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Compact Branch-line Power Divider Using Connected Coupled-line Structure

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Abstract

In order to improve performance for the size of the BLPD, the CCL is used for the realization as the delay line. As realizing lower coupling coefficient and lower characteristic impedance, the CCL has good performance of the phase delay. The CCL is applied as the compact BLPD with optimized coupling factor and matched impedance because the lower coupling coefficient and lower characteristic impedance are increased the size and the loss, respectively. Designed BLPD using the CCL has the size of $0.13\lambda_g \times 0.13\lambda_g$ *and the size-reduction ratio of fabricated BLPD using the CCL has 58.5%* ($21.08 \times 21.40\ mm^2$)*. Also, fabricated BLPD is measured the insertion loss of 3.16dB at the center frequency of 1.78GHz and the 20dB bandwidth is 9.58%. Differenced magnitude and phase between threw port and coupled port are measured 0.1dB and 89.9°, respectively. These performances are almost same compared with the conventional BLPD. Suggested application of the CCL can be used various devices and circuits for the size-reduction.*

Key words: *connected coupled-line (CCL), coupler, branch-line power divider (BLPD), phase*

1. Introduction

The coupled-line has been used in various application such as the coupler, filter, mixer, and balanced amplifier. From the research of Jones [1-4], the coupled-line is divided 10 types as the connected method. Among these, the open-ended coupled line and shorted coupled-line have been used as the coupler and filter, however the connected coupled-line (CCL), like as Fig. 1. is very low applied because the CCL has the characteristic of all pass. However, the CCL can be used as the delay line when the impedances are matched. In this paper, the characteristic of the phase-delay of the CCL is analyzed as the coupling factor for the size-reduction of the RF devices. Also, analyzed and optimized CCL is applied the compact branch-line power divider (BLPD).

The BLPD is useful device for the division of the RF signal power because it can be easily designed and fabricated on uniplanar substrate without via-hole and soldering. However, the BLPD has the disadvantage of the narrow band and large size because of the limitation of a quarter wavelength per line. Therefore, the BLPD has been researched with the target of broad-band, harmonic-suppression, and small-size [5-6].

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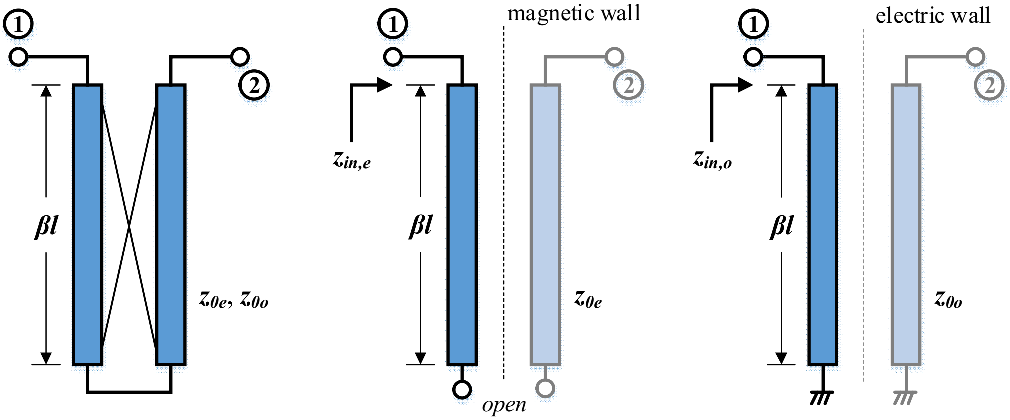
Especially, in order to realize the small-size of the BLPD, various methods have been researched such as the pi- or T-equivalent circuit, the stepped impedance line, and the CRLH line [7-9]. In this paper, the characteristic of the phase delay of the CCL is researched and its application is suggested by the BLPD.



(a) CCL structure (b) Even-mode (a) Odd-mode

Figure 1. Even and odd-mode configuration of the CCL

2. Analysis of the connected coupled-line structure

For the analysis of the CCL, the method of the even and odd-mode analysis can be used. Fig. 1 shows each mode configuration with the electric and magnetic wall.

