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14:45 - 17:50, October 20, 2017. Location: CPA Training Room, No1 Teaching Building, STDU. Session Chairs:

Prof. Jongsik Lim (Soonchunhyang University, Korea)

Dr. Guohui Zeng (Shanghai University of Engineering Science, China)

ID.16. Wide viewing angle negative dispersion retarder by stacking layers with opposite birefringence
*Hee Jung Ryu, Yongchae Jeong, Ji-Hoon Lee**
Chonbuk National University, Jeonbuk, Korea

ID.20. A Design of Impedance Transformer with Wide Stopband and $3f_0$ Harmonic Suppression
Changyu Park, Phirun Kim, Yongchae Jeong, Hyongsuk Kim, and Dongsun Park, Jongsik Lim,
[1]*Chonbuk National University Jeonju-si, Republic of Korea*
[2]*Soonchunhyang University Asan-si, Republic of Korea*

ID.21. A Design of Tunable Phase Shifter Using Capacitive Termination
Boram An, Junhyung Jeong, Girdhari Chaudhary, Seok-Hawn Park, Ji-Hoon Lee and Yongchae Jeong
Chonbuk National University

ID.45. Bidirectional Three-Level DC-DC Converter with Capacitor Voltage Balance Control
Myung-Chul Lee, Min-Kwon Yang, Jun Heo and Woo-Young Choi
Chonbuk National University, Jeonju, South Korea

ID.46. High-Efficiency Transformerless DVR with Bidirectional DC-DC Converter
Myung-Chul Lee, Min-Kwon Yang, Jun Heo and Woo-Young Choi
Chonbuk National University, Jeonju, South Korea

ID.77. Design and Implementation of Enterprise Credit Topic Crawler
*Zhang Cuixiao1,Li Xuan[1], *Shao Yunxia[2], Wang Yunli[2], Gao Jing[1], Zhao Guangzhen[1]*
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ID.94. Intelligent management system for small gardens Based on Multi-sensor fusion
Xiao-hui ZENG[1,2], Jing-xiang LV[1,2], Wen-lang LUO[1,2]**
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A Design of Impedance Transformer with Wide Stopband and $3f_0$ Harmonic Suppression

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***Abstract*—This paper presents an impedance transformer with out-of-band suppression characteristics. Five transmissions zeros are obtained in the wide stopband. Two transmission poles are appeared in the passband and provide good selectivity characteristics. For an experimental validation, the proposed impedance transformer was designed at the center frequency (f_0) of 2.6 GHz with impedance ratio of 3.33. The measured input and output return losses are 23.3 dB and 22.7 dB at the f_0, respectively. The 20 dB return loss bandwidth is obtained from 2.44 - 2.84 GHz. The insertion loss at f_0 is 0.29 dB and better than 0.32 dB within frequency range of 2.44 - 2.84 GHz. The transmission zeros are located at 1.38 GHz, 3.9 GHz, 5.66 GHz, 7.02 GHz, and 7.86 GHz, which provide high selectivity.**

Keywords—coupled line, impedance transformer, out-of-band suppression.

I. INTRODUCTION

The impedance transformer (IT) is one of the fundamental components employed in RF circuit design, and is widely used in impedance matching circuits, power dividers [1], combiners, and baluns [2]. The conventional quarter-wavelength IT is widely used due to its convenience of implementation. However, when this IT network is used, only passband matching is usually considered, and the out-of-band characteristic is ignored. In [3], open-circuited coupled line IT was presented with an optimization process. It can provide a wideband characteristic with impedance ratio of 1.5. Similarly, a wideband IT composed of a coupled three-line structure was proposed in [4]. However, this work focused on the passband matching characteristics and did not consider the out-of-band suppression characteristics. The out-of-band suppression characteristic is an important design issue when the IT is applied to frequency selective RF circuits such as high power, high efficiency, and highly linear power amplifiers [5], [6]. In [7], the two-section open-ended coupled lines IT was presented with a good out-of-band suppression. However, $3f_0$ frequency was still occurred.

