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Small-size Rat-race Ring Coupler Using Connected Coupled-line

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Abstract

In order to improve performance for the size of the rat-race ring coupler, the CCL is used for the realization as the delay line. As realizing lower coupling coefficient, the ratio of the size-reduction for the CCL is enhanced. The CCL is alternated with $\lambda_g/4$ of the rat-race ring, and optimized two CCLs are inserted for the size-reduction. the coupling coefficient is 0.2, and electrical lengths of each CCL are 28.2° and 21.7°. Designed rat-race ring using the CCL has the size of 18.76 × 20.45 mm^2 and the size-reduction ratio of fabricated rat-race ring using the CCL has 76.8%. Also, fabricated rat-race ring is measured the insertion loss of 3.20dB at the center frequency of 2.45GHz and the 20dB bandwidth is 24.04%. Differenced magnitude and phase between threw port and coupled port are measured 0.1dB and 177.4°, respectively. These performances are almost same compared with the conventional rat-race ring. Suggested application of the CCL can be used various devices and circuits for the size-reduction.

Key words: *connected coupled-line (CCL), coupler, rat-race ring, phase, size-reduction*

1. Introduction

Generally, the rat-race ring coupler is widely used as the half power divider or combiner, because its differenced phase between two outputs is out of phase [1-4]. However, the size of the rat-race ring coupler is not small for realization of the transmission line of the quarter wavelength. In order to overcome this advantage, the transmission line can be substituted with the composited right-, left-handed (CRLH) line or the equivalent circuit like as the Π-type or T-type [5-6]. For the size-reduction, the method of using the CRLH line is difficult to realization on uniplanar structure. Also, the performance of size-reduction of the method of using the equivalent circuit is not good.

The connected coupled-line (CCL) can be used as the delay line when the impedances are matched because the CCL has the characteristic of all pass. In this paper, size-reduced rat-race ring is suggested by using the characteristic of the phase-delay 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 [4].

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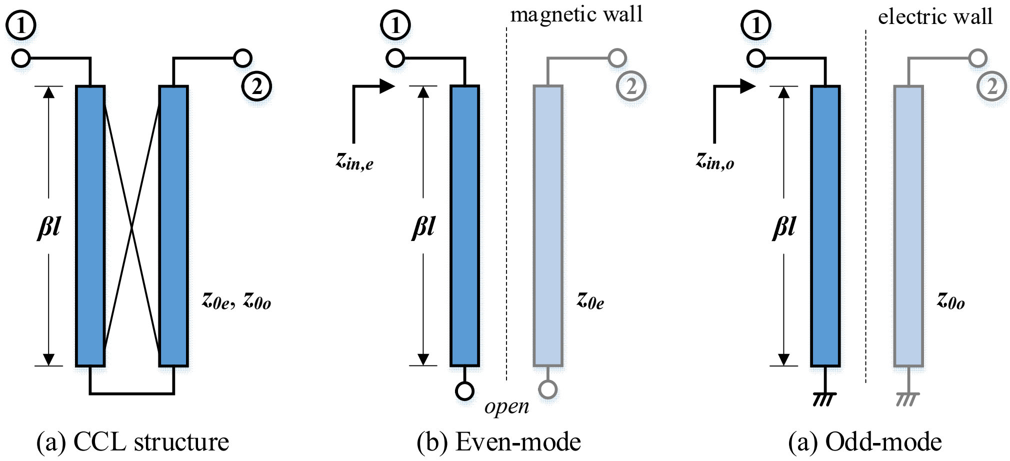

Figure 1. Even and odd-mode configuration of the CCL

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), input impedances of even-mode, $z_{in,e}$ and odd-mode, $z_{in,o}$ are followed:

$$z_{0e}=z\cdot\sqrt{\frac{1+C}{1-C}},\quad z_{0o}=z\cdot\sqrt{\frac{1-C}{1+C}} \tag{3}$$

