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Freuency Selective Coupled Lines Impedance Transformer

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Abstract

This paper presents the design of a frequency selective impedance transformer with wide out-of-band suppression characteristics using two coupled lines. Two transmission poles in the passband generated by a shunt coupled line provide a sharp frequency selectivity. For experimental validation, a 50-to-10 Ω impedance transformer has been implemented at a center frequency (*f_0*) of 2.6 GHz. The measured results are in good agreement with the simulations, showing a return loss higher than 20 dB and insertion loss less than 0.4 dB over a passband bandwidth of 0.26 GHz (2.4-2.66 GHz). The out-of-band suppression obtained higher than 13 dB from DC to 2.08 GHz and from 3.04 GHz to 7.2 GHz.

Keywords-Coupled line, impedance transformer, high selectivity, wide out-of-band.

I. Introduction

The impedance transformer (IT) is a building block of microrwave RF systems and widely used in impedance matching circuits, power dividers/combiners [1], antenna [2], and baluns. The out-of-band suppression characteristic of the IT will be benefit if such circuits are used in the design of high power, high efficiency, and highly linear power amplifiers [3]. Most of the conventional IT consider only a passband matching [4]-[5] and ignore the out-of-band signal suppression characteristic.

In this paper, a design method and implementation of frequency selective IT with the wide out-of-band suppression characteristics are presented based on a series and shunt parallel coupled lines. To verify the proposed network, a 50-to-10 Ω IT was designed, simulated, and fabricated at a center frequency (f_0) of 2.6 GHz.

II. Circuit Design

Fig. 1 shows the proposed structure of IT. It consists of a series parallel coupled line with odd- and even-mode impedances (Z_{0o} and Z_{0e}) and a shunt parallel coupled line with odd- and even-mode impedances (Z_{0os} and Z_{0es}) connected at coupling port 2 of series coupled line. The electrical lengths of both coupled lines are quarter-wavelengths (λ/4) at f_0. Moreover, a shunt coupled line is used to create transmission poles in the passband and provide high frequency selectivity near the passband. At f_0, the reflection coefficient only depend on Z_{0e} and Z_{0o} of the series coupled line and not Z_{0es} and Z_{0os} of the shunt parallel coupled line as shown in (1).

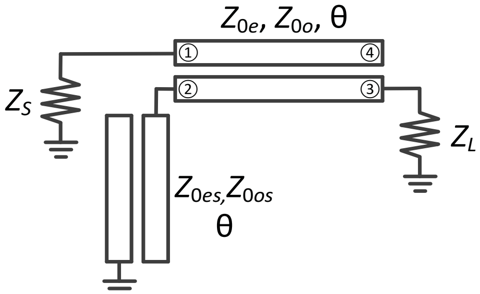


Fig. 1. Block diagram of proposed impedance transformer.

$$S_{11} = \frac{\left(Z_{0e} - Z_{0o}\right)^2 - 4rZ_S^2}{\left(Z_{0e} - Z_{0o}\right)^2 + 4rZ_S^2} \tag{1}$$

where r is an impedance transformation ratio (= Z_L/Z_S). The Z_{0e} with specified values of S_{11}, Z_S, and r at f_0 are obtained differently. For the under-matched condition (Z_{0e} - Z_{0o} < 2 Z_S $r^{1/2}$), the value of Z_{0e} is found in (2).

$$Z_{0e} = 2Z_S\sqrt{\frac{r\left(1 - S_{11}\big|_{f=f_0}\right)}{1 + S_{11}\big|_{f=f_0}}} + Z_{0o} \tag{2}$$

Similarly, Z_{0e} can be found in (3) for the over-matched condition (Z_{0e} - Z_{0o} > 2 Z_S $r^{1/2}$).

$$Z_{0e} = 2Z_S\sqrt{\frac{r\left(1 + S_{11}\big|_{f=f_0}\right)}{1 - S_{11}\big|_{f=f_0}}} + Z_{0o} \tag{3}$$

For perfectly matched condition (Z_{0e} - Z_{0o} = 2 Z_S $r^{1/2}$), S_{11} becomes zero so that value of Z_{0e} is found as (4).

$$Z_{0e} = 2Z_S\sqrt{r} + Z_{0o} \tag{4}$$

Fig. 2(a) shows the S_{11} and S_{21} characteristics in perfectly-, under-, and over-matched conditions with the specific S_{11} = -20 dB at f_0. This simulation is performed by fixing shunt coupled line as Z_{0es} = 112 Ω, Z_{0os} = Z_{0o} = 40 Ω, and varying Z_{0e} of 80.45 Ω, 89.44 Ω, and 84.72 Ω according to matching conditions (2) to (8), respectively. Morevoer, r is chosen as 5. As seem from this figure, the over-matched condition porvides the widest return loss bandwidth due to two transmission poles in the passband. Therefore, the over-matched condition is preferable

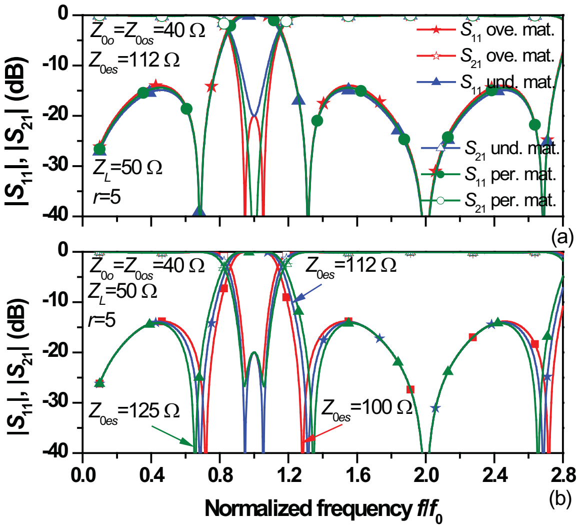


Fig. 2. Simulation S_{11} and S_{21} characteristic (a) under-, perfect, and over-matched condition and (b) over-matched with variation of Z_{0es}.