In this paper, the IT with the bandpass filtering characteristic and $3f_0$ suppression is analyzed and designed. The proposed IT provides two transmission poles in the passband and wide out-of-band suppression characteristic with five transmission zeros including $3f_0$.

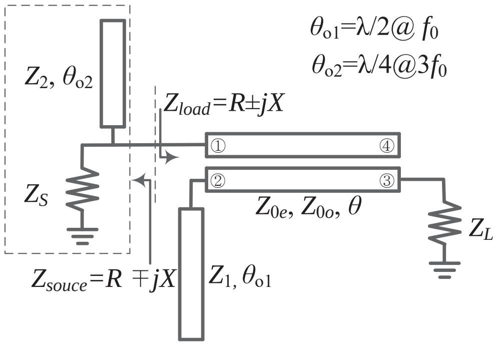


Fig. 1. Proposed structure of impedance transformer with $3f_0$ suppression.

II. DESIGN EQUATIONS

Fig. 1 shows the proposed structures of the IT. The proposed structure consists of a series parallel-coupled line with odd- and even-mode impedances (Z_{0o} and Z_{0e}) and shunt open transmission line (TL) stub. A shunt open stub TL with characteristic impedance of Z_1 was used to enhance the bandwidth and provide two transmission zeros at the lower and upper sides of the operating frequency band. Moreover, a shunt open stub TL with characteristic impedance of Z_2 was used to produce transmission zero at $3f_0$. From Fig. 1, the input impedance of Z_{source} and Z_{load} at f_0 can be found as (1).

$$Z_{source}\Big|_{@f_0} = \frac{3Z_S Z_2^2 - jZ_S{}^2 Z_2\sqrt{3}}{Z_S{}^2 + 3Z_2^2} \tag{1a}$$

$$Z_{load} = \frac{Z_L B^2 \csc^2\theta}{Z_L^2 + A^2\cot^2\theta} + j\left(\frac{B^2\csc^2\theta A\cot\theta}{Z_L^2 + A^2\cot^2\theta} - A\cot\theta\right), \tag{1b}$$

where

$$A = \frac{Z_{0e} + Z_{0o}}{2}, \tag{2a}$$

$$B = \frac{Z_{0e} - Z_{0o}}{2}, \tag{2b}$$

and θ is an electrical length of coupled line. For the impedance matching condition at f_0, Z_{source} and Z_{load} must have conjugate impedances. When the Z_2, Z_{0o}, and return loss (S_{11}) are selected by designer, then Z_{0e} and Z_1 can be calculated as follows.

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

$$Z_1 = \frac{Z_{0e}+Z_{0o}}{r-1} \tag{3b}$$

$$r = \frac{Z_L}{\mathrm{Re}(Z_{source})}\ , \tag{3c}$$

where r and S_{11} are the impedance transforming ratio between Z_L and $\mathrm{Re}(Z_{source})$, and predefined return loss at f_0, respectively. Since the Z_{source} is a complex impedance, then the θ should be varied to compensate the complex impedance. Therefore, θ of coupled line can be obtained as (4).

