Design of Dual-band Impedance Matching Circuit Using T-shape Shunt Stub

Hadi Andalib Ali-Abadi [1], Fatemeh Geran Gharakhili [1*]

[1] The Faculty of Electrical Engineering, Shahid Rajaee Teacher Training University.

Abstract

In this paper, a new dual-band impedance matching circuit is presented by using a two-section microstrip transmission line and an open-circuit T-shape shunt stub. The governing analytical relations of the structure is first obtained based on transmission lines theory. Then, by applying the matching conditions on the obtained relations, i.e. matching an arbitrary load impedance with source impedance of 50Ω at desired frequencies, nonlinear equations are generated, and solved simultaneously, meeting the electrical and physical specifications of all parts of the scheme. In order to evaluate the performance of the proposed circuit, the scheme is depicted and simulated using HFSS software. Simulation results show that the relative bandwidth of the first and the second band are 76% and 11.8%, respectively. In comparison to the previously- schemes in literature, our proposed circuit yields to a wider bandwidth and less occupied area.

1. INTRODUCTION

Matching networks or impedance transformers play an important role in RF circuits maximizing power transmit or receive in a wireless transceiver. In fact, a good matching network can maintain the signal-to-noise ratio at an optimal level by reducing the return coefficient of delivered power between the two connected circuits [1]. Today, mobile phones support multi-standards such as GSM, UMTS, DCS, GPS, Bluetooth, WLAN, simultaneously. The international standard organization has dedicated discrete frequency bands for each of these standards. Therefore, the need for designing matching networks with the ability to support multiple radio frequency bands with proper bandwidth is clear. Remarks that must be considered in the

*Corresponding Author's Email:
f.geran@sru.ac.ir

design of matching networks are: insertion and return losses, physical size, and bandwidth.

Researchers have so far presented several schemes to achieve multi-band matching circuits in literature. In [1], a dual-band impedance matching network has been designed by using a two-section transmission line and a two-section open-circuit shunt stub where bands and the load impedance have been considered arbitrary and complex. in [2], a two-section transformer of one-third wavelength is implemented to match impedances in fundamental frequency and the second harmonic. An impedance matching circuit was introduced in [3] by using a two-section transmission line at two desired frequencies, assuming purely real load impedance. The structure of [3] was improved in [4] by considering the complex load impedance. Analysis and design of the impedance matching circuit were achieved in [5] by a three-section transmission line where a purely real load was matched at three desired frequencies. The design of N-bands impedance matching circuit with the N-section transmission line was discussed in [6], and the proposed circuit was optimized by the PSO algorithm. In [7], a dual-band matching circuit with a three-section transmission line was proposed for a pure imaginary frequency-dependent load impedance. A quad-band impedance transformer was introduced in [8]. The proposed transformer matches a very high real load to the impedance of 50 Ω at four different frequencies. A tunable impedance matching network with wide impedance coverage was presented in [9].

In this paper, the idea presented in [1] is adopted to design a new dual-band matching network but we use the open-circuit T-shape shunt stub instead of the open-circuit two-section shunt stub. The open-circuit T-shape shunt stub has been introduced in [10] in order to design diplexer with operating frequencies close to each other. The performance of the proposed scheme in this paper is evaluated using HFSS software. The simulation results show that our proposed scheme outperforms the circuit presented in [1] by reducing the size and increasing the bandwidth in every bands.

The remainder of this paper is organized as follows. Section 2 introduces the dual-band impedance matching circuit configuration and its relations. Simulation and measurement results are presented in section 3. Finally, Section 4 concludes the paper.

2. CONFIGURATION OF THE PROPOSED MATCHING NETWORK

As shown in Fig. 1, The suggested matching circuit consists of two parts; a two-section transmission line, and the open-circuit T-shape shunt stub as the first and the second parts of the circuit. Since the seen admittance in the second part is purely imaginary, it can be said that the first part of the proposed scheme transforms the load admittance to the value $1/Z_0$, and the second part is used to naturalize the imaginary part of the first part admittance.

