LEI CHEN | Lecturer
School of Electronic and Information Engineering, Xi'an Technological University, Xi'an, People's Republic of China, 710032; e-mail: sumter1108@163.com

FENG WEI | Associate Professor
National Key Laboratory of Antennas and Microwave Technology, Xidian University, Xi'an, People's Republic of China, 710071

SLR Helps Shrink Quad-Band Filter

A novel use of stub-loaded resonators enables the design of this compact bandpass filter with four low-loss passbands and high out-of-band rejection.

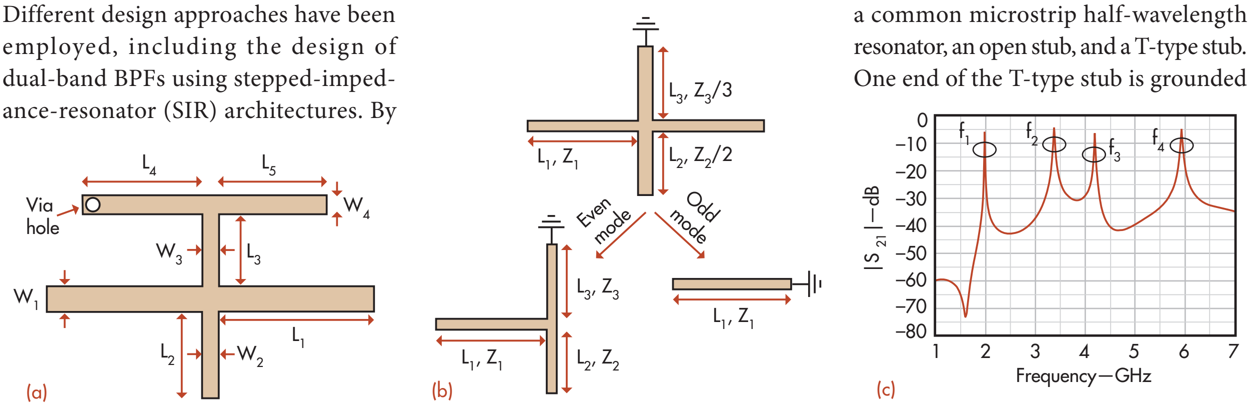
Bandpass filters (BPFs) are widely used in communications systems applications to transfer desired bands of signals, at the same time rejecting unwanted signals. As communications systems add more channels and bands, a growing number of BPFs is needed in these applications, or filters must be designed capable of channeling multiple bands. To demonstrate the feasibility of developing a quad-band BPF, a filter was designed based on stub-loaded resonators (SLRs) and modified from a three-band filter.

Multiband bandpass filters are useful for wireless applications as a way to transfer a number of different channels with a smaller number of filters. Different design approaches have been employed, including the design of dual-band BPFs using stepped-impedance-resonator (SIR) architectures. By adjusting impedance ratio and electrical lengths of SIR, two desired operating frequencies can be obtained.[1]

In refs. 2 and 3, tri-band BPFs were designed based on SLRs. Most previous work on multiband BPF architectures focused on the design of dual-band and tri-band BPFs, with few methods exploring the design of quad-band BPFs.[4-6] In ref. 4, coplanar-waveguide (CPW)-fed, dual-mode double-square-ring resonators were employed to obtain quad-band characteristics. In ref. 5, a quad-band BPF was achieved by combining four basic structures (outer-frame, U-shaped resonator, modified end-coupled microstrip line, and defected ground structures). In ref. 6, a quad-band BPF using a single type of half-wavelength resonator tapped by open-circuited stubs on a single layer was presented. However, the above-mentioned quad-band BPFs require multiple types of resonators or multilayered fabrication technology; these tend to increase filter size, cost, and complexity.

Based on a novel SLR, a compact BPF with quad-band characteristics was investigated. The quad-mode SLR can achieve four passbands simultaneously centered at 1.5, 2.5, 3.5, and 5.2 GHz. To improve the selectivity of the quad-band BPF, a cross-coupling structure between the SLRs and the filter's input/output (I/O) ports is employed. Measurements performed on a fabricated prototype agree closely with simulated results.