$$\cot^3\theta + a\cot^2\theta + b\cot\theta + c = 0\ , \tag{4}$$

where

$$a = -\frac{AX'}{\left(A^2-B^2\right)} \tag{5a}$$

$$b = \frac{\left(Z_L^2-B^2\right)}{\left(A^2-B^2\right)} \tag{5b}$$

$$c = -\frac{X'Z_L^2}{A\left(A^2-B^2\right)} \tag{5c}$$

$$X' = \frac{\sqrt{3}Z_S{}^2Z_2}{Z_S{}^2+3Z_2^2}\ . \tag{5d}$$

Fig. 2 shows the variations of characteristic impedances (Z_1, Z_{0e}) and electrical length (θ) according to Z_{0o}, Z_2, Z_S, respectively. As seem in Fig. 2(a), Z_1 and Z_{0e} are increased from 25.8 Ω to 60.43 Ω and 74.5 Ω to 144.52 Ω with Z_{0o} varied from 30 Ω to 100 Ω, respectively. However, the θ is decreased from 91.3° to 90.56° with the same variation of Z_{0o}. The simulation was done by fixing Z_L = 50 Ω, Z_2 = 60 Ω, and Z_S = 10 Ω. Similarly, Z_1 and Z_{0e} are increased from 32.37 Ω to 36.11 Ω and 92.97 Ω to 94.69 Ω with Z_2 varied from 20 Ω to 160 Ω, respectively, as seem in Fig. 2(b). Meanwhile, the θ is decreased from 92.62° to 90.36°. Thus, the θ of coupled line is decreased as Z_{0o} and Z_2 increase. From Fig. 2(c), the Z_{0e} is increased from 72.11 Ω to 137.66 Ω as Z_S increases from 2 Ω to 35 Ω. However, Z_1 and θ are increased from 5.1 Ω to 317.73 Ω and 90.03° to 107.03° with the same variation of Z_S, respectively. Therefore, there is a limitation of the fabrication of Z_1 for very low and very high Z_S.

To validate the analysis, the IT with Z_L = 50 Ω, Z_2 = 60 Ω, S_{11} = -20 dB, and r = 3.33 was designed. Fig. 3 shows the

