Design Feature

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# Triband Filter Employs SIW-Loaded Resonators

This compact filter design utilizes SIW circuit technology and several different resonator types, achieving three adjustable passbands with relatively low insertion loss.

Miniaturization is critical for many circuits and systems, and the use of substrate integrated waveguide (SIW) resonators has proven to support the design of compact filters. In particular, a novel triband filter based on SIW-loaded resonators provides passbands of 1.85, 2.575, and 3.05 GHz in a very small size.

The filter incorporates quarter-wavelength resonators and a loaded SIW resonant stub. The first and second passbands are obtained using the SIW-loaded resonator, which is smaller in size than a uniform impedance resonator (UIR); the quarter-wavelength resonators help generate the third passband. To demonstrate the approach and how miniaturization is possible even with three passbands, a practical filter was fabricated. The performance yielded was quite close to the predicted simulation values.

Wireless communications applications in different frequency bands have developed rapidly. In turn, this has created demand for filters with dual frequency bands in support of different wireless applications, such as wireless code-division multiple-access (WCDMA) systems and wireless local-area networks (WLANs). Using dual-band filters rather than multiple separate filters in multiband comm systems can help reduce their volume and mass. As a result, many different approaches have been studied for the design of multiple-band filters.[1-10]

Several synthesis methods for creating multiband filters using frequency transformations have been detailed previ-
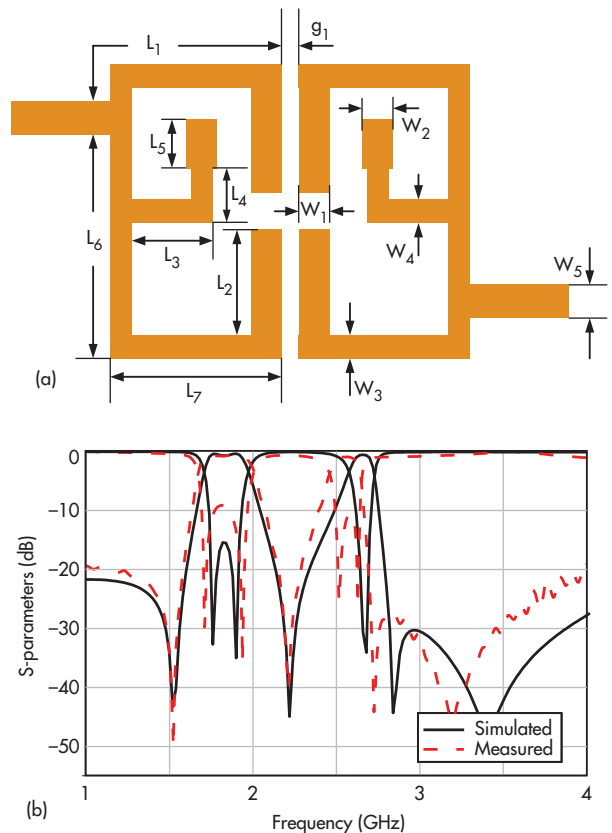
1. The layout (a) of the proposed triband filter is shown next to (b) simulated and measured responses for a dual-band filter

ously.[1-5] Synthesis of microwave filters involves controlling the passbands analytically. Several dual-mode, dual-band bandpass filters (BPFs) have been realized by using two nested dual-mode resonators of different sizes[6-8] or by means of multilayer circuit structures.[9,10] But most of these multiband filters have been designed without the guidance of a straight-
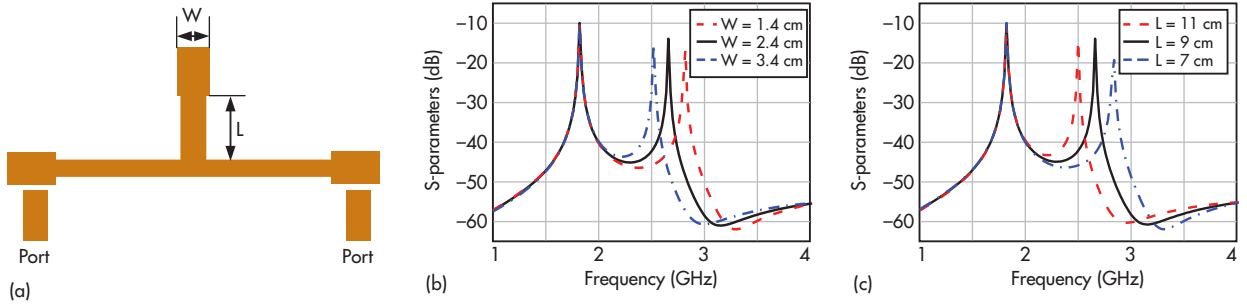
2. The layout (a) of the proposed resonator is shown next to (b) the simulated $|S_{21}|$ frequency response of a filter with different W values and (c) the simulated $|S_{21}|$ frequency response of a filter with different L values.

forward synthesis method; therefore, the design procedure isn't exact or consistent.