Figure 1(a) shows the structure of the novel quad-mode SLR, which consists of a common microstrip half-wavelength resonator, an open stub, and a T-type stub. One end of the T-type stub is grounded



1. The geometry of a quad-mode SLR (a) can be compared to the geometry and equivalent circuit of a conventional tri-mode SLR (b), with the weakly coupling frequency response of the quad-mode SLR also shown (c).

by means of a metallized via hole. The novel SLR is modified from a tri-mode SLR, as shown in *Fig. 1(b)*. Due to its asymmetrical structure, it is difficult to obtain analytical resonant frequencies for the quad-mode SLR. But since the tri-mode SLR is symmetrical, an odd-even-mode method can be implemented, as shown in *Fig. 1(b)*. Under conditions of $Z_1 = Z_2 = Z_3$, the three resonant frequencies of the tri-mode SLR can be expressed thusly:

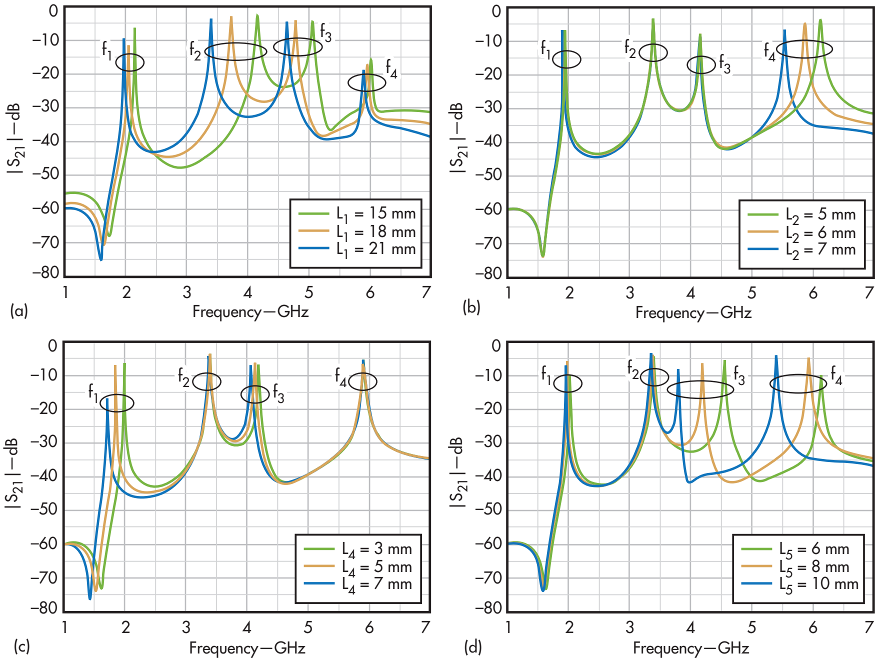
$$f_{e1} = c/4[(L_1 + L_3](\varepsilon_e)^{0.5} \quad (1)$$

$$f_{e2} = c/2[(L_1 + L_2](\varepsilon_e)^{0.5} \quad (2)$$

$$f_{o1} = c/4L_1(\varepsilon_e)^{0.5} \quad (3)$$

where:

c = the speed of light in free space.
ε_e = the effective dielectric constant of the substrate.



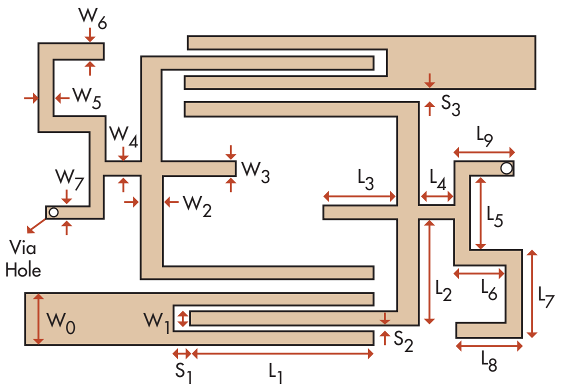
2. These are the simulated S-parameters for the quad-mode SLR for various dimensions: (a) L_1, (b) L_2, (c) L_4, and (d) L_5.

After substituting the shorted stub of tri-mode SLR with the T-type stub, quad-mode performance can be obtained. *Figure 1(c)* shows the simulated frequency responses of the novel quad-mode SLR under weakly capacitive coupling conditions. The quad-mode SLR obtains four resonant poles simultaneously.