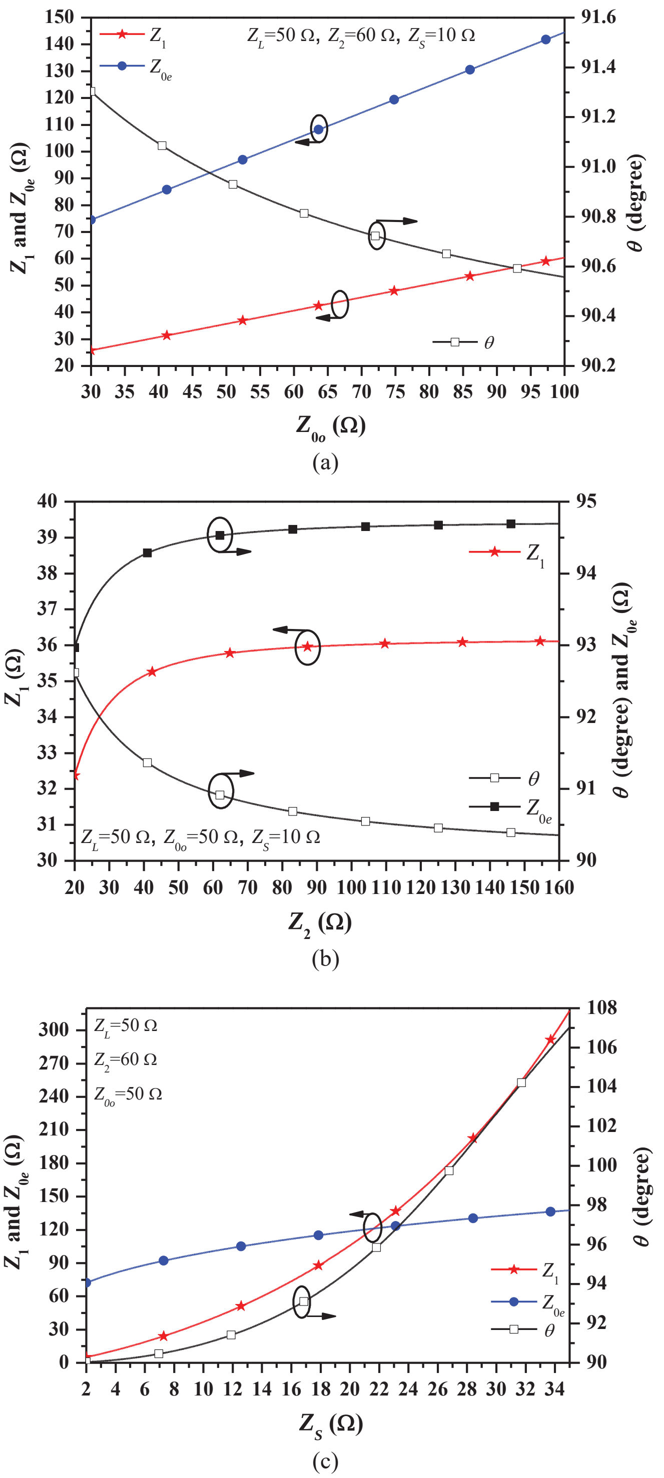


Fig. 2. Variations of Z_1, Z_{0e}, and electrical length according to (a) Z_{0o}, (b) Z_2, and (c) Z_S.

simulated S-parameters characteristic of the proposed IT with the normalized frequency. The -20 dB return loss was obtained at the center frequency with two poles in the passband. Moreover, several transmission zeros are obtained in the stopband including $3f_0$ and provides a wide stopband characteristic. Two transmission zeros near to passband

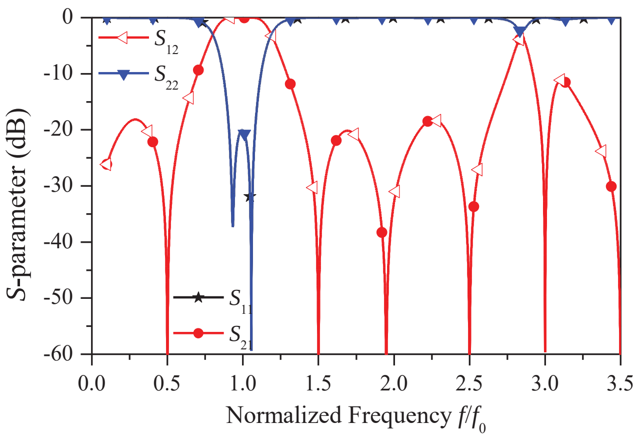


Fig. 3. *S*-parameter characteristics of proposed impedance transformer with $r = 3.33$, $Z_L = 50\ \Omega$, $S_{11} = -20$ dB, and $Z_2 = 60\ \Omega$.

($0.5f_0$ and $1.5f_0$) and at $2.5f_0$ are obtained with the open TL stub. Meanwhile, the transmission zero near to $2f_0$ is obtained from the coupled TL. The calculated elements values are shown in Table I.

TABLE I

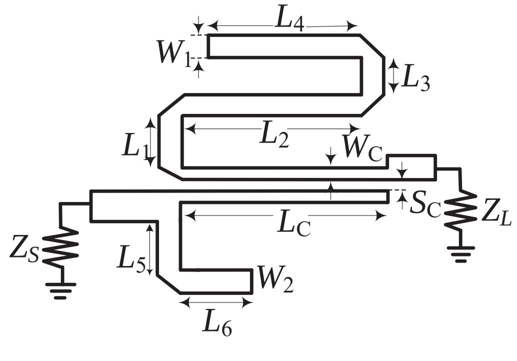
CALCULATED PARAMETERS OF PROPOSED IMPEDANCE TRANSFORMER

$Z_L = 50\ \Omega$, $Z_S = 15\ \Omega$, $Z_2 = 60\ \Omega$, $Z_{0o} = 50\ \Omega$, and $S_{11} = -20$ dB at f_0		
Z_{0e}	Z_1	θ
109.93	66.56	92.366

III. SIMULATION AND MEASUREMENT

To validate the proposed impedance transformer, $r = 3.33$ (15-to-50 Ω), $Z_2 = 60\ \Omega$ and $S_{11} = -20$ dB at $f_0 = 2.6$ GHz was designed, simulated, and measured. The calculated values are shown in Table I. The fabricable odd-mode impedance (Z_{0o}) of coupled line was chosen by designer. The circuit was fabricated on substrate with $\varepsilon_r = 2.2$ and $h = 31$ mils.

