Design of a Suspended Stripline Dual-Band Band-Stop Filter Loaded With Short-Ended Waveguide Stubs Embedded in the Metal Housing

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***Abstract*—This letter presents a novel dual-band band-stop filter (DBBSF) based on suspended stripline (SSL) with short-ended waveguide stubs on its metal housing. A short-ended waveguide stub embedded transversally in the metal housing of the SSL has been shown to introduce independent transmission zeros. It is mostly suitable for high harmonic depression. This letter describes a band-stop filter with four short-ended waveguide stubs around a center frequency of 12.5 GHz. A U-shaped slot in the SSL forms a resonator and provides an additional independent stopband. We designed and fabricated a DBBSF with short-ended stubs formed on the metal housing and U-shaped slots in the stripline. Our design produced stop bands at 6.6 and 12.5 GHz, corresponding to attenuation levels of 27 and 26 dB, respectively. The short-ended waveguide stubs on the metal housing do not require additional space. Excellent agreement was achieved between the measured and simulated results.**

***Index Terms*—Dual-band band-stop filter (DBBSF), short-ended waveguide stub, suspended stripline (SSL), U-shaped slot.**

I. Introduction

WITH the rapid development of wireless communication systems, the microwave band-stop filter (BSF) has become one of the fundamental components used to suppress interference from unwanted signals and pass the desired signal [1]–[5]. Dual-band BSFs (DBBSFs) have attracted much attention due to their compact structure [6]–[10]. Suspended stripline (SSL) has proven to be an excellent transmission line system with low insertion loss. Menzel has produced a series of valuable work on SSL filters [1], [2], [11]–[14]. Generally, the resonators on an SSL filter are designed suspended in the split-block metal housing of the stripline by extending both inside edges of the housing by 1 mm [15], as shown in Fig. 1(a). Because the coaxial connectors must screw into the split-block metal housing, the metal housing requires a certain thickness and occupies a certain volume. This letter proposes a short-ended waveguide stub embedded in the metal housing of an SSL filter, as shown in Fig. 1(b). The stub can introduce a transmission zero at a predetermined frequency to form a stopband. In [16]–[18], short-ended waveguide stubs were added in the E-planes of a waveguide and substrate integrated waveguide (SIW) to produce multiple transmission zeros, but they occupied extra space outside the waveguide and SIW.

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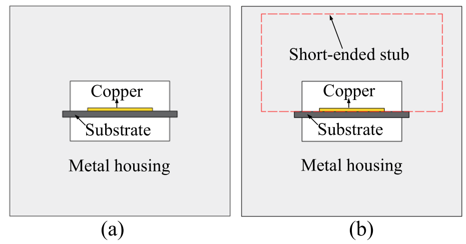

Fig. 1. Cross section of (a) SSL filter with and (b) short-ended stub in the metal housing.

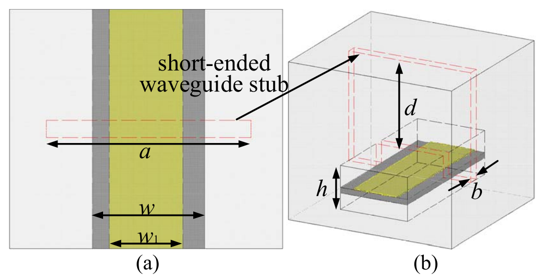

Fig. 2. Geometry of the SSL with a short-ended waveguide stub. (a) Top view and (b) 3-D view with $a = 12$ mm, $b = 1$ mm, $d = 8$ mm, $h = 4$ mm, $w = 6.6$ mm, and $w_1 = 4.6$ mm.

Section II presents an analysis of the proposed short-ended waveguide stub. Section III describes a DBBSF using four short-ended waveguide stubs. The substrate suspended in the metal housing is RT-Duroid 5880 laminate with a thickness of 0.254 mm and a relative dielectric constant ε_r of 2.2.