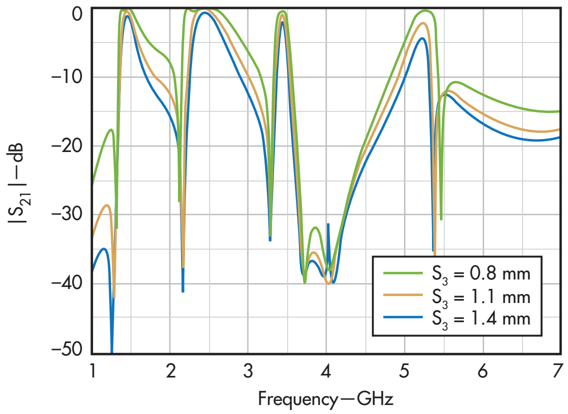
The transfer characteristics of the quad-mode SLR were studied for various dimensions with the help of the High-Frequency Structure Simulator (HFSS 11.0) full-wave electromagnetic (EM) simulation software from ANSYS (www.ansys.com), as shown in *Fig. 2*. It can be seen that the four resonant frequencies increase simultaneously as L_1 decreases. But only one or two resonant frequencies increase as L_2, L_4, and L_5 decrease, respectively. Therefore, by appropriately adjusting the resonator dimensions, four desired resonant frequencies can be achieved.

Figure 3 shows the structure of the novel quad-band BPF. It is composed of two SLRs and an interdigital I/O port. To realize good out-of-band performance, a cross-coupling structure between the SLRs and the I/O port was introduced, which can generate one transmission zero between two resonant frequencies.[2] The filter was fabricated on RT/duroid 5880 circuit substrate material from Rogers Corp. (www.rogerscorp.com) with a thickness of 1.0 mm and a relative dielectric constant (ε_r) of 2.2. The dimensions were selected as follows: W_0 =3.0 mm; $W_1 = W_2 = W_3 = W_4 = W_5 = W_6 = W_7$ = 1.0 mm; L_1 = 12.25 mm; L_2 = 8.5 mm; L_3 = 6.35 mm; L_4= 2.5 mm; L_5 = 5.0 mm; L_6 = 2.5 mm; L_7 = 8.0 mm; L_8 = 2.8 mm; L_9 = 3.0 mm; S_1 = 0.75 mm; S_2 = 0.2 mm; and S_3 = 0.35 mm. The via hole radius is 0.2 mm. As for bandwidth control, the external quality factor (Q_e) and coupling coefficient (k) should be considered. The values of Q_e and k are mainly determined by the gaps S_3, as shown in *Fig. 4*.

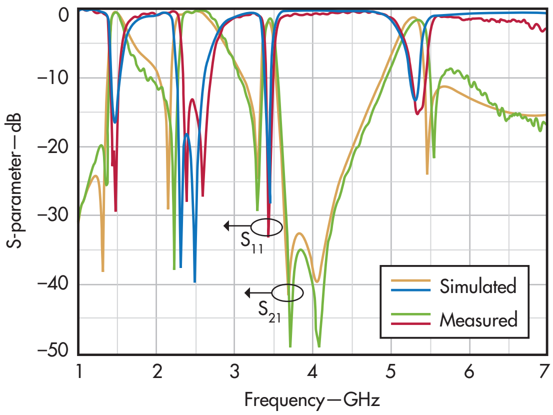
The designed and fabricated quad-band BPF was measured with a model N5230A vector network analyzer (VNA) from Agilent Technologies (www.agilent.com), as shown in *Fig. 5*. The measured center frequencies and 3-dB fractional bandwidths (FBWs) of the quad-band filter are as follows: 1.5 GHz (FBW = 9.5%), 2.5 GHz (FBW = 19.3%), 3.5 GHz (FBW = 3.6%), and 5.2 GHz (FBW = 6.1%), as expected. The measured minimum passband insertion losses are 0.45, 0.22, 1.35, and 1.59 dB, respectively, while the return losses of each passband are better than 15 dB. In addition, the novel quad-band bandpass filter can generate transmission zeros with a better than 20-dB suppression degree on both sides of the passbands. Due to its simple structure, com-



3. This is the circuit configuration for the quad-band bandpass filter.



4. These are simulated bandwidth responses for various dimensions of the quad-band SLR.



5. These are simulated and measured S-parameters for the designed quad-band BPF.

pact size, and good performance, it should be quite suitable for multiband communications systems. mw

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