Fig. 4 shows the layout and photograph of the fabricated IT. The physical dimension of the designed IT is shown in Table II. The overall size of proposed circuit is 22 mm × 16 mm. The simulated and measured characteristics of the IT are shown in Fig. 5. The input and output return losses are given as S_{11} = 23.3 dB and S_{22} =22.7 dB at the f_0, respectively. The 20 dB return loss is obtained within the operating band of 2.44 - 2.84 GHz. The insertion loss at the f_0 is 0.29 dB, showing a good agreement with the simulation result. Within the frequency range of 2.44 - 2.84 GHz, the measured insertion loss is better than 0.32 dB. The transmission zeros are located at 1.38 GHz, 3.9 GHz, 5.66 GHz, 7.02 GHz, and 7.86 GHz which provide high selectivity and wide out-of-band suppression characteristics. The out-of-band suppression characteristics at lower side of operating band is more than 20 dB from DC to 1.64 GHz. Similarly, the out-of-band suppression at upper passband is better than 11 dB from 3.46 GHz to 8.12 GHz.



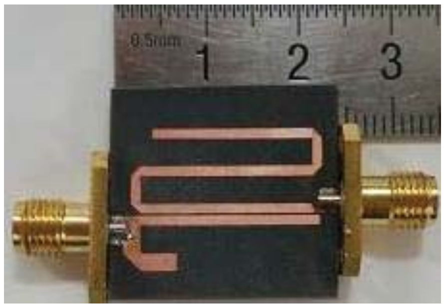


Fig. 4. Fabricated impedance transformer: (a) layout and (b) photograph.

TABLE II

PHYSICAL DIMENSION OF THE PROPOSED IMPEDANCE TRANSFORMER

$W_c = 0.98$	$W_1 = 1$	$L_4 = 17$	$L_6 = 3.82$
$S_c = 0.26$	$L_1 = L_3 = 3$	$W_2 = 1.8$	
$L_c = 19$	$L_2 = 18.3$	$L_5 = 1$	

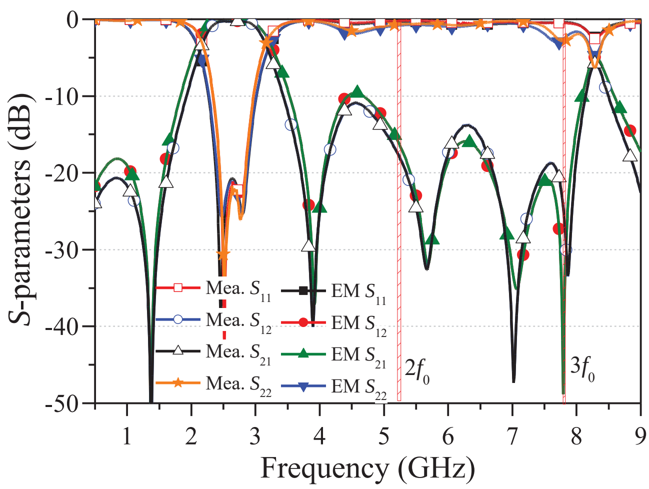


Fig. 5. Electromagnetic simulation and measured *S*-parameter results.

IV. CONCLUSION

In this paper, a design of impedance transformer with out-of-band suppression characteristics including $3f_0$ is presented. The $3f_0$ harmonic was completely suppressed by a shunt open transmission line stub. Both the simulation and measurement results are provided to validate the proposed analysis. The proposed circuit is simple to design and fabricate and also expected to be applicable in various RF circuits and systems that require frequency selective performances.

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