L-section matching with notches and its application for composite lowpass filter with spurious signal suppression

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L-section matching circuits are used for various applications. Such circuits can be advanced to provide notch responses to suppress undesired spurious signals. The design guide that allows integration of notch responses in the L-section matching circuits is presented. With given impedance at the targeted matching frequency and notch frequencies, a matching circuit with the spurious signal suppressing notches can be simply designed based on the closed-form equations provided. A composite lowpass filter (LPF) based on the image parameter method is composed of two matching sections and two filter sections. Replacing conventional matching sections with the proposed L-section matching circuits, an LPF with spurious signal notches can be realised. The proposed matching circuit and filter with spurious suppression notches will bring an added dimension of design freedom for modern communication systems that demand stringent out-of-band requirements.

Introduction: Modern communication devices demand compact size and multi-functionalities. Therefore, communication chips and other high-frequency components are crammed into a small space with short distances. Such compact layout requirement leads to electromagnetic interferences due to spurious leakages that degrade the overall performance of the multi-band operating devices. For example, current mobile phones are designed to operate at multiple frequency bands including long-term evolution (LTE) bands and global positioning system (GPS) band. The transmission (TX) frequency band of LTE B13 is from 777 to 787 MHz and its second harmonic frequency band is from 1.554 to 1.574 GHz. If a power amplifier module used in the mobile phone does not sufficiently suppress the second harmonic of the B13 signal, this spurious signal could affect the GPS communication chip operating at 1.575 GHz. In addition, there are also undesired coupling between the LTE communication chips. The LTE communication chip handling B12 signal should suppress its third harmonic of the TX band (2.097–2.148 GHz) because the third harmonic band overlaps with B4 receive (RX) band (1.95–2.399 GHz).

In this Letter, the L-section matching circuit that integrates spurious signal suppressing notches is proposed and the design process based on closed-form equations is provided. With the proposed notches equipped L-section matching circuit, harmonic signals from devices such as amplifiers can be reduced. Moreover, to demonstrate the practical benefits, the authors present a novel composite lowpass filter (LPF) with spurious signal suppressing notches at 1.6 and 2.1 GHz based on the proposed L-section matching circuit.

L-section matching with notches: The L-section matching circuits are well analysed and the closed-form design equations are available that can be simply used to design them. Therefore, the L-section matching circuits are popular in broad applications [1]. There are two configurations for the L-section matching circuits. One is composed of a series inductor and shunt capacitor. The other one consists of a series capacitor and shunt inductor. If a series arm of an L-section matching forms parallel resonator and a shunt arm has a series resonator, the matching circuit can be designed to provide two TX zeros (or two stop-band notches) at two desired frequencies.

Fig. 1 shows the circuit diagram of the proposed L-section matching circuit. The circuit has matching functionality as well as spurious signal suppression capability at two targeted frequencies. The closed-form equations for the proposed L-section matching with two arbitrarily spaced notch responses are provided in the following equations:

$$A = 1/Z_0 \quad (1)$$

$$B = \frac{1}{1-(\omega_0-\omega_2)^2} \quad (2)$$

$$C = \frac{1}{1-(\omega_0-\omega_1)^2} \quad (3)$$

$$C_2 = \sqrt{\frac{A-A^2R}{\omega_0^2B^2R}} \quad (4)$$

$$L_1 = \frac{X}{\omega_0 C} + \frac{BC_2}{C\left(A^2+\omega_0^2B^2C_2^2\right)} \quad (5)$$

$$C_1 = \frac{1}{\omega_1^2 L_1} \quad (6)$$

$$L_2 = \frac{1}{\omega_2^2 C_2} \quad (7)$$

where Z_0 is the system impedance prior to the transformation. R and X are the real and imaginary impedances transformed by the proposed L-section matching circuit, respectively. ω_1 and ω_2 are the angular harmonic suppression notch frequencies from the series arm and shunt arm of the matching circuit, respectively. ω_0 is the target frequency of matching.