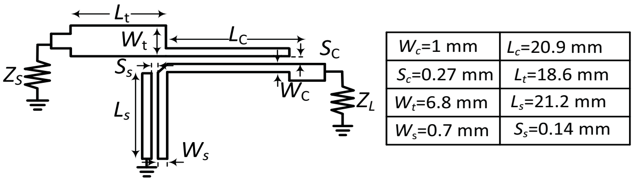
for designing of the proposed IT. Fig. 2(b) shows the S-parameter characteristics according to different Z_{0es} for the over-matched condition by assuming S_{11} = -20 dB at f_0. As Z_{0es} decrease, transmission zeros are moved toward the passband, but return loss passband bandwidth becomes slightly narrower.

III. Simulation and Measurement

To experimentally validate the proposed network, a 50-to-10 Ω IT with r = 5 and S_{11} = -20 dB at f_0 = 2.6 GHz was designed, simulated, and measured. As shown simulation performances in Fig. 2, the over-matched condition is chosen. Using (3), Z_{0e} is calculated as 89.44 Ω by selecting Z_{0o} = 40 Ω. The odd- and even-mode impedances of the shunt coupled line are chosen as Z_{0es} = 112 Ω and Z_{0os}=40 Ω. The circuit was fabricated on an RT/Duroid 5880 substrate (Rogers Inc.) with a dielectric constant (ε_r) of 2.2 and a thickness (h) of 31 mils. The electromagnetic (EM) simulation was performed using HFSS v15 from Ansoft.

Fig. 3 shows the EM simulation layout of the designed proposed IT network with its physical dimensions. A $\lambda/4$ IT at the source port is used for the measurements with a 50 Ω termination network analyzer. The circuit size of the proposed IT network is 22.5 × 13.4 mm^2 (ignoring the $\lambda/4$ IT for the measurement).

Fig. 4 shows the EM simulation and measurement results in addition of a photograph of the fabricated circuit. The measured results are agreed well the simulations. From the measured results, the return loss is determined as 22 dB at f_0 = 2.6 GHz. Similarly, the 20 dB return loss bandwidth is 0.26 GHz (2.4 - 2.66 GHz). The instertion loss in the passband (2.4 - 2.66 GHz) is smaller than 0.4 dB, including the loss of the $\lambda/4$ IT. The transmission zeros near the passband are obtained, providing a sharp out-of-band suppression characteristics. The shunt coupled line generates transmission zeros at 1.88 GHz, 3.36 GHz, and 7.1 GHz, respectively. Moreover, the series quarter- wavelength coupled line generates a transmission zero at 5.6 GHz. The out-of-band signal suppression characteristics are more than 13 dB from DC to 2.08 GHz at the lower side of passband, and from 3.04 GHz to 7.2 GHz at the upper side of passband. Therefore, the proposed IT provides the sharp frequency-selective matching characteristics as well as the wide out-of-band suppression characteristics.



W_c=1 mm	L_c=20.9 mm
S_c=0.27 mm	L_t=18.6 mm
W_t=6.8 mm	L_s=21.2 mm
W_s=0.7 mm	S_s=0.14 mm

(a) (b)

Fig. 3. (a) EM simulation layout and (b) physical dimensions of the proposed impedance transformer.

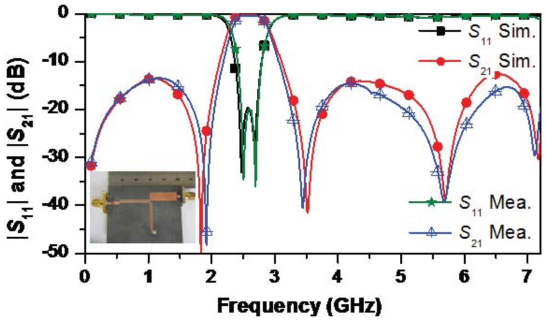


Fig. 4. EM simulation and measurement results.

IV. Conclusion

This paper presents the design of frequency selective impedance transformer with wide out-of-band suppression characteristic by controlling the characteristic impedances of series and shunt coupled lines. The proposed network can provide a relatively high impedance transforming ratio and is simple to design, fabricate, and also expected to be applicable in various RF circuits and systems that require frequency selective performance. In microwave active circuits design, a $\lambda/4$ parallel coupled line is generally used instead of a DC-blocking capacitor. Because the proposed frequency selective impedance transformer can be used as DC-block as well as matching network, the proposed frequency selective impedance transformer can be applicable in the microwave circuits design.

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