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A Dual-Band Bandstop Filter Having Open Stubs and Two Equivalent T-Shaped Lines

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Abstract A compact dual-band microstrip bandstop filter (BSF) with two midband frequencies of 2.0 GHz and 3.0 GHz is presented. This filter is based on a conventional open-stub BSF with a midband frequency of 2.0 GHz. The series quarter-wavelength connecting line of the conventional BSF is replaced by two equivalent T-shaped lines to form the dual-band BSF. The impedances and electrical lengths in the equivalent T-shaped lines are found by equating the ABCD matrices of half of the original connecting line and one equivalent T-shaped line. Then the dimensions of the two equivalent T-shaped lines are calculated, and these two T-shaped lines generate a stopband around 3.0 GHz. The proposed BSF is simulated and fabricated. Simulation and measurement show this filter generates two stopbands around 2.0 GHz and 3.0 GHz.

Keywords Bandstop filter, Open stub, Impedance, Equivalent T-shaped line

1. Introduction

Microstrip bandstop filters are being widely used in local oscillators, mixers, duplexers, switches, and other microwave subsystems. Various techniques have been developed to synthesize and design BSFs [1]. Dual-band bandstop filters are highly desired in some situations for their two separate stopbands. For example, dual-band BSFs have been used on RF/microwave amplifiers to reduce signal distortion [2, 3]. Various methods have been proposed to form dual-band BSFs. Dual stopbands can be obtained through frequency-variable transformation to the lowpass prototype [2] and cul-de-sac configuration [4], and the application of right/left-handed metamaterials [5], parallel open stubs at different lengths [6] and dual mode ring oscillators [7].

Conventionally, a dual-band BSF can be obtained by cascading two different BSFs. The side effect of this technique is an increase in circuit size. Size reduction of dual-band BSFs has been a hot research topic in recent years [8-16]. In this paper, a dual-band BSF is formed by replacing the series connecting line of a conventional open-stub BSF with two equivalent T-shaped lines. The impedances and electrical lengths in the equivalent T-shaped line can be found by equating the two ABCD matrices of the original transmission line and the equivalent T-shaped line. Then the dimensions of the two equivalent T-shaped lines are calculated. The proposed BSF is simulated on Sonnet Suite 14.52. Then the proposed filter is fabricated and measured. Simulation and measurement agree, showing this BSF generates two stopbands around 2.0 GHz and 3.0 GHz.

2. Open-Stub Bandstop Filter

Figure 1(a) shows the configuration of a conventional open stub BSF. Usually the length of the two stubs and the separation between the two stubs are a quarter of the wavelength at the midband frequency [17, 18]. The substrate material is Rogers TMM10i with a relative dielectric constant of 9.9 and a loss tangent of 0.002. The thickness of the substrate is 1.27 mm. The back of the substrate is the ground plane. The dimensions of all the transmission lines are calculated directly on AppCAD software. AppCAD is a free RF/microwave design software provided by HP/Agilent. The width of the feed line and the width of the open stubs in this BSF are both 1.2 mm, which yields a characteristic impedance of 50 Ohm. The two open stubs are 14.61 mm long and the separation between the centers of the two open stubs is also 14.61 mm.

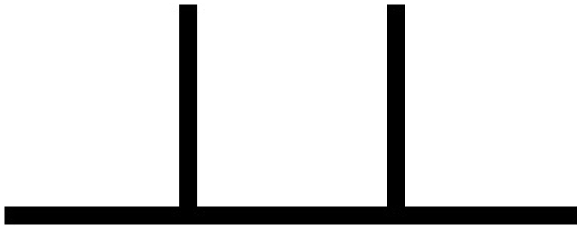

Figure 1(a). Layout of a conventional open-stub BSF

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This conventional BSF is simulated on Sonnet Suite 14.52 at selected stub separations. Sonnet Suite is a planar 3D electromagnetic simulation software based on Method of Moments. The simulation results are shown in Figure 1(b). The midband frequency is at 2.0 GHz for these three stub separations, although the stopband profile varies. The length of the two open stubs must be kept at a quarter of the wavelength, so the impedance seen from the connecting point onto the horizontal transmission line is short-circuited. However, the separation between the two open stubs does not need to be kept at a quarter of the wavelength, thus it can be tuned.