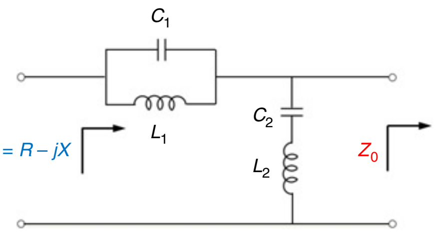

Fig. 1 *Circuit diagram of the L-section matching with spurious signal suppression notches*

The closed-form equations, (4)–(7), are calculated by simultaneously solving four equations for four unknowns (L_1, L_2, C_1, and C_2). Equations (6) and (7) are from two angular harmonic notch frequencies, ω_1 and ω_2. The remaining (4) and (5) are from known targeted real and imaginary impedances, R and X. Based on these equations, circuit parameters of the L-section matching with notches are calculated. If there is no harmonic suppression notch on the shunt arm of the L-section matching, B is 1. On the contrary, C is 1 when there is no notch on the series arm of the L-section matching. Fig. 2 shows the comparison between the conventional L-section matching (matching condition: $Z_0 = 31\ \Omega$ at $\omega_0 = 800$ MHz) and the proposed L-section matching with notches (matching condition: $Z_0 = 31\ \Omega$ at $\omega_0 = 800$ MHz, $\omega_2 = 1.6$ GHz and $\omega_1 = 2.1$ GHz notches).

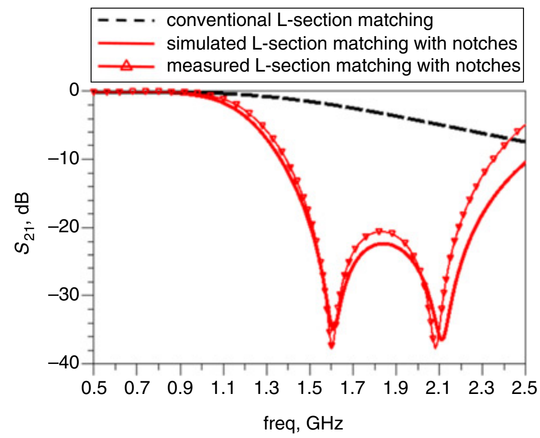

Fig. 2 *Comparison between the conventional L-section matching and the proposed L-section matching with notches*

Harmonic suppressing LPF: Fig. 3*a* shows the circuit diagram of the conventional composite LPF based on the image parameter method [1–3]. The cutoff frequency is 1 GHz. It is cascaded with two *m*-derived matching sections, constant-k section, and m-derived sharp cutoff section. Replacing the matching section with the proposed L-section matching, a novel composite LPF with spurious signal suppression notches is realised. Fig. 3*b* shows the circuit diagram of the proposed composite LPF with two notch responses. In this design, notch frequencies are set to 1.6 and 2.1 GHz to suppress the interference with GPS and LTE B4.

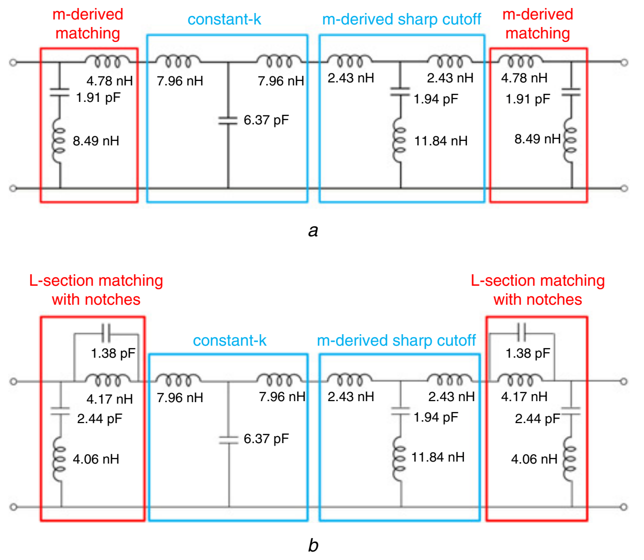

Fig. 3 *Circuit diagrams of composite LPF with 1 GH cutoff frequency*

a Conventional design
b Proposed design with spurious signal suppression notches at 1.6 and 2.1 GHz

The design process of the proposed composite LPF with notches is as follows:

(i) Design constant-k section and m-derived sharp cutoff section [1].
(ii) Plot an image impedance of filter sections from step i.
(iii) With given notch frequency locations (1.6 and 2.1 GHz in the proposed filter) and the image impedance from step ii, calculate circuit parameters of the proposed L-section matching from (1) to (7).
(iv) Add the designed L-section matching with harmonic suppression notches to each end of the filter as shown in Fig. 3*b*.