To clarify the scheme operation, it is assumed that termination loads are Z_{L1} and Z_{L2} at frequencies f_1 and f_2, respectively.
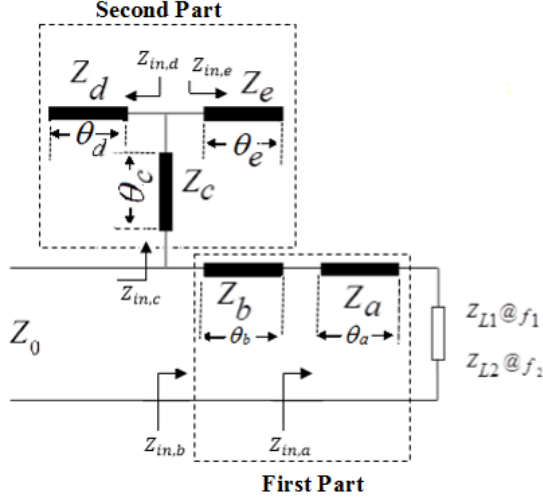
Fig. 1. The proposed matching circuit.

$$Z_{L1} = R_{L1} + jX_{L1}$$
$$Z_{L2} = R_{L2} + jX_{L2} \tag{1}$$

To reduce the number of unknown variables and simplify the relations, all of the characteristic impedances are considered to be known. The seen input impedances from part "a" and "b" at frequencies f_1 and f_2 are:

$$Z_{in,a\_f_1} = Z_a \frac{Z_{L1} + jZ_a \tan(\theta_a)}{Z_a + jZ_{L1} \tan(\theta_a)}$$

$$Z_{in,a\_f_2} = Z_a \frac{Z_{L2} + jZ_a \tan(k\theta_a)}{Z_a + jZ_{L2} \tan(k\theta_a)}$$

$$Z_{in,b\_f_1} = Z_b \frac{Z_{in,a\_f_1} + jZ_b \tan(\theta_b)}{Z_b + jZ_{in,a\_f_1} \tan(\theta_b)}$$

$$Z_{in,b\_f_2} = Z_b \frac{Z_{in,a\_f_2} + jZ_b \tan(k\theta_b)}{Z_b + jZ_{in,a\_f_2} \tan(k\theta_b)}$$

$$k = \frac{f_2}{f_1} \tag{2}$$

where θ_a and θ_b are the electrical length of transmission lines of the part "a" and "b" at frequency f_1, and the coefficient k is the ratio of the second to fundamental operating frequency.

Now, unknowns θ_a and θ_b are determined in a way that the real part of the seen impedance at the beginning of the first part is converted to Z_0 in both frequencies. Again, assuming the characteristic impedances, i.e. Z_c, Z_d, and Z_e, are given. The seen impedance at the beginning of T-shape branch are as follows:

$$Z_{in,c\_f_1} = Z_c \frac{Z_{in,de\_f_1} + jZ_c \tan(\theta_c)}{Z_c + jZ_{in,de\_f_1} \tan(\theta_c)}$$

$$Z_{in,c\_f_2} = Z_c \frac{Z_{in,de\_f_2} + jZ_c \tan(k\theta_c)}{Z_c + jZ_{in,de\_f_2} \tan(k\theta_c)} \tag{3}$$

where θ_c is the unknown electrical length of transmission line "c" at frequency f_1. Moreover, Z_{in,de,f_1} and Z_{in,de,f_2} are respectively equal to:

$$\frac{1}{Z_{inde,f_i}} = Y_{in,d\_f_i} + Y_{in,e\_f_i} \quad i = 1,2 \tag{4}$$

where:

$$Y_{in,h\_f_1} = j\frac{1}{Z_h} \tan(\theta_h)$$

$$Y_{in,h\_f_2} = j\frac{1}{Z_h} \tan(k\theta_h), \quad h = d,e \tag{5}$$

θ_d and θ_e are the unknown electrical length of transmission lines "d" and "e" at frequency f_1. The seen admittance in the end of transmission line Z_0 is,

$$Y_{in,Z_0\_f_i} = \frac{1}{Z_{in,b\_f_i}} + \frac{1}{Z_{in,c\_f_i}}, \quad i = 1,2 \tag{6}$$