From the research of Jones [1], the terminal voltage can be driven as:

$$\begin{aligned} V_1 &= -\frac{j}{2}\cdot(I_1+I_2)\cdot z_{0e}\cot\beta l+\frac{j}{2}\cdot(I_1-I_2)\cdot z_{0o}\tan\beta l \\ &= -\frac{j}{2}\cdot(z_{0e}\cot\beta l-z_{0o}\tan\beta l)I_1-\frac{j}{2}\cdot(z_{0e}\cot\beta l+z_{0o}\tan\beta l)I_2 \end{aligned} \tag{1}$$

From Eq. (1), the impedance parameters can be defined by the input impedance of even and odd-mode.

$$\begin{aligned} Z_{11} &= -\frac{j}{2}\cdot(z_{0e}\cot\beta l-z_{0o}\tan\beta l)=\frac{z_{in,e}+z_{in,o}}{2}, \\ Z_{12} &= -\frac{j}{2}\cdot(z_{0e}\cot\beta l+z_{0o}\tan\beta l)=\frac{z_{in,e}-z_{in,o}}{2} \end{aligned} \tag{2}$$

In Eq. (2), $z_{in,e}$ and $z_{in,o}$ are the input impedance of even-mode and odd-mode, respectively. Now, the magnitude and phase of the transfer function are

$$|S_{21}|^2=\frac{(z_{0e}\cot\beta l+z_{0o}\tan\beta l)^2}{(1+z_{0e}z_{0o})^2+(z_{0e}\cot\beta l-z_{0o}\tan\beta l)^2}, \tag{3}$$

$$phase(S_{21}) = \tan^{-1}\left(\frac{1 + z_{0e} z_{0o}}{z_{0e}\cot\beta l - z_{0o}\tan\beta l}\right). \tag{4}$$

From the Eq. (3), the insertion loss of the CCL is ideally zero with any coupling efficient, *C* in case of the impedance of the CCL is matched. These results shows Fig. 2.

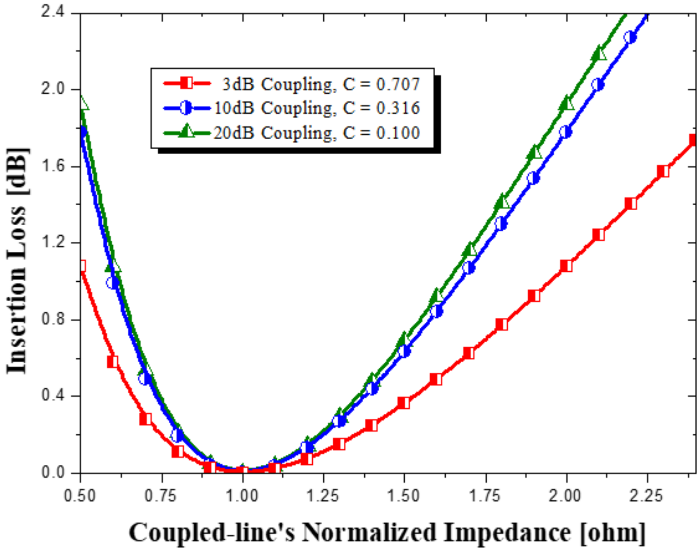


Figure 2. Characteristics of loss of the CCL as the coupling coefficient and impedance

From the Fig. 2, the transmission loss is increasing as the impedance mismatching. However, although low coupling coefficient, lossless transmission line using the CCL can be realized. Other hands the phase of the CCL is decreasing as increased coupling coefficient, *C* as shown in Fig. 3.

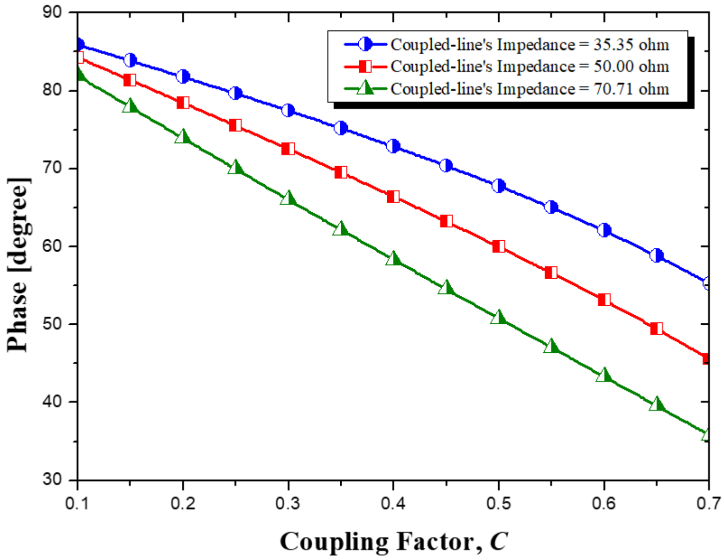


Figure 3. Characteristics of phase of the CCL as the coupling coefficient and impedance