To save space even beyond what is possible with a dual-band filter, a novel triband microstrip version was developed with passbands for three different wireless communications systems. The path to the triband filter design begins with a dual-band filter with 0-deg. feed (*Fig. 1*), which is composed of two SIW-loaded resonators. The first and second passbands can be generated by the SIW-loaded resonators. The two passbands can be adjusted to their desired values by changing the dimensions of the SIW-loaded resonators.

To create the third passband—and the triband filter—the quarter-wavelength resonators are embedded inside the microstrip printed-circuit board (PCB). This is done in such a way that the center frequency of the third passband can also be controlled and adjusted. To demonstrate the design approach, a triband filter with passbands of 1.69 to 2.02 GHz, 2.52 to 2.65 GHz, and 3.06 to 3.2 GHz was fabricated and measured, with the measured results showing good agreement with computer simulations.

In following this design approach, the initial dual-band filter design with SIW-loaded resonator is shown in *Fig. 1(a)*; the filter includes two SIW-loaded resonators to produce the first and second passbands of the triband filter. Two ports with characteristic impedance of 50 Ω are symmetrical by the center of filter, and introduce transmission zeros outside of the passbands.

The configuration of these SIW-loaded resonators is shown in *Fig. 2(a)*. It consists of a SIW structure and another SIW resonant stub loaded at the transmission-line center. To obtain a desired passband, the first center frequency (f_1) can be controlled by tuning the length of the SIW, while the second center frequency (f_2) is adjusted by tuning the length of the loaded SIW stub.

The physical parameters of the initial dual-band filter are given in the *table*. The relative dielectric constant of the PCB substrate material is 2.65 and the thickness of the substrate is 1
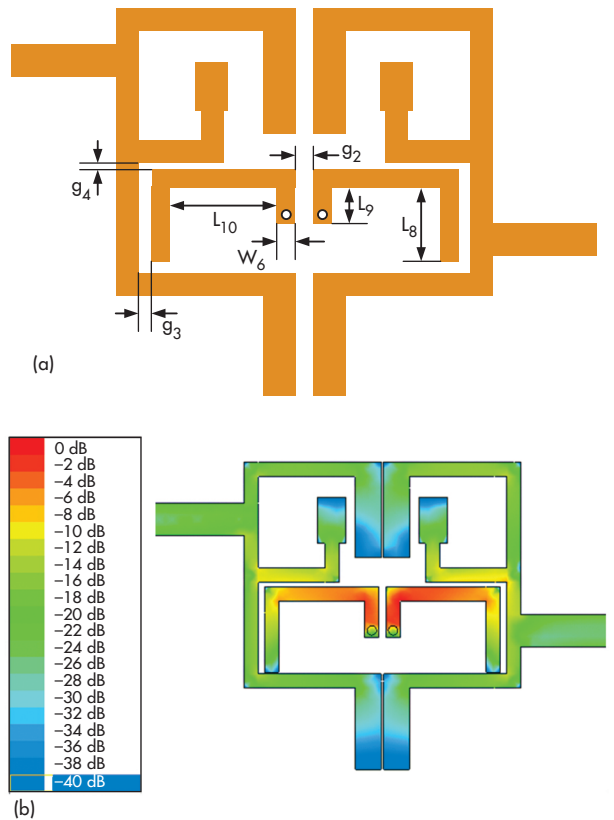
3. The layout (a) of the triband filter is shown next to (b) the current distribution of the filter at the third resonant frequency.

mm. Because the SIW resonant stub is loaded at the SIW center where the voltage is zero at f_1, the first center frequency will not be affected by adding the SIW stub, which can be studied by even-odd-mode analysis,[11] as shown in *Fig. 2(a)*. Overall, the size of the resonator loaded with a SIW stub is smaller than other approaches, with more parameters that can be adjusted to control the frequency response.

> ## The use of dual-band filters rather than multiple separate filters in multiband communication systems can help reduce their volume and mass."

The stub dimensions L and W can be adjusted to control the second filter passband center frequency, f_2, without impacting the first filter passband center frequency, f_1. *Figures 2(a), (b), and (c)* show simulated results for the proposed resonators with different dimensions L and W, while the other dimensions are fixed. As these results indicate, the first passband center frequency (f_1) is unchanged while the second passband center frequency (f_2) can be adjusted by varying the dimensions L and W.

