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Quad-Band Resonator Depends on CRLH/D-CRLH Structures

The design of this novel multi-band resonator allows for multiple passbands while keeping size to a minimum.

This article presents the design and implementation of a compact quad-band bandpass filter based on coupling between via-free dual-composite right-/left-handed (D-CRLH) and composite right-/left-handed (CRLH) microstrip structures. The filter can be used for multiband wireless applications like WiMAX and WLAN, as well as other high-frequency applications. Its topology results in four bands with highly selective, sharp bandpass responses.

A design is introduced to realize a quad-band resonator. Also presented are the equivalent circuit model, an analytical study, and simulation and fabrication measurement results.

Introduction

The electromagnetic (EM) propagation phenomena in one direction through an effectively homogeneous material can essentially be modeled by a one-dimensional transmission-line.[1] However, in practice, such a pure left-handed (PLH) transmission line is impossible to manufacture. A more practical model is the CRLH,[1] or its dual-version counterpart, the D-CRLH.[2]

A CRLH or D-CRLH transmission line may be obtained by chaining several unit cells. These types of artificial lines exhibit dual-band behavior. Consequently, dual-band microwave devices can be created with CRLH and D-CRLH structures.[9-12]

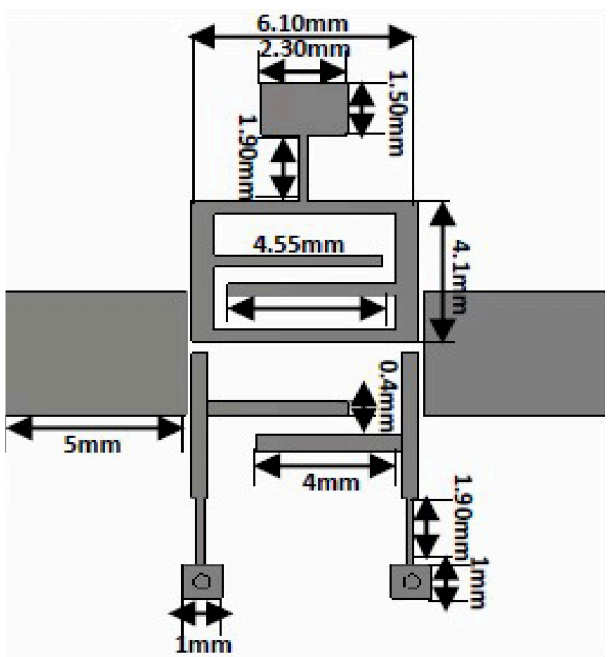
Today, one of the main goals when designing a device is to reduce the dimensions as much as possible. Many compact and multiband filters have been suggested based on metamaterials—metamaterial-based filters are considered novel devices.[3-8] Coupled metamaterial resonator filters are used to create compact bandpass filters.[6-8]

The design of the microwave resonator is significant. Resonators are widely used as elements for high-quality oscillators in satellite military communication systems, as well as multiband antennas for wireless applications.[13]

With the proposed structure, it's possible to have four passbands. The resonator, which measures just 16.5 × 16.5 mm, delivers the performance at multiple frequencies and the compact size required for many modern communication circuit designs.

Theory and Design

The multiple-band resonator is fabricated on standard commercial circuit material *(Fig. 1)*. It consists of a CRLH unit cell coupled with a D-CRLH unit cell. A coupled gap transmission-line resonator is based on coupling between the D-CRLH and CRLH transmission lines. The CRLH transmission line is responsible for low frequencies, while the D-CRLH transmis-



1. This is the configuration for the novel quad-frequency resonator based on metamaterial transmission lines.

sion line is associated with high frequencies. The resonator is designed using a Rogers (www.rogerscorp.com) RO4350B substrate with a dielectric constant of 3.48 and a thickness of 1.524 mm. The total dimensions are 16.5 × 16.5 mm.