In Eq. (3), z and C are the normalized impedance of the coupled-line and coupling coefficient, respectively. Now, the magnitude and phase of the transfer function are

$$\begin{aligned} |S_{21}|^2 &= \frac{(z_{0e}\cot\beta l+z_{0o}\tan\beta l)^2}{(1+z_{0e}z_{0o})^2+(z_{0e}\cot\beta l - z_{0o}\tan\beta l)^2} \\ &= \frac{2z^2(2C^2\cos 2\beta l - C^2\sin^2 2\beta l+2)}{(1-C^2)(1+z^2)^2\sin^2 2\beta l+2z^2(2C^2\cos 2\beta l+2\cos^2 2\beta l+C^2\sin^2 2\beta l)} \end{aligned}, \tag{3}$$

$$
\begin{aligned}
phase(S_{21}) &= \tan^{-1}\left(\frac{1+z_{0e}z_{0o}}{z_{0e}\cot\beta l - z_{0o}\tan\beta l}\right) \\
&= \tan^{-1}\left(\frac{\sqrt{1-C^2}\left(1+z^2\right)\sin 2\beta l}{2z\cos 2\beta l + 2zC}\right)
\end{aligned}. \tag{4}
$$

From the Eq. (4), 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.

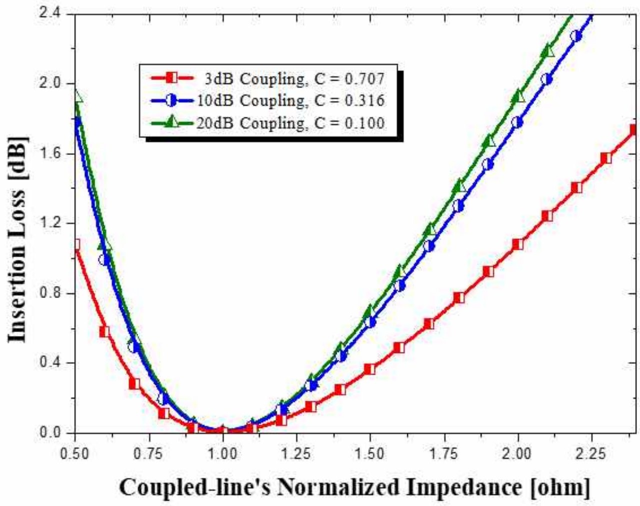

Figure 2. Characteristics of loss of the CCL as the coupling coefficient and impedance

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.

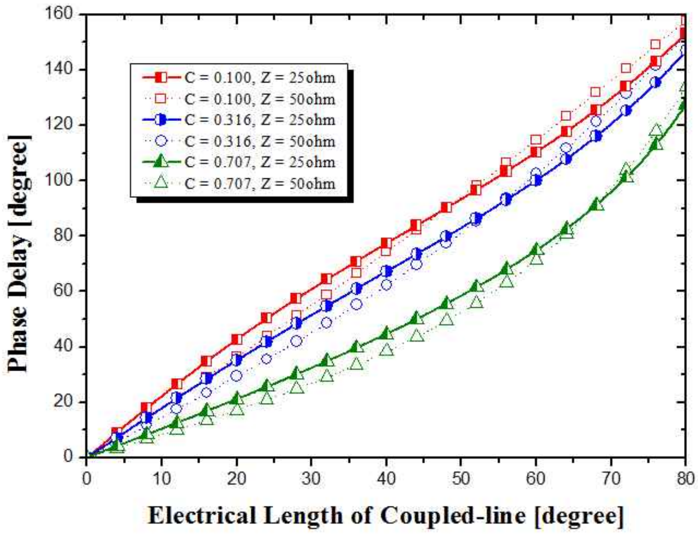

Figure 3. Characteristics of phase of the CCL as the electrical length

Fig. 3 shows the phase of the CCL as the electrical length with the condition of matching. In the Fig. 3, the dot line and solid line are indicated impedances of 50 ohm and 25 ohm, respectively. In case of short coupled-line than $\lambda_g/8$, the CCL of the lower coupling coefficient has better performance of delay.

