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IMPROVED COMPACT BROADBAND BANDPASS FILTER USING BRANCH STUBS CO-VIA STRUCTURE WITH WIDE STOPBAND CHARACTERISTIC

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Abstract—In this paper, a broadband bandpass filter (BPF) with superior spurious suppression over a wide frequency range at least up to 20 GHz at −20 dB has been designed. The proposed broadband bandpass filter has designed using quarter-wavelength short stubs alternating with branch stubs co-via structure, and inserting the bandstop filters to substitute for redundant connecting lines. Compare with some traditional co-via structure, this work by using the branch stubs to construct the co-via structure, not only reduce the size around 70% but also decrease the radiation loss due to some complex meander

configurations occurring in the connecting lines. For the prototype broadband filter, center frequencies around 4 GHz were selected. The bandwidth of passband was between 1.95 GHz and 6.25 GHz, in which the insertion-loss amounts to around −1.5 dB. The suppression range of stopband is between 8.2–20.3 GHz, in which the insertion-loss amounts to around −20 dB.

1. INTRODUCTION

Recently, the broadband bandpass filters are particularly promising in the design of broadband filters with compact size and superior stopband performance due to the fast development of broadband wireless communication systems. Because of the rapidly expanding broadband systems, the requirements for filter design have become stricter.

Until this date, developing broadband BPFs were made [1–11]. Edge coupled microstrip lines [1], even if accompanies stepped impedance open stubs [2] and the parallel-coupled lines with multimode resonator [3, 4] were also used for realizing broadband bandpass filters. Even if the ring resonators using direct-connected orthogonal feeders [5] and triangular resonator bandpass filter with fractal-shaped defection [6] also have achieved the good broadband ones. To suppress spurious bands over a very wide band, filters was used a cascaded lowpass or bandstop filter or else multi-rejection behavior defected ground structures were proposed [7–9]. However, these filters have several drawbacks, such as large size by using cascaded circuits and complex meander configuration for compact size but the waves are scattered, and reducing the transmittance power is reduced due to reflection loss and radiation loss at the given obstacle.

Recent years, a method to implement broadband bandpass filters with cascaded series and shunt transmission line sections was proposed [10, 11]. This method, with short-circuited stubs, indicated that the physical implementation of these filters consists of a cascade of shunt stubs of equal length alternating with non-redundant connecting lines of equal length, each of them twice the stub electrical length.

In this study, the redundant connecting lines of a traditional broadband bandpass filters (Fig. 1(a)) was effectively substituted by the stub structure, and is shown in Fig. 1(b). The stubs significantly were improved filter behavior by attenuating the undesired spurious bands without using extra cascaded circuits. Furthermore, the proved co-via structure is formed by the branch stub based on impedance transformation theory. By this way, not only to reduce the size but