Fig. 3 shows the phase of the CCL as the coupling coefficient when the length of the CCL is $\lambda_g/8$. The CCL with the characteristic impedance and 3-dB coupling (C = 0.707) has no loss and the same phase delay with the ideal transmission line from the Eq. (3) and (4). From the Fig. 3, the lower coupling coefficient and the lower impedance can be realized large phase delay and smaller devices.

3. Branch-line divider using the connected coupled-line structure

In this paper, the compact BLPD is suggested using by the CCL. The line of BLPD is realized with the electrical length of 46.8° and the CCL. The CCL is designed with the coupling coefficient and electrical length of 0.1 and 23.4°, respectively.

The BLPD with the CCL is designed the center frequency of 1.8GHz on the tefron substrate with the dielectric constant and height of 2.55 and 0.76mm, respectively. The size of fabricated the BLPD is 21.08 × 21.40 mm^2 ($0.13\lambda_g \times 0.13\lambda_g$) as shown in Fig. 4 and the size-reduction ratio is 58.5%. Fig. 4 is the photograph of the fabricated the BLPD using the CCL.

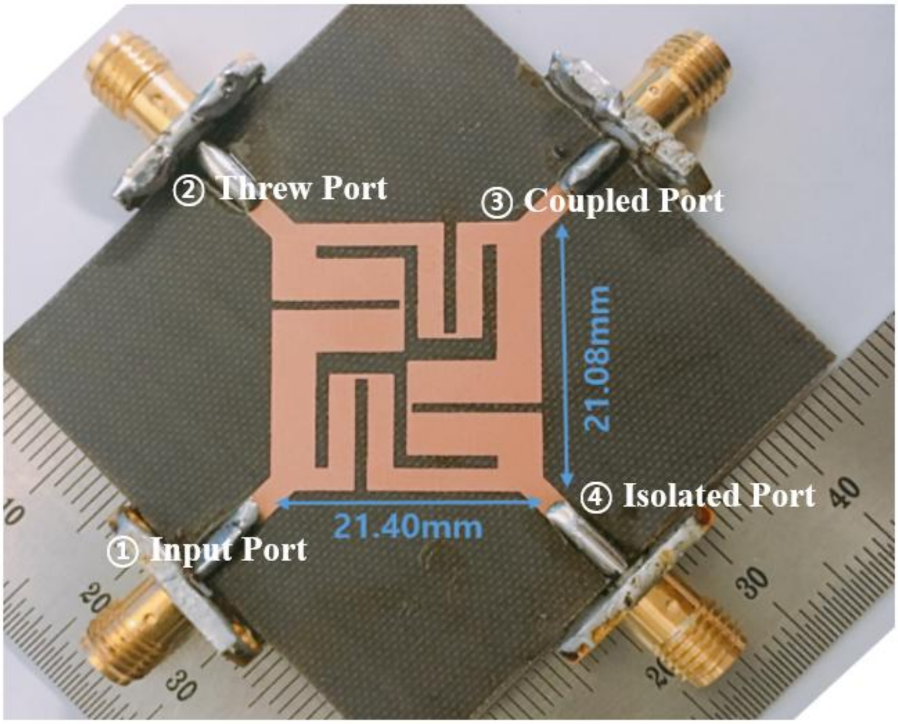


Figure 4. Photograph of fabricated the BLPD using the CCL

Simulated BLPD has the insertion loss and return loss of 3.13dB and 27.01dB at the center frequency of 1.8GHz, respectively. Also, the 20dB bandwidth is 8.82%. The simulated and measured results show Fig. 5.