3. Rat-race ring using the connected coupled-line structure

In this paper, the size-reduced rat-race ring is suggested using by the CCL. Each quarter-wavelength line of rat-race ring is realized with the electrical length of 41.0° and two CCLs as shown in Fig. 4. CCLs are designed with the coupling coefficient of 0.2 and each electrical lengths are 28.2° and 21.7°.

The rat-race ring with the CCL is designed the center frequency of 2.45GHz on the tefron substrate with the dielectric constant and height of 2.55 and 0.76mm, respectively. The size of fabricated the rat-race ring is 18.76 × 20.45 mm^2 as shown in Fig. 4. The size is reduced 76.8% than conventional rat-race ring (38.36 × 43.06 mm^2). Fig. 4 is the photograph of the fabricated the rat-race ring using the CCL.

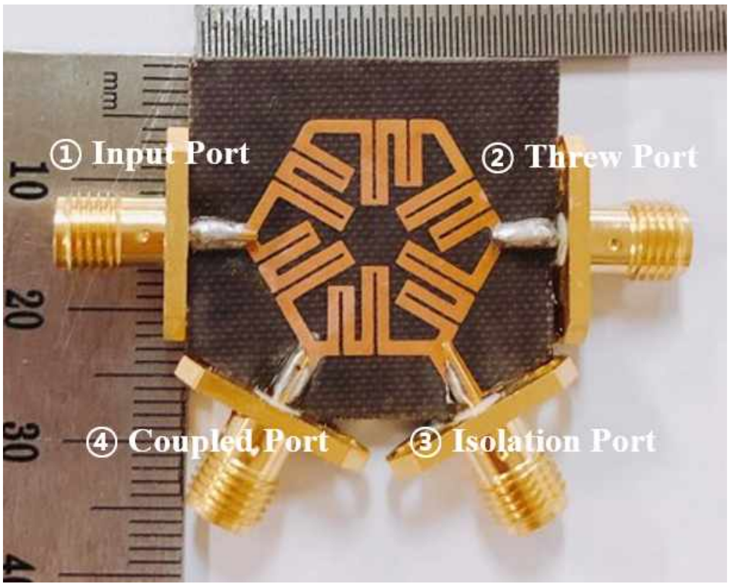

Figure 4. Photograph of fabricated the rat-race ring using the CCL

Simulated rat-race ring has the insertion loss and return loss of 3.15dB and 28.45dB at the center frequency of 2.4GHz, respectively. Also, the 20dB bandwidth is 29.17%. The simulated and measured results show Fig. 5.

Fabricated rat-race ring has the insertion loss and return loss of 3.20dB and 23.58dB at the center frequency of 245GHz, respectively, and the 20dB bandwidth is 24.04%. Also, differenced magnitude and phase between threw port and coupled port is measured 0.1dB and 177.4° at the center frequency of 2.45GHz, respectively, as shown in Fig. 6.

