Multi-Stage Rat-race Ring Coupler for Broadband Application

Sun-Kuk Noh, Tae-Soon Yun

Abstract*: *In this paper, the design method of the multi-stage rat-race ring for the wideband application is suggested. Suggested structure is simply uniplanar structure. Designed multi-stage rat-race ring with 3dB-coupling has the differenced phase of in-phase or out-of-phase. Theoretically, the bandwidth of 3 stage rat-race ring has 202.6% compare with the single rat-race ring. Fabricated 3 stage rat-race ring has the insertion loss and bandwidth of 3.29dB and 62.7%, respectively. Also, the differenced magnitude and phase between outputs is measured 0.04dB and 181.47°, respectively.

Index Terms*: *rat-race ring, coupler, bandwidth, multi-stage.

I. INTRODUCTION

In the communication system, it is necessary to divide or combine signal's power. The tight coupler such as the wilkinson's divider, branch-line divider, and rat-race ring coupler has basically the performance of half power dividing. These couplers have been researched with the target of small-size, harmonic-suppression, and broadband application [1-8]. Although disadvantage of the size by $3\lambda_g/4$, the rat-race ring coupler is useful because can be made two signals with out-of-phase.

Usually, in order to realize the broadband for the tight coupler, the multi-stage method is used. That is, the output ports of the reverse stage are connected the input ports of the next stage. By method of the multi-stage, the bandwidth of the wilkinson's divider and branch-line divider can be enhanced [4-5,9-13]. However, the realization of the multi-stage of the rat-race ring coupler is very difficult because the output ports of the rat-race ring coupler are separated. Therefore, the addition of the transmission line or replacement of alternating is studied in the rat-race ring using the chebyschev function [6]. Also, the insertion of the shorted coupled-line for enhancing delay performance is researched [7,9-13].

In this paper, the rat-race ring coupler with multi-stage structure is suggested for the broadband application.

II. DESIGN OF MULTI-STAGE RAT-RACE RING COUPLER

In the planar structure, the connection of ports for multi-stage is difficult in the rat-race ring coupler. Therefore, three rings are connected with consideration of the phase as shown in Fig. 1.

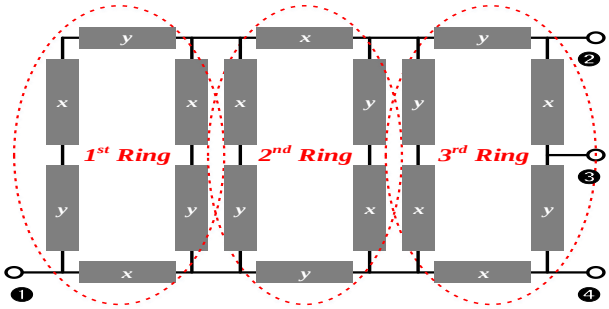

Fig. 1 Schematic of the multi-stage rat-race ring

Fig. 1 shows the schematic of the multi-stage rat-race ring coupler. The electrical lengths of all section are the quarter wavelength. Each rings are overlapped with 2 lines of the quarter wavelength as shown in Fig. 1. Overlapped lines are designed independently in this paper, but can be united by the half impedance.

Also the ports are same pattern with single rat-race ring, that is, the suggested rat-race ring coupler has the out-of-phase outputs in case of the input port of the number 1 and has the in-phase outputs in case of the input port of the number 3.

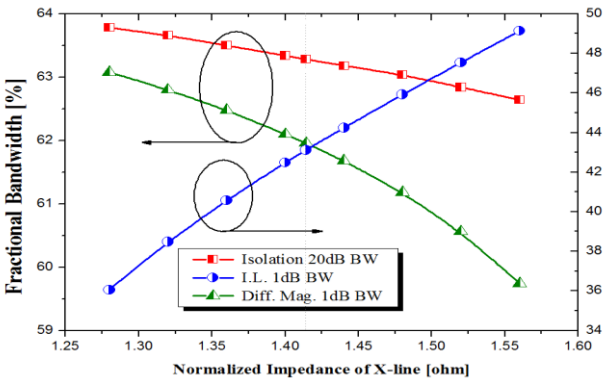

Fig. 2 Fractional bandwidth as the impedance

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Sun-Kuk Noh, SW Convergence Education Institute, Chosun University, Gwangju, Republic of Korea.
Email: nsk7078@chosun.ac.kr
Tae-Soon Yun, Dept. of Electronics Engineering, Honam University, Gwangju, Republic of Korea., (Corresponding Author*)

Generally, the normalized impedances of all section in the rat-race ring are the 1.414 for lossless 3dB coupling. In order to indicate the bandwidth as the impedance of lines, the impedances of each section of the rat-race ring are set variables as shown in Fig. 1.

For the lossless condition, the impedances of x- and y-line in the Fig. 1 are followed:

$$z_x \cdot z_y = 2 \tag{1}$$

In the Fig. 2, symbols of the square, circle, and triangle are indicated the bandwidth of the 20dB isolation, 1dB different magnitude between outputs, and 1dB insertion loss, respectively.

When all impedances are set $1.414Z_0$, the bandwidth of the 20dB isolation for the multi-stage rat-race ring is 63.3%. And the bandwidth of 1dB different magnitude between outputs and 1dB insertion loss is 62.0% and 43.1%, respectively.

As increasing of the impedance of x-line, z_x, the bandwidth of the isolation is decreasing. However, the bandwidth of the insertion loss is proportional to the impedance.