Figure 2 shows the equivalent circuit of the proposed quad-band bandpass filter that features coupling between the CRLH and D-CRLH structures. The two lower-frequency bands are produced from the CRLH transmission line, while the two higher-frequency bands come from the D-CRLH transmission line. The CRLH structure has a highpass-filter profile with two possible passbands (left-handed at lower frequencies and right-handed at higher frequencies).

The D-CRLH transmission line has a lowpass-filter profile, which also allows for two possible passbands (right-handed at lower frequencies and left-handed at higher frequencies). However, with the D-CRLH transmission line, nonlinear propagation phase is opposed. The D-CRLH transmission line has gained more interest than the CRLH transmission line because it's simpler to realize thanks to via-free requirements for microstrip configuration.

Inductor and Capacitor Values

The four resonant frequencies are 3.9, 4.6, 6.2, and 7.1 GHz. The relationship between frequencies and the inductors/capacitors are as follows:

$$F_1 = \frac{1}{2\pi\sqrt{C_{L1}L_{R1}}} \quad (1)$$

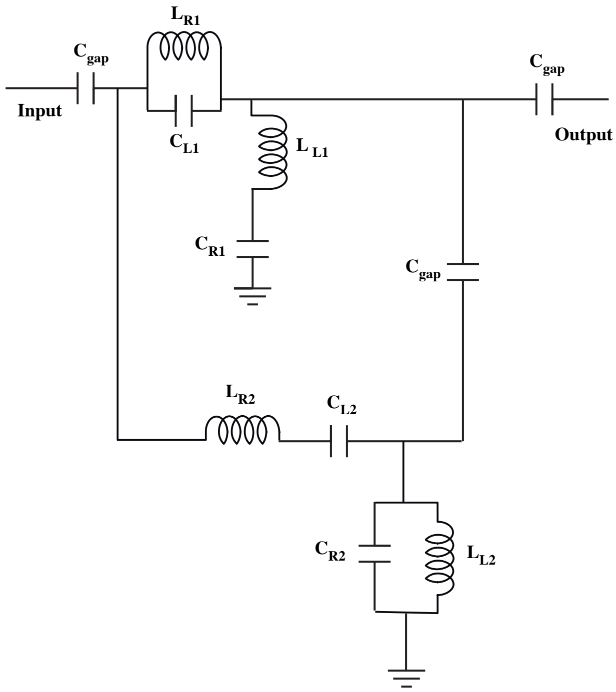
$$F_2 = \frac{1}{2\pi\sqrt{C_{R1}L_{L1}}} \quad (2)$$

$$F_3 = \frac{1}{2\pi\sqrt{C_{L2}L_{R2}}} \quad (3)$$

$$F_4 = \frac{1}{2\pi\sqrt{C_{R2}L_{L2}}} \quad (4)$$

The coupled capacitor is realized using an air gap, C_{gap}, that's equal to 0.014 pF. The remaining values are:

C_{L1} = 1.2 pF
L_{R1} = 1.387 nH
C_{R1} = 0.935 pF
L_{L1} = 1.284 nH
C_{L2} = 0.482 pF
L_{R2} = 1.367 nH
C_{R2} = 0.325 pF
L_{L2} = 1.546 nH



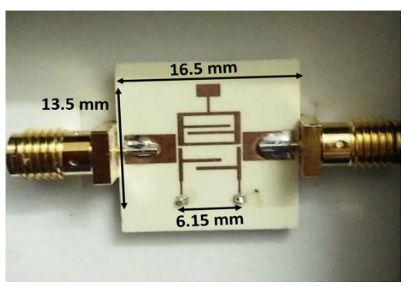
2. Shown is the equivalent circuit of the proposed quad-band bandpass filter that incorporates coupling between CRLH and D-CRLH structures.