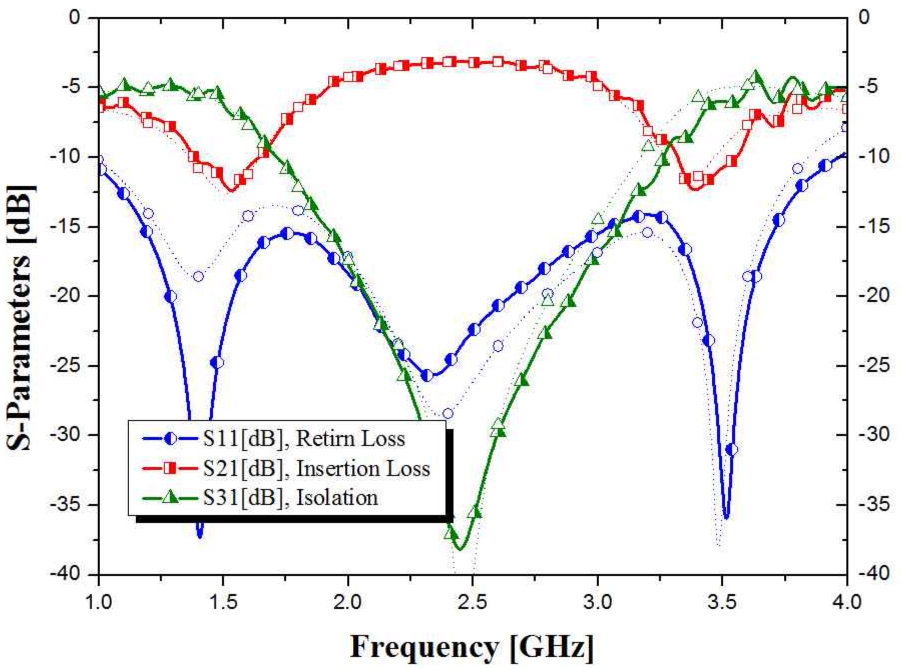

Figure 5. Simulated and measured results of the rat-race ring using the CCL

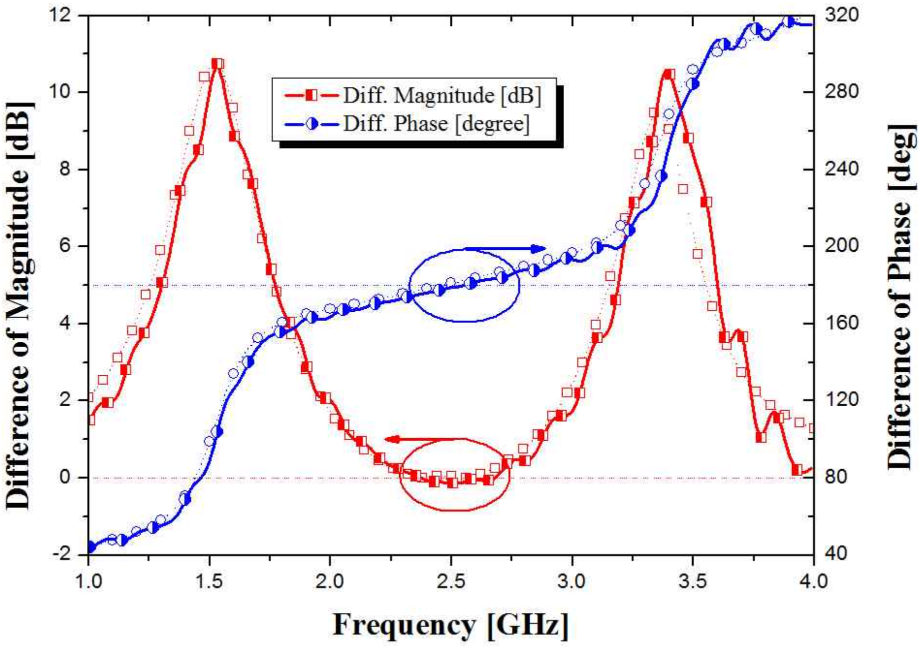

Figure 6. Measured results of differenced magnitude and phase of the rat-race ring

Fig. 6 shows the differenced magnitude and phase of the rat-race ring. In the range from 2.1 to 2.8GHz, the differenced magnitude and phase have below 1dB and 180.0 ± 10.0°, respectively.

4. Conclusion

In this paper, the phase characteristic of the CCL structure is analyzed and the compact rat-race ring using the CCL structure is suggested. The CCL is suitable for application of the size-reduction because has the good phase delay when the CCL is realized with lower coupling coefficient and lower characteristic impedance. Although the loss of the CCL is increasing as lower coupling coefficient, it can be solved the impedance matching.

For example of application of the CCL structure, designed rat-race ring has the size of 18.76 × 20.45 mm^2 and the size-reduction ratio of fabricated rat-race ring has 76.8%. Also, other performances such as the loss, bandwidth, and differenced phase are almost same compared with the conventional rat-race ring.

Suggested application of the CCL can be used various devices such as the divider, filter, and antenna for the size-reduction. Also, suggested the rat-race ring coupler using the CCL structure can be applied in the compact wireless communication system.

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