Table. 1. *Electrical characteristics of proposed matching circuit at 0.9 GHz.*

Electrical Characteristics	$Z_a(\Omega)$	$\theta_a(°)$	$Z_b(\Omega)$	$\theta_b(°)$	$Z_c(\Omega)$	$\theta_c(°)$	$Z_d(\Omega)$	$\theta_d(°)$	$Z_e(\Omega)$	$\theta_e(°)$
Initial value	60	35	40	15.8	70	73.26	70	20.38	70	50.62
Final value	60	41.5	40	15.8	70	73.26	70	15.6	70	46.8

The impedance matching is completed if the following conditions are satisfied:

$$Real(Y_{in,Z_0-f_i}) - \frac{1}{50} = 0$$
$$Im(Y_{in,Z_0-f_i}) = 0, \quad i = 1,2 \tag{7}$$

Now, the obtained nonlinear equations are solved using Matlab commercial software in order to calculate all unknown satisfying conditions of Eq. 7 (electrical lengths of transmission lines).

3. SIMULATION RESULTS AND MEASUREMENT

As mentioned, the aim of this paper is designing the matching circuit for mobile phones in the GSM, GPS and Bluetooth bands. The circuit is realized using microstrip structure that has been inserted on FR4 substrate with a relative permittivity $\varepsilon_r = 4.6$ and thickness $1.6\,mm$. For the design simplicity, all characteristics impedance of whole transmission lines are selected between 40 to 110 Ω. Characteristics impedance values of different parts are reported in the second row of Table 1.

To compare this work with [1], the load impedance has been considered as combination of series resistor 100 ohm and

capacitor 5 pF similar to [1]. Assuming $f_1 = 0.9\,GHz$ and $f_2 = 2.4\,GHz$, nonlinear Eqs. (7) are solved in Matlab to convert the electrical lengths to the physical characteristics of the transmission lines. The resultant structure is plotted in HFSS software as shown in Fig. 2. The structure size is $0.3\lambda_g \times 0.2\lambda_g$, while the approximated area of the given structure in [1] is $0.5\lambda_g \times 0.18\lambda_g$; where, λ_g is the guided wavelength at 0.9 GHz. Simulation results is depicted in Fig. 3. As is evident from Fig. 3, the reflection coefficient has little deviation at the desired frequencies. The reflection coefficient at desired frequencies can be optimized. Optimized values of the scheme are given in the third row of Table 1 and its the reflection coefficient is plotted in Fig. 3. As is clear from Fig. 3, thanks to wider bandwidth of the first band, this band supports GPS and DCS1800 standards.

For investigating the effect of various parameters in the proposed scheme on the reflection coefficient, a parametric study on the matching circuit dimensions has been performed.