II. Short-Ended Waveguide Stub

The conventional structure of the SSL filter consists of a metal housing and a substrate on which resonators are usually designed along the direction of propagation. To use the metal housing of the SSL efficiently, a method to introducing stopbands by constructing short-ended waveguide stubs is proposed. Fig. 2 shows a top view and 3-D view of the SSL with a short-ended waveguide stub, where d is the height and a is the width of the stub. The short-ended waveguide stub is disposed transversally in the direction of propagation. Fig. 3 shows the equivalent circuit of the SSL with the stub, where Z_0 represents the characteristic impedance of the SSL

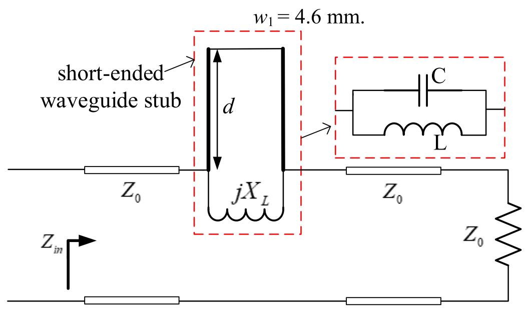

Fig. 3. Equivalent circuit of the SSL with a short-ended waveguide stub.

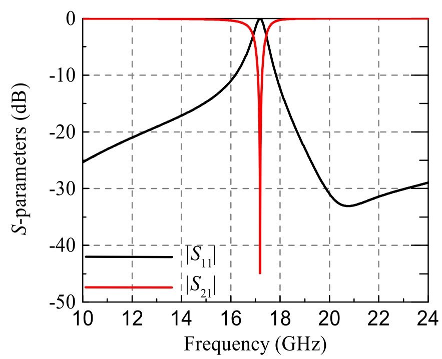

Fig. 4. Full-wave simulated S-parameters of the SSL with a short-ended waveguide stub.

and the impedance of the load. The fact that the width a of the stub is larger than the width w of the substrate changes the magnetic field distribution of the TE_{10} mode propagation in the stub; the portion of the stub extending out from both the sides of the substrate is equivalent to a parallel inductive load with an inductive reactance of jX_L.

The input impedance of the SSL is

$$Z_{in} = Z_0 + 1 \Bigg/ \left(\frac{1}{jX_L} + \frac{1}{jZ_b \tan(\beta d)} \right) \tag{1}$$

where β is the waveguide wavenumber and d is the height of the stub.

The reflection coefficient of the SSL is

$$\Gamma = \frac{jZ_b X_L \tan(\beta d)}{2Z_0[X_L + Z_b \tan(\beta d)] + jZ_b X_L \tan(\beta d)}. \tag{2}$$

At a transmission zero, $|\Gamma|^2 = 1$, we have

$$d = \frac{1}{2\pi}\left[\arctan(-{}^{X_L}/_{Z_b}) + n\pi\right]\lambda_{gTE10} \tag{3}$$

where $n = 1, 2, 3 \ldots$ and λ_{gTE10} represents the wavelength of the waveguide.

The following conclusions can be obtained from (3).

1) A short-ended waveguide stub embedded transversally in the metal housing of the SSL can introduce a transmission zero when its length d is around a quarter of a wavelength. However, as there is a strong discontinuity between the waveguide stub and the SSL, d need not be exactly one-quarter of a wavelength.
2) The short-ended waveguide stub is equivalent to an LC parallel resonator around the resonant frequency.
3) As the dimensional parameters, that is, the waveguide broadside a and the length d, increase, the resonant frequency shifts to a lower frequency, while the length b of the waveguide narrow side has less effect on the resonant frequency.