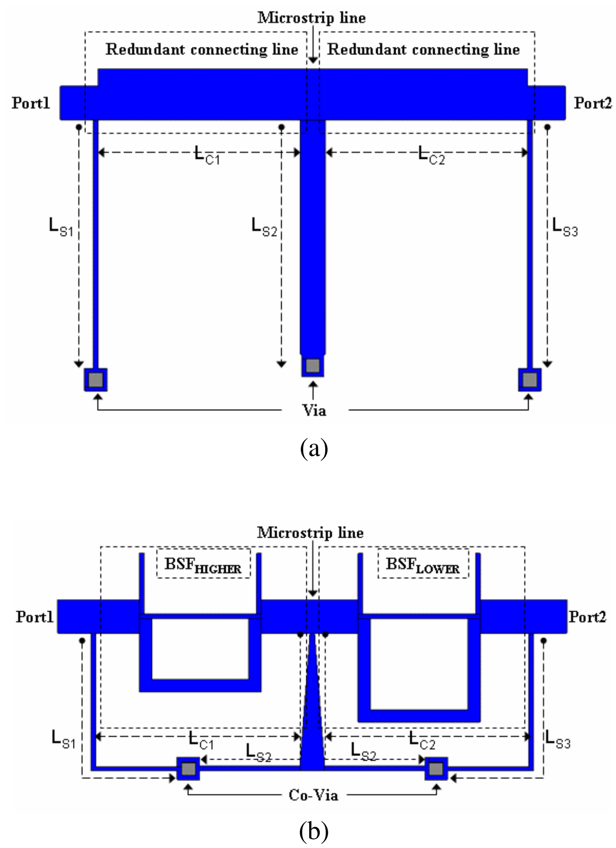


Figure 1. Geometry of (a) the traditional broadband BPF and (b) the proposed branch stubs co-via broadband bandpass filter with combined BSF substituted for redundant connecting lines.

also to avoid the complex meander configurations would be realized in the connecting lines, which is benefic for the passband performance.

2. PROPOSED BROADBAND BANDPASS FILTER

In the cause of suppressing the undesired spurious bands, let redundant connecting lines effectively be applied to build the bandstop structure, which results in size reduction, as compared to the conventional broadband bandpass filters implementation. Based on a circuit model for a pseudo distributed bandpass filter with 3 short-circuited stubs, the filter design was constructed and shown in Fig. 2. The

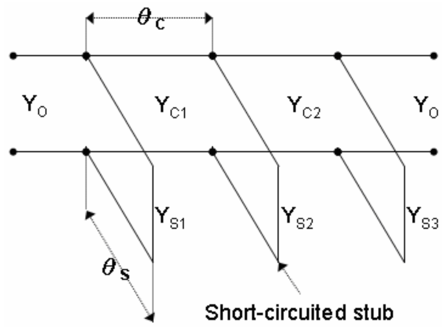


Figure 2. Circuit model for a pseudo distributed bandpass filter with three short-circuited stubs.

characteristic admittances of the short-circuited stubs are defined by Y_{S1}, Y_{S2} and Y_{S3}, and the characteristic admittances for the redundant connecting lines are defined by Y_{C1} and Y_{C2}. The terminal admittance is defined as Y_O. The electrical length of redundant connecting lines (θ_C) is equal to that of the stubs (θ_S) [16–18]. The electrical lengths were chosen as $\theta_C = \theta_S = 45°$ for both the redundant connecting lines and the short-circuited stubs at 4 GHz. In order to obtain the desired circuit parameters, the characteristic admittances for the short-circuited stubs and the redundant connecting lines are selected as $Y_{S1} = Y_1 = Y_{S3} = Y_3 = 0.0087\,\Omega^{-1}$, $Y_{S2} = Y_2 = 0.0164\,\Omega^{-1}$, and $Y_{C1} = Y_{1,2} = Y_{C2} = Y_{2,3} = 0.0258\,\Omega^{-1}$. The design equations for determining these characteristic admittances described in [18], simplified as below formulas.

$$Y_{C1} = Y_{C2} = g_0\left(\frac{2g_1}{g_2}\right) \tag{1}$$

$$Y_{S1} = Y_{S3} = Y_0\left(\sqrt{\left(g_0\sqrt{\frac{2g_1}{g_2}}\right)^2 + (g_0 g_1 \tan\theta)^2} - g_0\sqrt{\frac{2g_1}{g_2}}\right) \tag{2}$$

$$Y_{S2} = 2Y_0\left(\sqrt{\left(\frac{2g_0 g_1}{\sqrt{g_2 g_3}}\right)^2 + (g_0 g_1 \tan\theta)^2} - \frac{2g_0 g_1}{\sqrt{g_2 g_3}}\right) \tag{3}$$

$$\theta = \frac{\pi}{2}\left(1 - \frac{FBW}{2}\right) \tag{4}$$

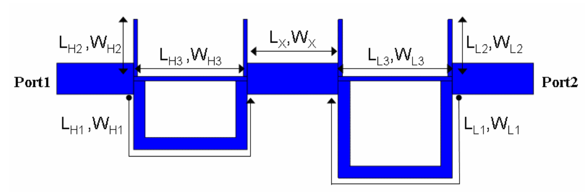
To illustrate the performance, a microstrip of broadband bandpass filter centered at 4 GHz with a fractional bandwidth (FBW) of 120% is simulated in a FR4 substrate (permittivity = 4.4, thickness = 0.8 mm).