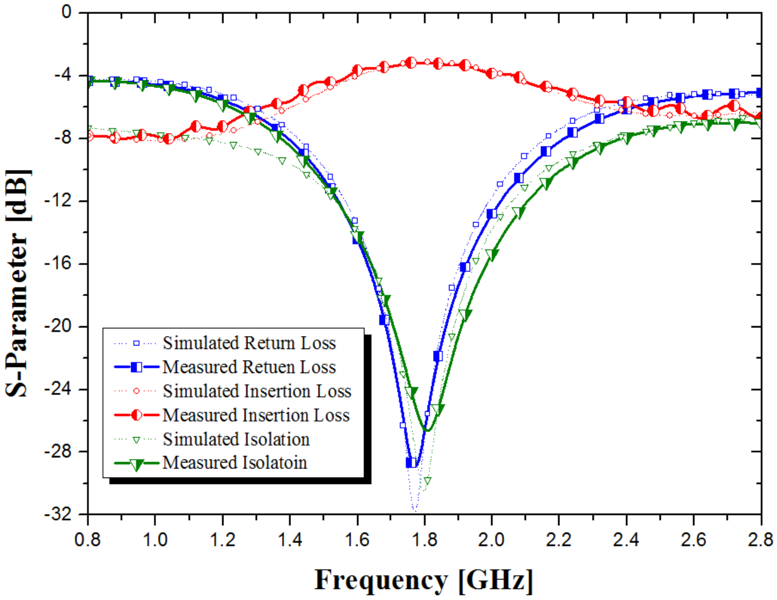


Figure 5. Simulated and measured results of the BLPD using the CCL

Fabricated BLPD has the insertion loss and return loss of 3.16dB and 26.54dB at the center frequency of 1.78GHz, respectively, and the 20dB bandwidth is 9.58%. Also, differenced magnitude and phase between threw port and coupled port is measured 0.1dB and 89.9° at the center frequency of 1.78GHz, respectively, as shown in Fig. 6.

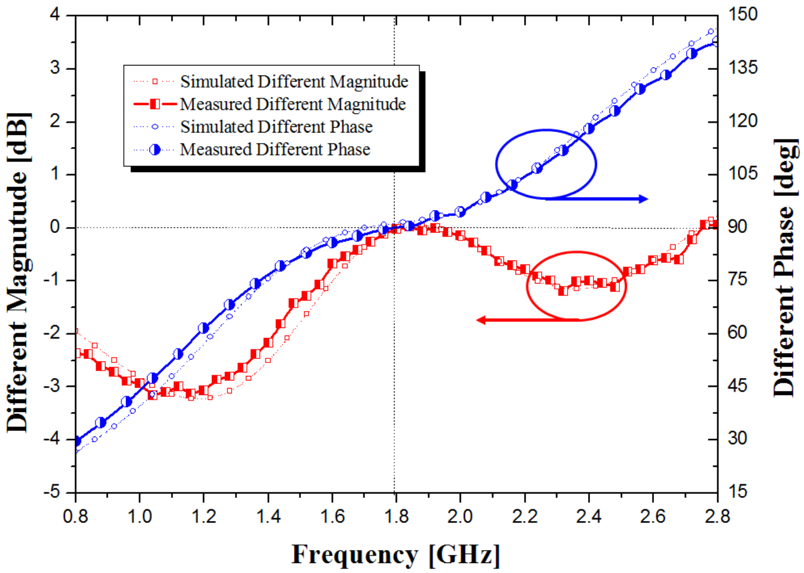


Figure 6. Measured results of differenced magnitude and phase of the BLPD

Fig. 6 shows the differenced magnitude and phase of the BLPD. In the 20dB bandwidth, the differenced magnitude and phase have below 0.3dB and 90.0 ± 3.0°, respectively.

4. Conclusion

In this paper, compact BLPD using the CCL is suggested. The CCL has good performance of phase delay when the CCL is realized with lower coupling coefficient and lower characteristic impedance. In addition, the loss of the CCL is unaffected by the coupling coefficient if the impedance is matched.

The suggested BLPD shows of typical example of realization of the CCL for the size-reduction. Designed BLPD has the size of $0.13\lambda_g \times 0.13\lambda_g$ and the size-reduction ratio of fabricated BLPD has 58.5%. Also, other performances such as the loss, bandwidth, harmonics, and differenced phase are almost same compared with the conventional BLPD.

Suggested application of the CCL can be used various devices and circuits for the size-reduction.

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