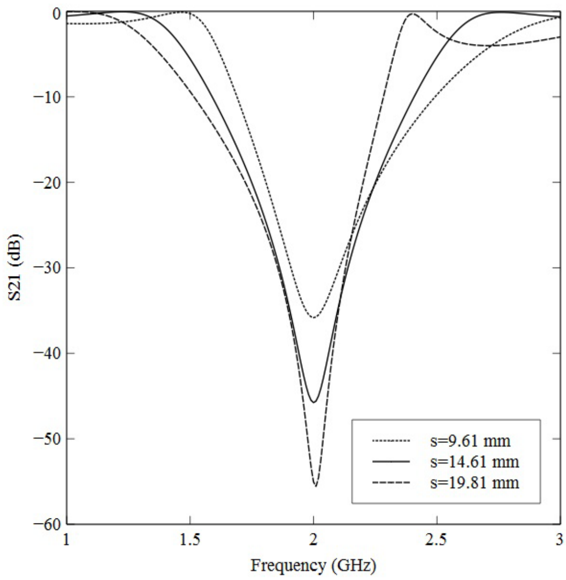

Figure 1(b). Simulation results of the conventional BSF at selected stub separations

3. Equivalent T-shaped Line

Equivalent T-shaped Line was proposed by Tu and Chang to generate a stopband around second harmonic frequency on a conventional BSF and on an open-stub bandpass filter [18]. Figure 2(a) shows the schematics of an original transmission line and its equivalent T-shaped transmission line. Z_1 and θ_1 are the impedance and the electrical length of the original transmission line. Z_2 and θ_2 are the impedance and half of the electrical length of the horizontal line in the equivalent T-shaped line. Z_3 and θ_3 are the impedance and the electrical length of the vertical line in the equivalent T-shaped line.

The impedances and electrical lengths in the equivalent T-shaped line can be found by equating the two ABCD matrices of the original transmission line and the equivalent T-shaped line [18, 19]. Ning, Luo, and Bu derived two general formulae for the equivalent T-shaped line as [19]

$$Z_2 = \cot\theta_2 \frac{1-\cos\theta_1}{\sin\theta_1} Z_1 \quad (1)$$

$$Z_3 = \tan\theta_3 \frac{\cos^2\theta_2}{\cos(2\theta_2)-\cos\theta_1} \frac{1-\cos\theta_1}{\sin\theta_1} Z_1 \quad (2)$$

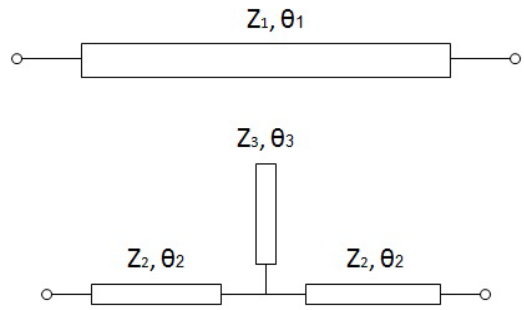

Figure 2(a). An original transmission line and its equivalent T-shaped line

The two electrical lengths θ_2 and θ_3 need to be chosen properly, and then Z_2 and Z_3 can be calculated. The horizontal line in the equivalent T-shaped line can be shorter than the original horizontal transmission line. So that the equivalent T-shaped line has a potential size reduction effect in horizontal direction.