As shown in Fig. 4, parameter studies of the proposed structure indicate the results
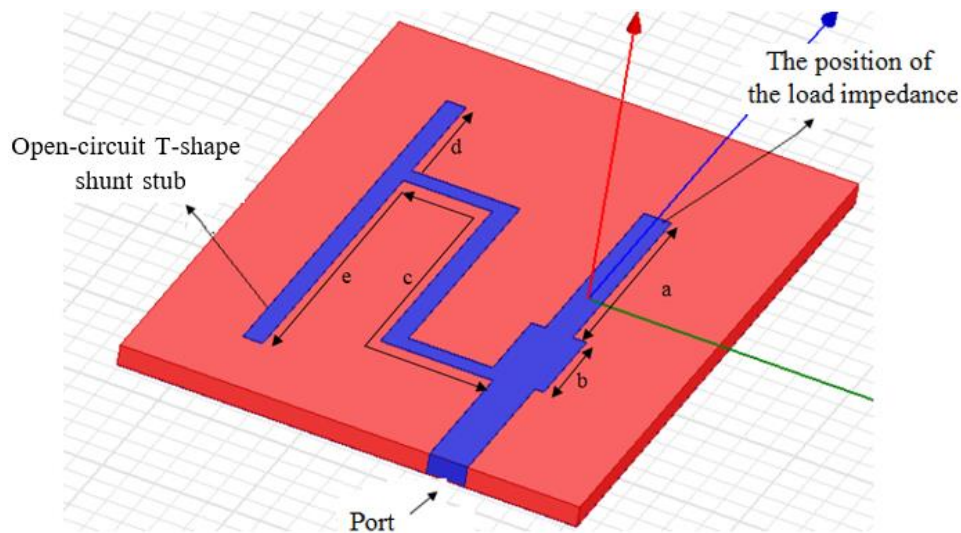
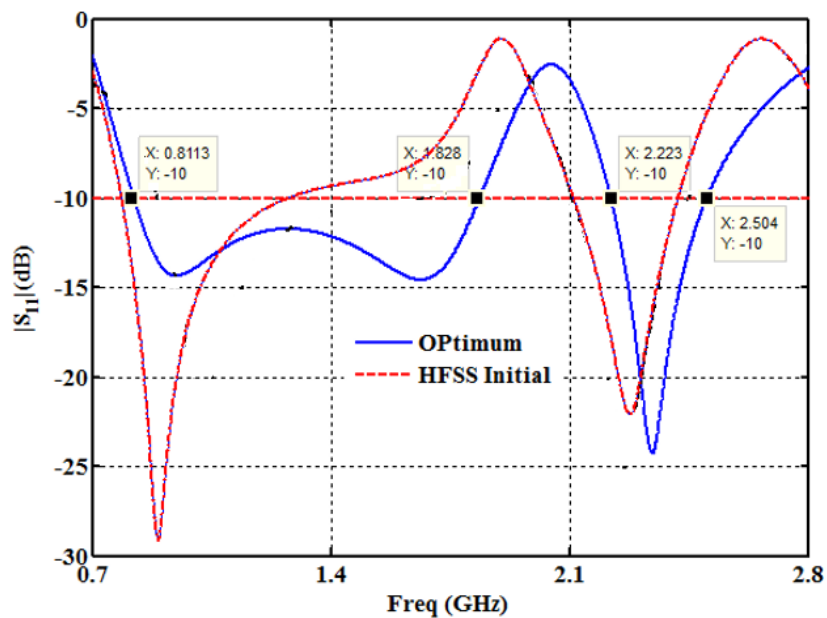***Fig. 2. The Proposed scheme in HFSS software.***

Fig. 3. The return reflection coefficient of the scheme with the load impedance as combination of series resistor of 100 ohm and capacitor of 5 pF (before and after optimization).
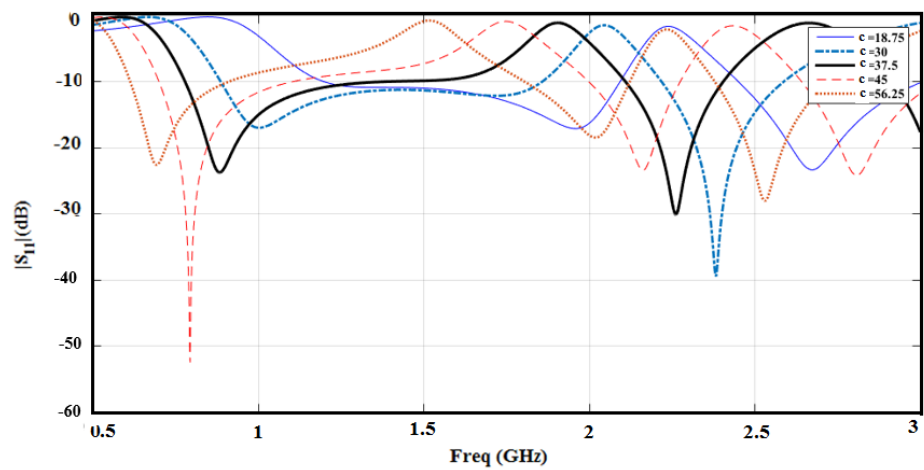
that are listed in following:

- Decrease the length of section "a" of matching network leads to decrease the bandwidth of first band.

- Decrease the length of section "b" of matching network leads to increase the bandwidth of first band.