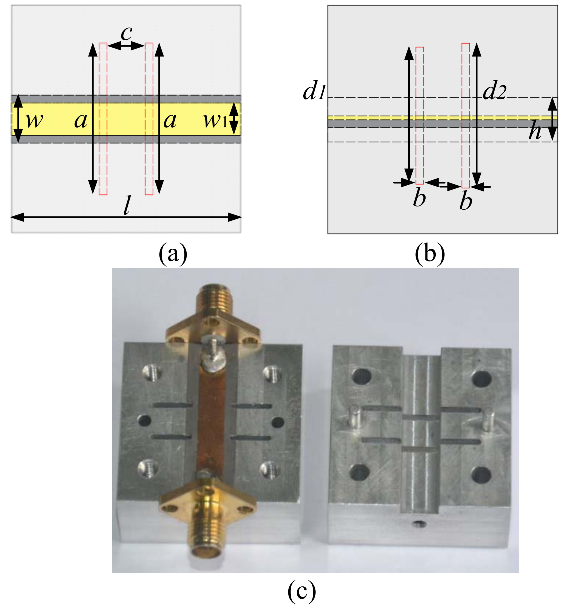

Fig. 5. Structure of the BSF. (a) Top view, (b) side view, and (c) photograph of the fabricated filter with $a = 20$ mm, $b = 1$ mm, $d_1 = 18$ mm, $d_2 = 19$ mm, $c = 5$ mm, $w = 6.3$ mm, $w_1 = 4.3$ mm, $h = 5.8$ mm, and $l = 30$ mm.

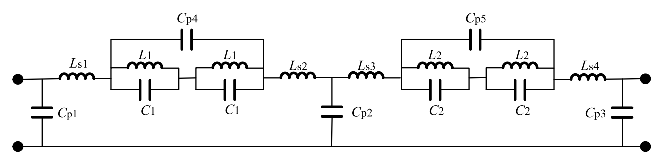

Fig. 6. Equivalent circuit of the BSF.

The slot width b should be small so as to introduce fewer effects in the passband. A full-wave simulation of the SSL with a short-ended waveguide stub shows that the stub length d need not be exactly one-quarter of a wavelength, because of the discontinuity between the SSL cavity and the waveguide stub. Two stubs that are equivalent to two parallel LC circuits connected in series may be constructed simultaneously on the metal housing above and below the substrate, thus introducing two independent resonant frequencies.

III. DBBSF Design

We used the above analysis of the short-ended waveguide stub to design a DBBSF. The basic dimensions of the SSL were determined by the characteristic impedance, which is usually 50 Ω. The slot length was determined from (3).

Section III-A presents a BSF we designed that adopts four short-ended waveguide stubs. Section III-B presents a DBBSF that adopts four short-ended waveguide stubs and two U-shaped slots in the stripline.

A. Band-Stop Filter

Our short-ended waveguide stub had a high loaded quality factor, which resulted in a very narrow stopband bandwidth, as shown in Fig. 4. To increase the stopband bandwidth, we used the method of cascading short-ended waveguide

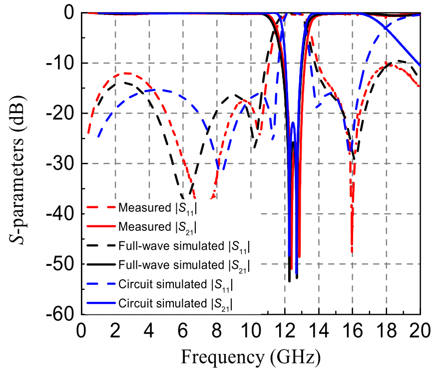

Fig. 7. Measured and simulated S-parameters of the BSF.

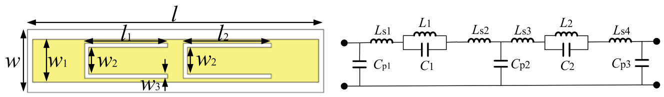

Fig. 8. Geometry of the two U-shaped slots with $w_2 = 2.7$ mm, $w_3 = 0.5$ mm, $l_1 = 8.4$ mm, and $l_2 = 8.9$ mm.

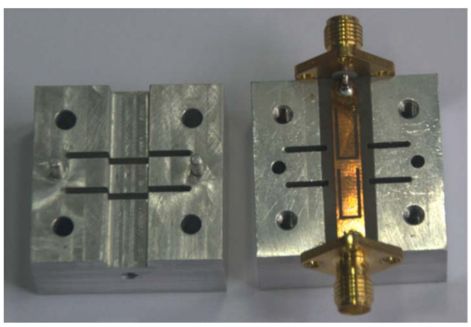

Fig. 9. Photograph of the DBBSF with U-shaped slots.

stubs. The first step was to construct two stubs with identical dimensions above and below the substrate to form a new rectangular cavity resonator that had a lower loaded quality factor compared with a single stub. This increased the bandwidth of the stopband. The new resonator is equivalent to two identical parallel *LC* circuits connected in series. The second step was to construct another rectangular cavity resonator to produce a resonant frequency adjacent to the one obtained in the first step. Eventually, the two rectangular cavity resonators formed by the four stubs produced two adjacent resonant frequencies, and a BSF was designed with the structure shown in Fig. 5.