Compact Resonator Fabrication

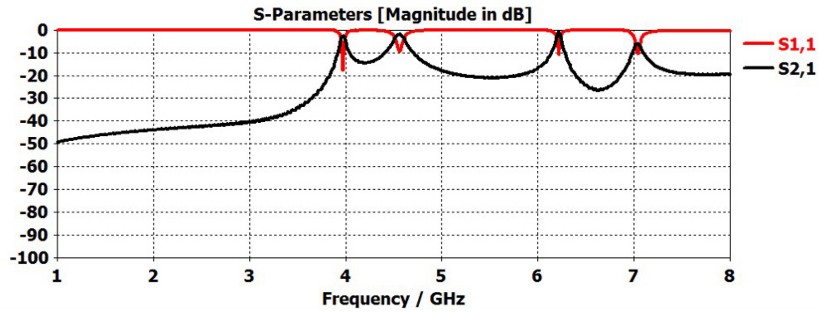
Figure 3 shows the metamaterial-based quad-band resonator constructed with a CRLH cell coupled with a D-CRLH cell. The resonator is fabricated on commercial printed-circuit-board (PCB) material from Rogers with a dielectric constant of 3.48 and a thickness of 1.524 mm. The circuit material is laminated with 0.035-mm-thick copper foils on both sides of the dielectric material. This miniature quad-frequency resonator is representative of how this transmission-line technology can be applied to allow for multiple frequency bands while also miniaturizing the circuit size.

Figure 4 shows the S-parameters of the proposed design, revealing four resonant frequencies: 3.9, 4.6, 6.2, and 7.1 GHz. The return loss at these frequencies is equal to 18, 11, 12, and 11 dB, respectively. The respective insertion loss at the four frequencies is 2, 0.57, 0.32, and 4 dB.

Figure 5 compares the quad-frequency resonator's measured and simulated performance. The 3-dB bandwidth of the first band is 36.5 MHz; the 3-dB bandwidth of the second band is 84.5 MHz. For the third and fourth bands, the 3-dB bandwidths are 250 and 320 MHz, respectively. Hence, the



3. Here's a photo of the fabricated quad-band resonator constructed with a CRLH cell coupled with a D-CRLH cell.



4. The plot reveals S_{21} and S_{11} simulation results of the proposed design.

quality factors (Qs) for the four respective bands are calculated as 106.84, 54.43, 24.8, and 22.187.

Conclusion

In this article, we introduced a new form of compact quad-band bandpass filters based on hybrid techniques. The resonant frequency of this type of filter can be easily tuned. In addition, the Qs are very high with sharp responses. As stated earlier, this miniature quad-frequency resonator represents how this transmission-line technology can be applied to allow for multiple frequency bands while also miniaturizing the circuitry.

The novel D-CRLH/CRLH structure used in the quad-frequency resonator is designed with two cells coupled together. The CRLH cell is responsible for generating the two lower-frequency bands, i.e., the first and second bands. Meanwhile, the D-CRLH cell generates higher-frequency resonance, which corresponds to the third and fourth bands. This work is significant in terms of research for multi-frequency bandpass filters.

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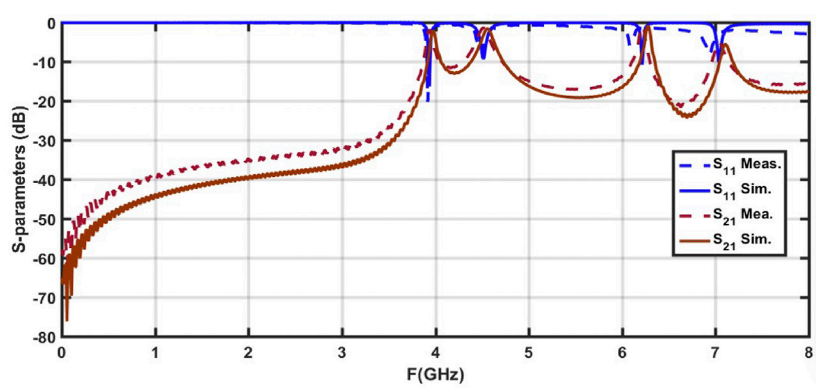

5. The simulation results are in close agreement with the S_{21} and S_{11} measurements of the quad-frequency resonator.