Low-pass filters have been widely used to suppress harmonics and spurious signals. The conventional defected ground structure (DGS) [12, 13] and electromagnetic bandgap (EBG) structures [14], even if substrated integrated waveguide (SIW) resonators [15] can provide wide stopband characteristics with a sharp cutoff frequency response. In order to achieve a sharp cutoff frequency response, more sections are needed, but increasing sections will also increase the loss in the passband and circuit size.

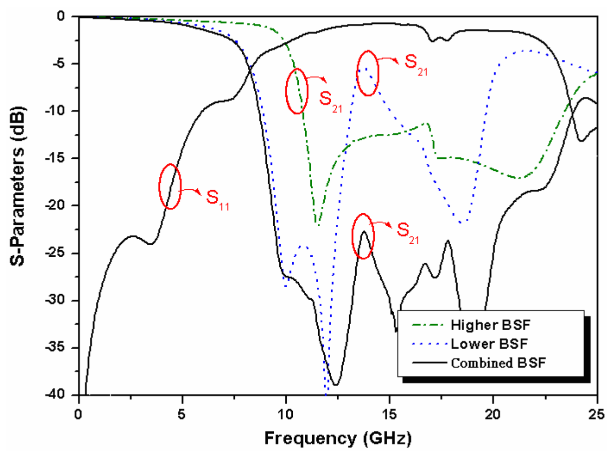
The combined bandstop structure is shown in Fig. 3(a). It can be seen that it was designed as two adaptable performances separately, which one operated on higher wide stopband, and another operated on lower sharp stopband. The transmission lines of the inserted bandstop filter consisted of three sections for the same cut-off frequency to obtain a wide stopband [8] as a uniform structure, which are one-wavelength section as L_{H1}, quarter-wavelength section as L_{H2}, half-wavelength section as L_{H3}, among the higher wide bandstop structure (HBS). In this paper, a non-uniform structure with different resonance of the sections was proposed, the one-wavelength section (L_{L1}) of the proposed lower sharp bandstop structure (LBS) is differ from the higher wide bandstop structure (HBS) operated frequency of the one-wavelength section (L_{H1}) for producing the demanded sharp lower rejection behavior without adding too much size as like uniform structure maybe lengthen all the three sections just for the same lower rejection. As a whole, each section was designed with a center stopband frequency of 15.2 GHz except L_{L1} designed as wavelength at 12.2 GHz. This way makes the stopband be formed as a sharp one, and operated on lower frequency avoiding size increased too much. Just as well, the proposed combined bandstop filter results in size reduced and more feasibility for any integrated microwave circuits. The performance of the combined non-uniform bandstop filters achieves a wide stopband and a good selectivity as shown in Fig. 3(b).

The short-circuited stubs (L_{S1}, L_{S3}) have been bent with 90 degree angles in such a way to result in the same via hole with the middle parted short-circuited stub (L_{S2}), which based on impedance transformation theory. Therefore, the proposed filter by using the branch stubs to form the co-via structure demonstrates the feasibility of this concept is proposed. Not only reduce the size around 70% and reduce the radiation loss due to the complex meander configurations occur in the connecting lines.

Additionally, we can get a fine tuning of the passband bandwidth adopting the tapped line technique to design the middle stub. In Fig. 4, the simulated magnitude of S_{11} dB) for the broadband bandpass filter, are plotted as functions of tapped stub width (W_{ts}). To base on the



(a)



(b)

Figure 3. (a) Geometry and (b) simulated S-Parameters of the combined bandstop filter consists of higher BSF and lower BSF.

transmission-line model, and the circuit model for a pseudo distributed bandpass filter, as the tapped stub width decreases, the equivalent characteristic admittance of the middle short-circuited stubs (Y_{S2}) decreases to result in the fractional bandwidth increases.