- Variation the length of section "c" causes changes in the bandwidth and
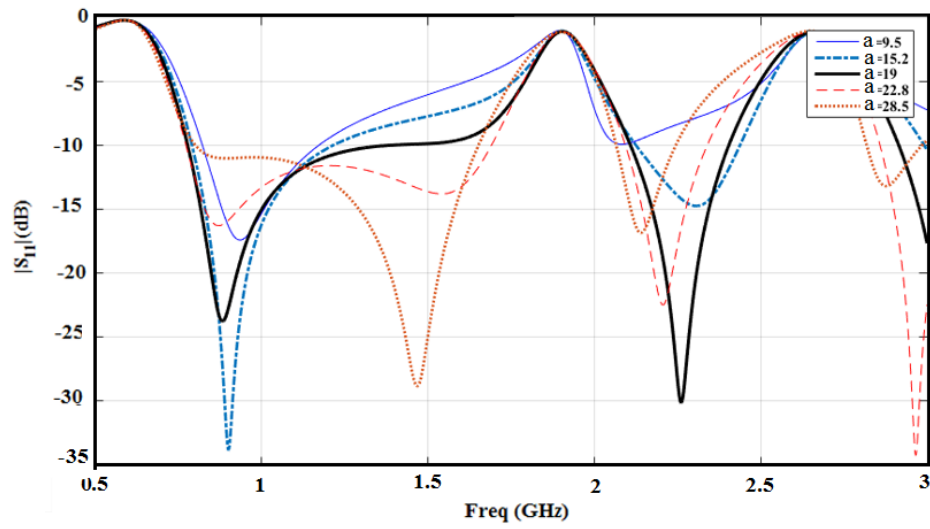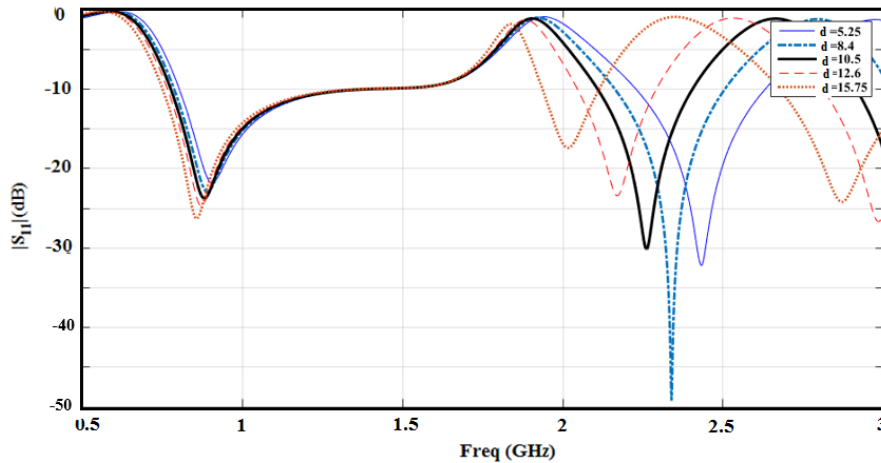
(a)
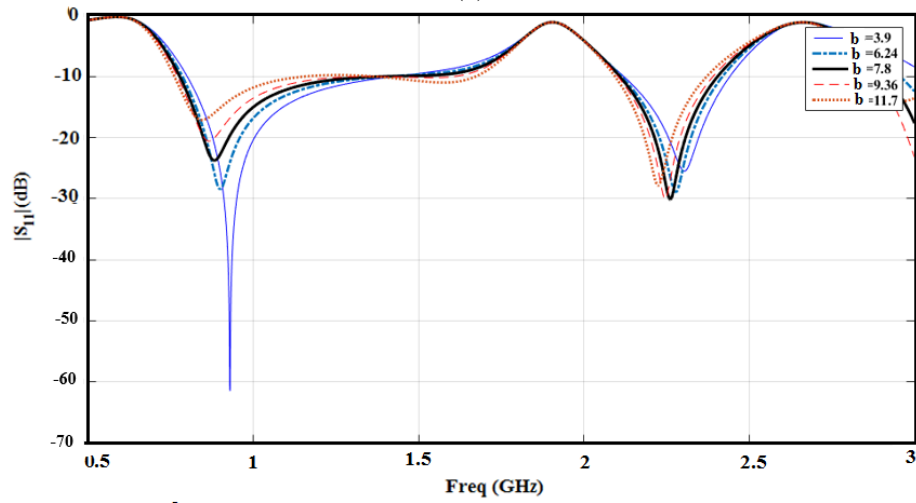
(b)

(c)

Continued

(d)

Fig. 4. Parameter studies of the proposed structure. (a) effect of length of "a" section on reflection coefficient, (b) effect of length of "b" section on reflection coefficient, (c) effect of length of "c" section on the reflection coefficient and (d) effect of length of "d" section on the reflection coefficient.