To analyze the proposed BSF we used the equivalent circuit model shown in Fig. 6. The model considers the couplings between the stubs forming the rectangular cavity resonators. The resonant characteristics of an SSL with a short-ended waveguide stub are similar to those of the basic defected ground structure (DGS) cell in a microstrip line. The capacitance and inductance of each stub were obtained from the equivalent circuit model and the analysis of the DGS cell in [19] and [20]. The other circuit parameters were optimized, and C_1, C_2, C_{p1}, C_{p2}, C_{p3}, C_{p4}, C_{p5}, L_1, L_2, L_{s1}, L_{s2}, L_{s3}, and L_{s4} were 3.76, 3.21, 0.26, 0.45, 0.26, 1.25, 1.12 pF, 0.027, 0.029, 0.23, 0.43, 0.47, and 0.23 nH, respectively.

Fig. 7 shows good agreement between the measured, full-wave simulated, and circuit simulated S-parameters of the filter. The target filter had a stopband with a center frequency at 12.5 GHz and a bandwidth of 1.35 GHz. The attenuation of the stopband was more than 26 dB. The out-of-band response was also satisfactory with a return loss of better than 12 dB and an insertion loss of less than 0.3 dB.

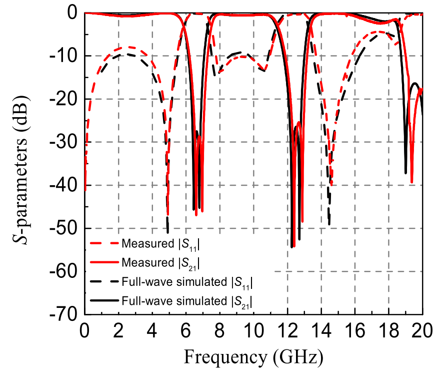

Fig. 10. Measured and simulated S-parameters of the DBBSF.

TABLE I
COMPARISON WITH OTHER BSFS

Technology	Bands	f_0 (GHz)	Attenuation in stop band (dB)	3-D size (λ_g)
[2] SSL	Single	7.5	> 17	$0.85 \times 0.57 \times 0.37$
[4] SSL	Single	5	> 24	$0.91 \times 0.36 \times 0.24$
[6] SIW	Dual	10.25/11.23	> 15.48	$2.31 \times 0.84 \times 0.01$
[7]Waveguide	Dual	9/11	> 21	$0.56 \times 0.52 \times 0.22$
This work	**Dual**	**6.6/12.5**	**> 26**	$\mathbf{0.75 \times 0.50 \times 0.47}$

f_0 is the resonant frequency.

B. Dual-Band BSF

No resonant structures were constructed on the SSL in Section III-A. Section III-B proposes the introduction of two U-shaped slots etched in the SSL to generate the second stopband, thus forming a DBBSF [21]. The configuration and equivalent circuit of the two U-shaped slots are shown in Fig. 8.

The DBBSF was designed by combining the U-shaped slots with the stubs proposed in Fig. 5. A photograph of the fabricated DBBSF is shown in Fig. 9. The measured results for the fabricated filter are shown in Fig. 10, which shows good agreement with the full-wave simulation. The dual stopbands are at 6.6 and 12.5 GHz with bandwidths of 1.1 and 1.28 GHz, with the corresponding attenuation levels of 27 and 26 dB, respectively. Table I provides a comparison between the proposed DBBSF and several previous works using SSL, SIW, and waveguide technologies; our proposed filter has greater attenuation in the stopband.

IV. CONCLUSION

This letter presents short-ended waveguide stubs formed in the metal housing of an SSL. The metal housing of the traditional SSL filter was effectively used for the stubs without occupying extra space on the stripline. The DBBSF we designed used four stubs on the metal housing and two U-shaped slots in the stripline. The overall size of the dual-band band-stop SSL filter was $0.75 \times 0.50 \times 0.47\ \lambda_g^3$. The short-ended waveguide stubs allowed the SSL filter to have flexible stopbands.

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