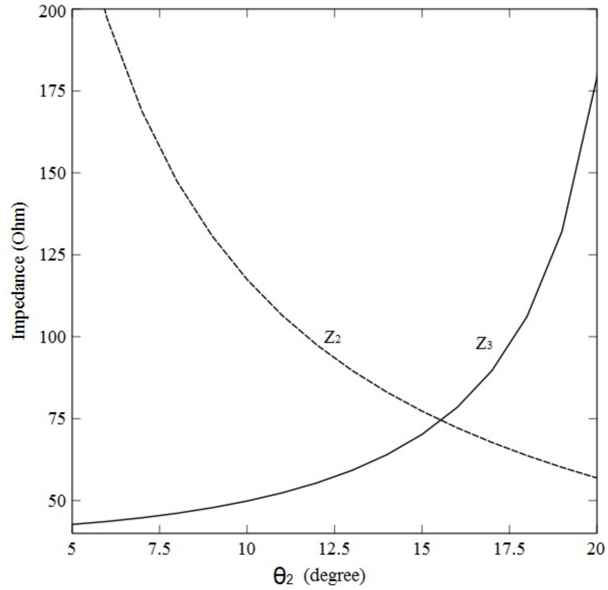

Figure 2(b). Z_2 and Z_3 versus θ_2 with 60 degrees θ_3

4. Proposed Bandstop Filter

The proposed BSF is realized by replacing the connecting line between the two open stubs of the conventional BSF (described earlier) with two equivalent T-shaped lines. The two equivalent T-shaped lines yield a second stopband. For half of the connecting line, Z_1 should be 50 Ohms, and the electrical length θ_1 should be 45 degrees. The vertical electrical length θ_3 was chosen as 60 degrees for the second stopband to be around 3.0 GHz. Then Z_2 and Z_3 are calculated as functions of θ_2 (Figure 2(b)). Next, the equivalent horizontal electrical length θ_2 was chosen as 15 degrees. Then Z_2 and Z_3 can be calculated as 77.29 and 70.20 Ohms. Figure 3(a) is the layout of the equivalent double T-shaped lines. All dimensions are calculated directly on AppCAD software. The vertical Z_3 line is 0.53 mm wide and 10.06 mm long. The Z2 connecting line between the two Z_3

lines is 0.40 mm wide and 5.07 mm long. The double T-shaped lines structure is simulated on Sonnet Suite 14.52. Simulation results are shown in Figure 3 (b). A stopband is generated around 3.0 GHz and the deepest rejection is more than -25 dB.

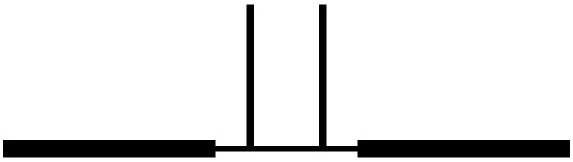

Figure 3(a). Layout of the equivalent double T-shaped lines

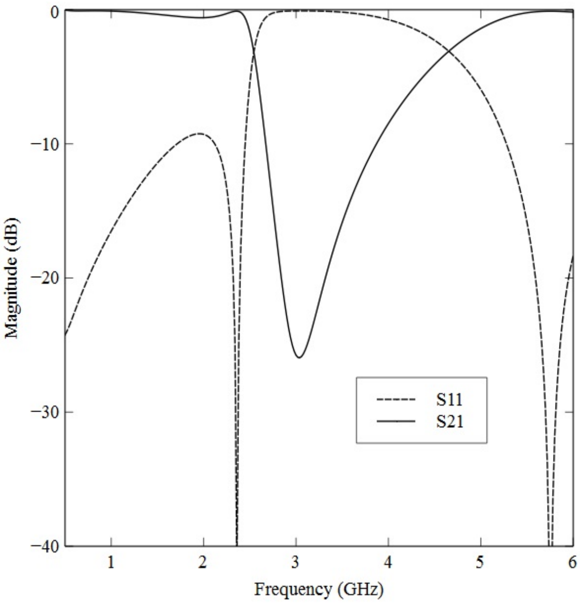

Figure 3(b). Simulation results of the double T-shaped lines

The proposed BSF is a combination of the conventional open-stub BSF and the double equivalent T-shaped lines. The whole connecting line between the two open stubs is replaced by two equivalent T-shaped lines mentioned above. Layout of this proposed BSF is shown in Figure 4(a). The distance between the centers of these two original open stubs is tuned to 15.34 mm to reduce the impedance discontinuity effect. The original two open stubs were tuned to 0.2 mm longer.