The above proposed techniques are very simple and useful for the design of good suppression broadband bandpass filters with more compact dimensions and similar in-band performance. Fig. 5 shows the proposed broadband bandpass filters are designed with/without the inserted bandstop filters (BSFs) by using the full-wave EM simulation [19]. It is obvious from Fig. 5 that the proposed compact broadband bandpass filter obtains a wide stopband characteristic by using the combined BSF, which consisted of higher wide bandstop structure (HBS) and lower sharp bandstop structure (LBS).

3. IMPLEMENTATION AND EXPERIMENTAL RESULTS

The photograph of the fabricated filter is shown in Fig. 6. The dimensions of the designed broadband bandpass filter with a fractional bandwidth (FBW) of 120% are: $L_{S1} = L_{S3} = 11.1$ mm, $L_{S2} =$

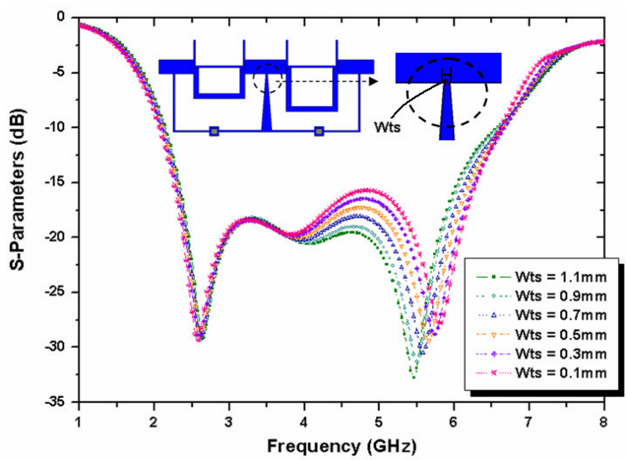


Figure 4. Simulated magnitude of S_{11} (dB) for the broadband bandpass filter in different width of the tapped stub (W_{ts}).

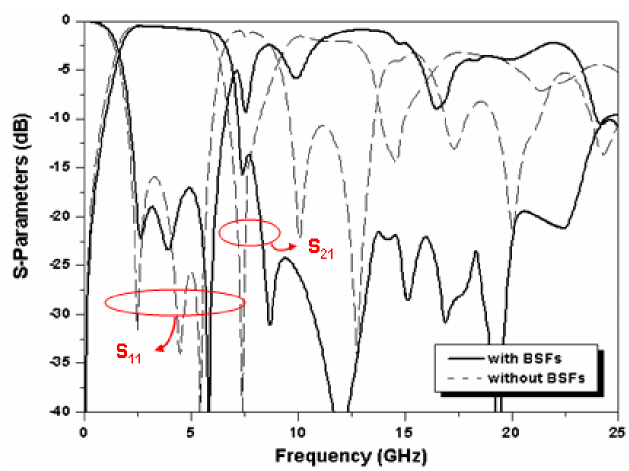


Figure 5. Simulated S-parameters of the proposed broadband bandpass filter with/without BSFs.

10.5 mm, $L_{C1} = L_{C2} = 9.5$ mm, and $L_{H1} = 10.8$ mm, $L_{L1} = 13.5$ mm, $L_{H2} = L_{L2} = 2.7$ mm, $L_{H3} = L_{L3} = 5.4$ mm, $L_X = 4.3$ mm, $W_X = 1.5$ mm and $W_{H1} = W_{L1} = 0.55$ mm, $W_{H2} = W_{H3} = W_{L2} = W_{L3} = 0.2$ mm, and is shown in Fig. 3(a). Via-holes with a diameter of 0.6 mm each were used to attach the stubs to the ground plane.

