{1e} and Z_{1o}, respectively. The folded half-wavelength resonators are fed by the input and output lines through the horizontal parallel-coupled lines having a width of w_2, a length of L_2, and a coupling gap-width of S_2. The even- and odd-mode characteristic impedances of the horizontal coupled lines are Z_{0e} and Z_{0o}, respectively. The input and output lines have a strip width of w_0 and a characteristic impedance of Z_0=50Ω.

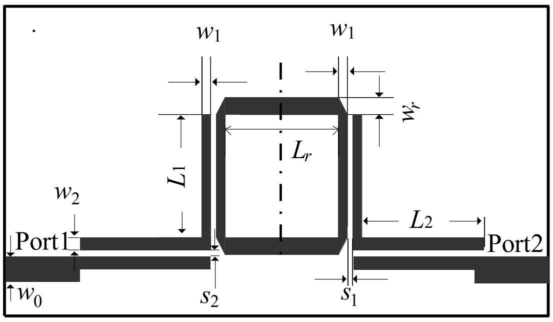

Fig. 1. Configuration of the proposed quasi-millimeter-wave UWB bandpass filter consisting of a microstrip dual-mode square ring resonator and two folded half-wavelength stepped-impedance resonators.

The whole structure of the filter is symmetric with respect to the central dash-dotted line shown in Fig. 1. Therefore, we need only to analyze half of the structure using the even- and odd-mode method [5, 13, 14]. In the analysis, we calculated first the input impedance of the vertical parallel-coupled lines using the general four-port Z-matrix of the parallel-coupled lines [14]. Then, we calculated the input impedance of the horizontal parallel-coupled lines following the same method. From the input impedances of the even- and odd-mode circuits, we get the transmission and reflection coefficients of the filter, and from which, we obtain the formulas for determining the frequencies of reflection zeroes in the passband and transmission zeroes in the stopband, as well as the 3dB edge-frequencies of the filter. For example, the formula for determining the electrical length θ_t at which the transmission zero occur is expressed by

$$\sin^2\theta_t = 2/(a+1) \tag{1}$$

Here, $a = (Z_{1e} + Z_{1o})/2Z_r$ is the ratio of impedances described above. We see that by changing the impedance ratio a, we can vary the positions of the transmission zeroes of the filter, and thus improve the skirt property of the passband of the filter.

Next, a microstrip UWB BPF with a midband frequency of 25.5 GHZ and a fractional bandwidth of 22% is designed. From the derived formulas, we get all the required circuit parameters of the filter as follows: Z_{1e}=149Ω, Z_{1o}=79Ω, Z_r=92Ω, Z_{0e}=133Ω, Z_{0o}=63Ω, and Z_0=50Ω. A low loss substrate by Nippon Pillar Packing Co., Ltd is used to realize the filter with a configuration shown in Fig. 1. The substrate has a relative dielectric constant of 2.2 and a loss tangent of 0.00075 @ 10GHz. The thickness of the substrate is chosen very thin (0.25mm) in order to suppress the occurrence of high-order modes and substrate surface-waves that are easy to occur at high frequencies around 26GHz and degrade significantly the performance of the filter. Based on the circuit parameters given above, the dimensions of the filter are determined by using a commercial electromagnetic simulator, Sonnet em [15]. We get w_0=0.78mm, w_1=0.16mm, L_1=2.08mm, s_1=0.1mm, w_2=0.22mm, L_2=2.23mm, s_2=0.06mm, w_r=0.26mm, and L_r=2.18mm.

The frequency response of the designed filter is simulated by using Sonnet em, and is shown in Fig. 2. In the simulation, the metallic and dielectric losses of the filter have been taking into consideration by using the conductivity of copper σ=5.8×10^7 S/m and the loss tangent tanδ=0.00075 of the substrate. Radiation loss is also included because no shielding box of the filter is used. It is seen from Fig.2 that the center frequency of the filter is 25.6 GHz, and the 3dB fractional passband bandwidth is about 21.9% (from 22.84 to 28.45GHz). Within the passband, four reflection zeroes are observed. The insertion loss is about 0.9dB at the center frequency, and the return loss is less than 20dB at most frequencies. Sharp transition between the passband and the stopband is obtained due to the transmission zeroes closely near by the passband. In the stopband, attenuations larger than 38dB are realized from DC to about 48GHz because of the multiple transmission zeroes. The FCC's UWB indoor spectrum mask shown in the figure by the dash-dotted line is satisfied favorably well.

Compared with our previously developed quasi-millimeter-wave UWB BPFs in [11-13], the current filter has a significantly reduced size and better performance. Fabrication of the filter and experiment verification of it characteristics will be done in the near future.

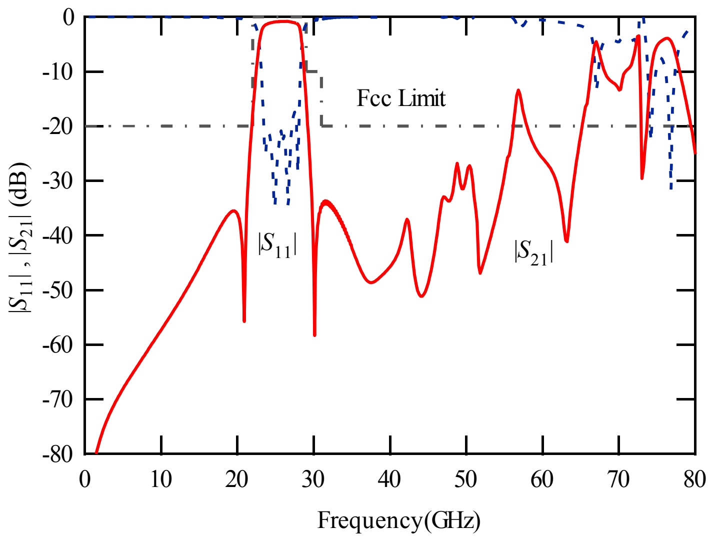

Fig. 2. Simulated frequency response of the designed UWB bandpass filter. The FCC's spectrum mask shown by the dash-dotted line is satisfied quite well over a wide frequency range.

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