The proposed BSF is simulated and then fabricated. The fabricated BSF (Figure 4(b)) is measured with an Agilent N5230A network analyzer after two-port calibration. The simulated and measured results are shown together in Figure 4(c) for comparison. The simulated and measured results are close to each other. The measured insertion loss is shifted to lower frequency from the simulated result by about 60 MHz. There are also some ripples in the measured data. For the second stopband, the measured is about 2 dB shallower than the simulated. The differences between measured and simulated results should be caused mainly by PCB fabrication process tolerance and substrate material property variations. Based on the measurement, the midband frequencies of the two stopbands are still very close to 2.0 GHz and 3.0 GHz respectively.

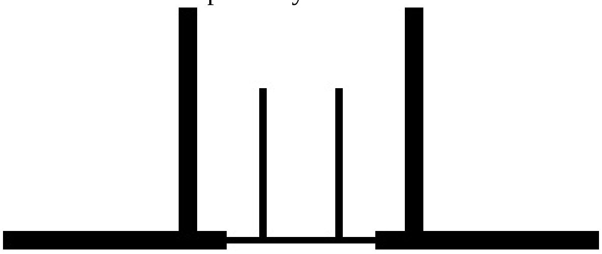

Figure 4(a). Layout of the proposed BSF

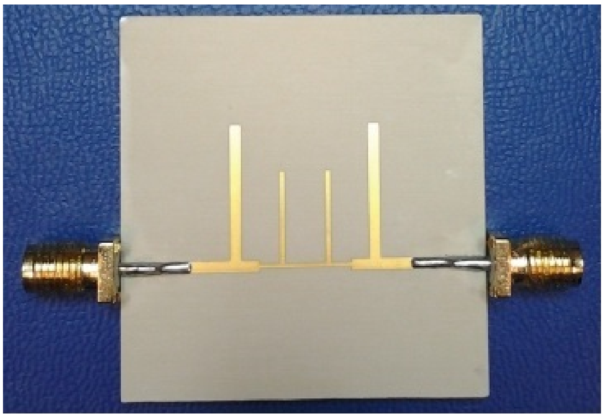

Figure 4(b). Picture of the fabricated filter

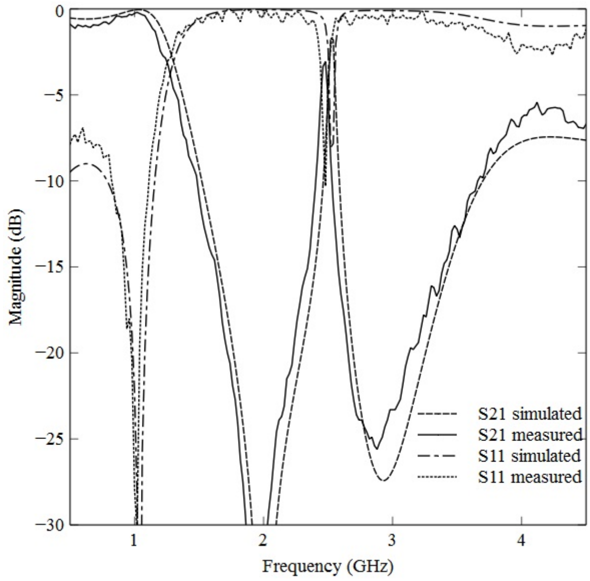

Figure 4(c). Simulation and measurement results of the proposed dual-band BSF

5. Conclusions

The series connecting line of a conventional open-stub BSF with a midband frequency of 2.0 GHz is replaced by two equivalent T-shaped lines to form a dual-band BSF. The impedances and the electrical lengths in the equivalent T-shaped lines are found by calculations on ABCD matrix. Then the dimensions of the T-shaped lines are calculated on AppCAD software. Simulation of the double T-shaped lines shows the formation of a stopband around 3.0 GHz. The proposed BSF is simulated and fabricated. Simulated and measured results agree, showing two stopbands are generated around 2.0 GHz and 3.0 GHz.

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