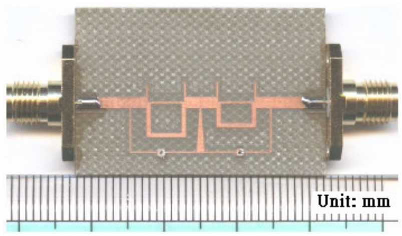


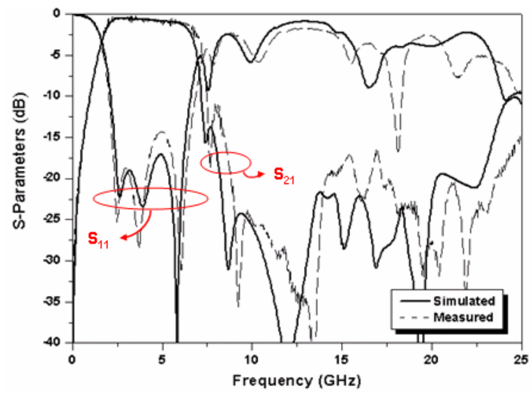
Figure 6. Photograph of a fabricated broadband bandpass filter.

The bandpass filters are realized and are verified by full-wave EM simulation. An Agilent E8364A network analyzer is employed for the measurement of frequency responses of the designed bandpass filter. Fig. 7 shows the simulated and measured performances of (a) S-parameters and (b) group delays of the proposed broadband bandpass filter. Table 1 shows the comparison of the proposed filter with other reported broadband bandpass filters as [2, 7–9].

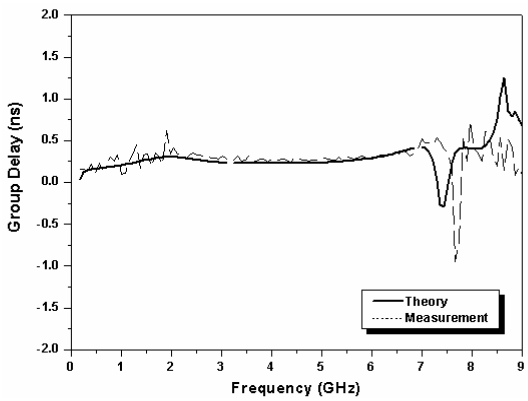
Table 1. Comparison with other reported broadband BPFs.

	[2]	[7]	[8]	[9]	This work
Fractional bandwidth	110%	110%	110%	110%	120%
Upper stop band (20dB)	2.35fo	3.2fo	4.38fo	2.92fo	5.07fo
Variation of Group Delay (ns)	0.21	0.2	0.15	0.15	0.15
Planar structure	Yes	Yes	Yes	No	Yes
Size (mm^2)	13.5×18.6	12.4×37.3	9.3×33.3	6.8×44.5	10×19.6
Dielectric constant	3.38	3.05	3.38	2.65	4.4

Proposed filter characteristics are good with in-band insertion losses below 1.5 dB and return losses better than 15 dB between 1.95–6.25 GHz. The performance of out-of-band is also good with spurious passband attenuation higher than 20 dB up to at least 20.3 GHz and a flat group delay, which the variation of the measured group delay is less than 0.15 ns in broadband passband. For the selected center frequency and on a substrate with a dielectric constant of 4.4, substrate height of 0.8 mm, the proposed microstrip filter is only 19.5 mm × 10 mm in size.



(a)



(b)

Figure 7. Measured and simulated (a) S-parameters and (b) group delay of the proposed broadband bandpass filter.

4. CONCLUSION

A good suppression broadband bandpass filter (BPF) has been designed and implemented in this study. The bandpass filters are realized and are simulated by full-wave EM simulation. Experimental results of the fabricated filter were agreed well with the design specification. The proposed filters showed wide passband, low insertion loss, flat group delay, and excellent out-of-band performance. Therefore, the filter looks promising for use in wireless communications due to its small size and excellent performance.

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