To obtain the third passband center frequency (f_3), a pair of quarter-wavelength resonators are embedded into the dual-band filter *[Fig. 3(a)]*. For the most part, the third passband frequency (f_3) is determined by the length of the quarter-wavelength resonators.

Compared with a conventional triband filter, this novel triband filter can be fabricated in a smaller footprint through its use of SIW technology. It consists of two sets of resonators: the SIW-loaded resonators and the quarter-wavelength resonators that are embedded within the PCB design. To achieve the desired bandwidths for all three passbands, separate tuning of the passbands is required.

For example, the quality factor, Q_e, depends on the position of the filter tap. The coupling coefficients at center frequencies

4. This is the fabricated dual-mode, dual-band filter.

f_1 and f_2 are determined by coupling length L_2 and coupling spacing g_1. The coupling coefficients of the third filter passband are determined by length L_9 and gap g_3 between the quarter-wavelength resonators.

The structure of the proposed triband filter is effective in controlling the coupling of the three filter passbands between the two resonators. *Figure 3* shows the current distribution of the proposed triband filter at the third resonance frequency. The current is mainly distributed at the two quarter-wavelength resonators at the third resonance frequency, in agreement with the computer simulations.

The *table* lists the physical parameters for the triband filter, while the other dimensions are the same as for the dual-band filter shown in *Fig. 1(a)*. The relative dielectric constant and the thickness of the PCB substrate measure 2.65 and 1 mm, respectively.

The full-wave electromagnetic (EM) simulator IE3D from Mentor Graphics Corp. (www.mentor.com) was employed in the computer simulation of the dual-band and triband filter circuits. It was also used to extract the parameters that are listed in the *table*.

To demonstrate this design approach using SIW circuitry and a combination of resonators, a filter was fabricated *(Fig. 4)* and measured with a commercial vector network analyzer (VNA), a model 8719ES from Agilent Technologies (now Keysight Technologies; www.keysight.com). The measured results were compared with simulations of the design *(Fig. 5)* using the IE3D simulation software. According to the simulations, the triband filter produced passbands at 1.69 to 2.02 GHz, 2.52 to 2.65 GHz, and 3.06 to 3.20 GHz.

Simulations showed passband insertion losses of about 0.6 dB at the center of each band. According to the measurements, the triband filter produced passband center frequencies at passbands at 1.85, 2.85, and 3.13 GHz, with measured insertion losses of 0.73, 1.20, and 1.30 dB, respectively, at the center of each passband. The transmission zeros out of the passband greatly improved the frequency selectivity.
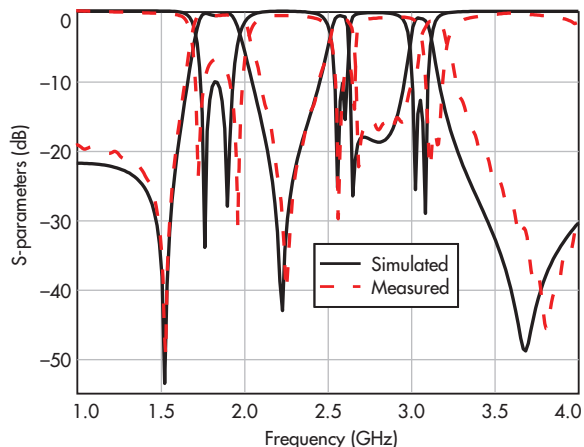
In summary, a compact triband bandpass filter was presented and demonstrated, realized by means of SIW-loaded resonators working with additional quarter-wave resonators to achieve the three separate passbands. The first and second passbands are obtained by the SIW resonator, while the third passband results from the quarter-wave resonant structure.

The design permits control of the center frequencies and bandwidths of the three passbands. A prototype fabricated
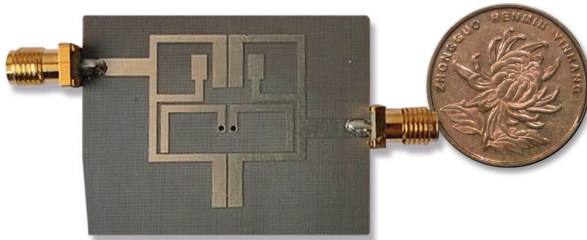
THE PHYSICAL PARAMETERS OF THE DUAL-BAND FILTER (DIMENSIONS IN mm)

L_1	L_2	L_3	L_4	L_5
15.2	6.9	6.9	4.5	3.9
L_6	L_7	W_1	W_2	W_3
12.97	11.7	2.2	2.4	1.2
W_4	W_5	g_1		
1.2	2.73	0.2		

5. These plots compare the simulated and measured frequency responses of the dual-band filter.

according to this design strategy provided measured performance quite close to the simulated values. mw

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