- Resonance frequencies of the first and second bands.
- Variation the length of section "d" moves the resonance frequency of the second band only having no impact on the first band.

Figure 5 shows the fabrication of the proposed matching network for two different complex loads. Loads have been considered to be $R = 100\Omega$, $C = 5\,pF$. Electrical characteristics of fabricated network is given in the second row of Table 1. Reflection coefficients of fabricated structures measured by an Agilent 8722-ES network analyzer. The simulation results and the measurement results for both loads are compared in Fig. 6. Showing a good agreement between the simulation results and the measurement results.

4. CONCLUSION

In this paper, a new dual-band impedance matching circuit has been designed, simulated and fabricated using an open-circuit T-shape shunt stub. First, unknown electrical lengths of transmission lines are calculated by solving the obtained nonlinear equation of the scheme satisfying the matching condition at desired frequencies. Then, by converting electrical characteristics to physical characteristics, the proposed scheme is simulated by HFSS software. Simulation results show that the relative bandwidth of the first and the second band of matching circuit are 76% and 8.11%, respectively. The prototype of the proposed matching circuit is fabricated. Observing a good agreement between the simulation and measurement results is our main outcome in this paper.

REFERENCES

[1] M.-L. Chuang, "Dual-band impedance transformer using two-section shunt stubs," *IEEE Transactions on Microwave Theory and Techniques,* vol. 58, pp. 1257-1263, 2010.

[2] Y. Chow and K. Wan, "A transformer of one-third wavelength in two sections-for a frequency and its first harmonic," *IEEE Microwave and Wireless Components Letters ,* vol. 12, pp. 22-23, 2002.

[3] C. Monzon, "A small dual-frequency transformer in two sections," *IEEE Transactions on Microwave Theory and Techniques,* vol. 51, pp. 1157-1161, 2003.

[4] Y. Wu, Y. Liu, and S. Li, "A dual-frequency transformer for complex impedances with two unequal sections," *IEEE Microwave and Wireless Components Letters,* vol. 19, pp. 77-79, 2009.

[5] M. Chongcheawchamnan, S. Patisang, S. Srisathit, R. Phromloungsri, and S. Bunnjaweht, "Analysis and design of a three-section transmission-line transformer," *IEEE Transactions on Microwave Theory and Techniques,* vol. 53, pp. 2458-2462, 2005.

[6] M. Khodier and N. Dib, "Design of multi-band transmission line transformer using particle swarm optimization," in *Antennas and Propagation Society International Symposium 2006, IEEE*, 2006, pp. 3305-3308.

[7] X. Liu, Y. a. Liu, S. Li, F. Wu, and Y. Wu, "A three-section dual-band transformer for frequency-dependent complex load impedance," *Microwave and Wireless Components Letters, IEEE,* vol. 19, pp. 611-613, 2009.

[8] R. Kumar Barik, S.S. Karthikeyan, " A novel quad-band impedance transformer with ultra-high transforming ratio", *AEU-International Journal of Electronics and Communications*, vol. 78, pp. 157-161, 2017.

[9] Y. C. Wong, R. S. Singh, S. B. A. Radzi, N. B. A. Hamid, "Tunable impedance matching network with wide impedance coverage for multi frequency standards RF front-end," *AEU- International Journal of Electronics and Communications*, vol. 82, pp. 74-82, 2017.

[10] M.-L. Chuang and M.-T. Wu, "Microstrip diplexer design using common T-shaped resonator," *IEEE Microwave and Wireless Components Letters,* vol. 21, pp. 583-585, 2011.