Fig. 4 shows the implemented composite LPF with spurious signal suppression notches and its dimensions. The proposed L-section matching section is realised with surface mounting (SMT) components. The lumped components in constant-k section and m-derived sharp cutoff section are converted to microstrip lines using TX line's even/odd mode analysis and slope parameter theory [3, 4].

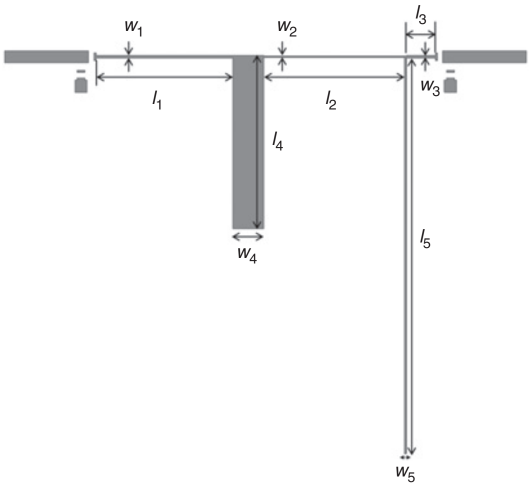

Fig. 4 *Top view of the proposed composite LPF with spurious signal suppression notches and its dimension (parameters: $l_1 = 17.95$ mm, $l_2 = 18.48$ mm, $l_3 = 3.78$ mm, $l_4 = 22.78$ mm, $l_5 = 52.11$ mm, $w_1 = 0.33$ mm, $w_2 = 0.22$ mm, $w_3 = 0.31$ mm, $w_4 = 4.1$ mm, and $w_5 = 0.27$ mm)*

The fabricated composite LPF with notches is shown in Fig. 5. The LPF is fabricated on RT/duroid 5880 laminate ($\varepsilon_r = 2.2$, $h = 20$ mil) and Murata 0402 size inductors and capacitors are used for realisation of the L-section matching with spurious signal suppression notches. Fig. 6 shows the simulated and measured *S*-parameters results of the proposed LPF. Overall, the measured *S*-parameters show good agreement with the simulated results. The slight discrepancies between notch frequencies and depth are due to the use of discrete SMT components and fabrication errors.

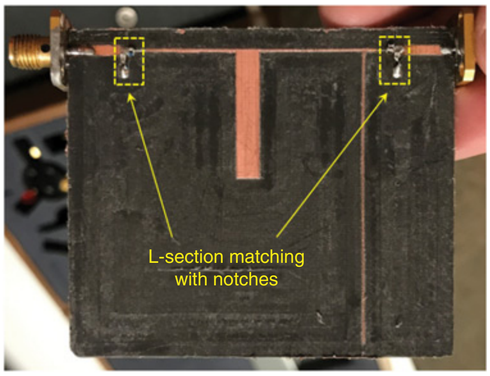

Fig. 5 *Photograph of the proposed composite LPF with spurious signal suppression notches*

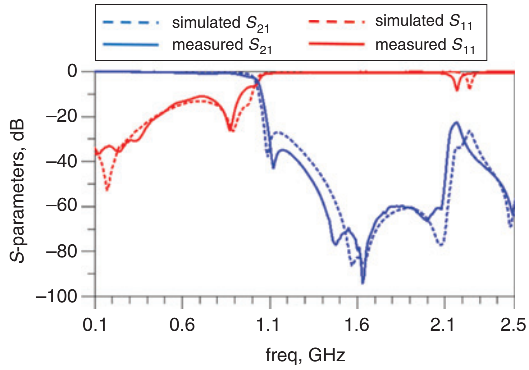

Fig. 6 *Simulated and measured S-parameter of the proposed composite LPF with spurious signal suppression notches*

Conclusion: An analytical method for designing an L-section matching circuits with two arbitrarily spaced spurious signal suppressing notches is presented in this Letter. To verify its versatility, the proposed L-section matching is applied in realising a composite LPF design. The proposed matching circuits may be beneficial for compact high-frequency devices that demand high isolation between multiple operating bands.

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One or more of the Figures in this Letter are available in colour online.

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