In the lossless condition, the bandwidth of the multi-stage rat-race ring is improved 202.6% compared with the single rat-race ring of 31.2%.

From these results, the broadband rat-race ring coupler is designed by using EM simulator for the 5G communication system of 3.5GHz. Designed parameters of the substrate such as dielectric constant, loss tangent, and height are 2.55, 0.0023, and 0.76mm, respectively.

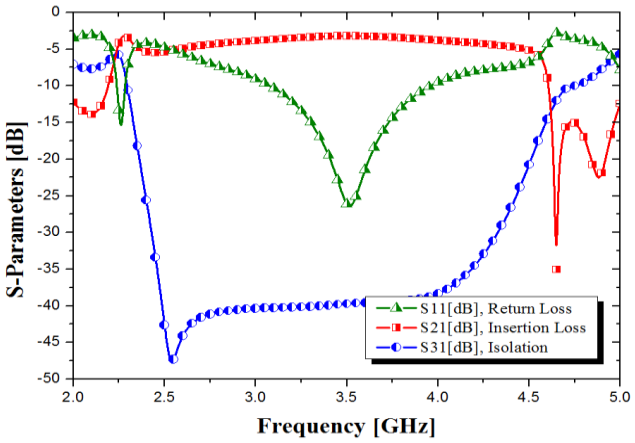

Fig. 3 Designed results of the multi-stage rat-race ring

In the Fig. 3, symbols of the square, circle, and triangle are indicated the insertion loss, return loss, and the isolation, respectively. Simulated rat-race ring coupler has the insertion loss and isolation of 3.22dB and 39.75dB at the center frequency of 3.5GHz, respectively. Also, the 20dB bandwidth of the isolation is 61.14%.

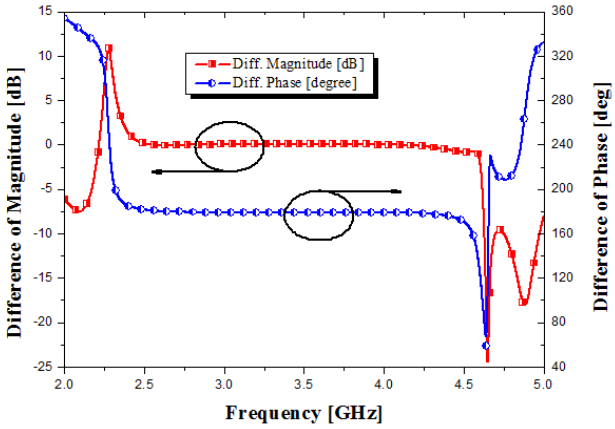

Fig. 4 Designed different magnitude and phase of the multi-stage rat-race ring

Fig. 4 shows the different magnitude and phase between outputs. Simulated different magnitude and phase is 0.10dB and 179.24°, respectively. When the input port is replaced the isolation port, the different phase between outputs is simulated 0.10° at center frequency. The bandwidth of 1dB different magnitude is 61.71%.

III. MANUFACTURING OF THE RAT-RACE RING

Designed multi-stage rat-race ring coupler is fabricated by the etching process.

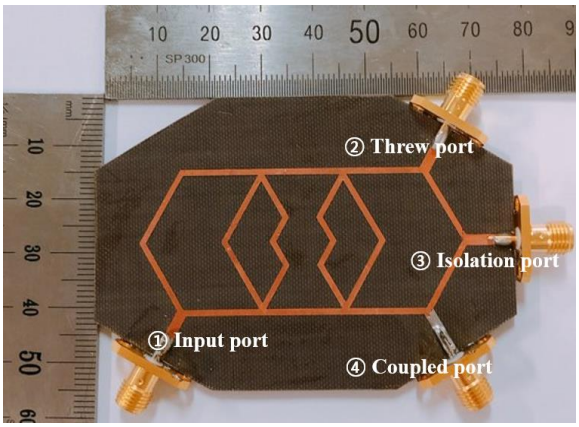

Fig. 5 Photograph of fabricated multi-stage rat-race ring

Fig. 5 shows the photograph of fabricated the multi-stage rat-race ring coupler. The connectors of the SMA type are connected for the measuring. The size of the multi-stage rat-race ring coupler excepted feeding line is 27.7 × 63.4 mm^2. In order to derive in-phase result, the input port has to be alternated with the isolated port in a different way from the Fig. 5.

Fabricated multi-stage rat-race ring coupler is measured by the VNA of Anritsu MS4624D .

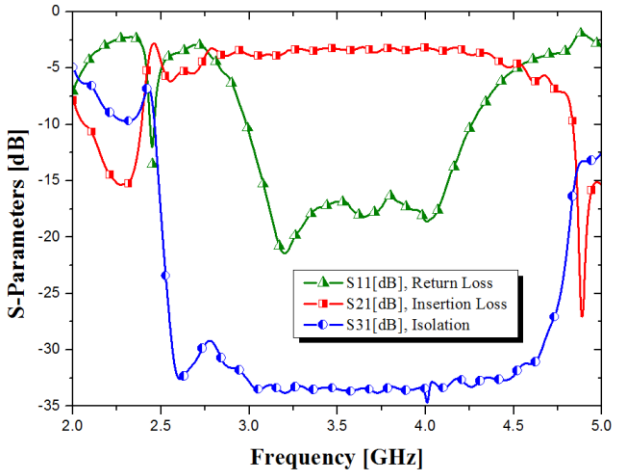

Fig. 6 Measured results of the multi-stage rat-race ring

Fig. 6 shows measured S-parameters of multi-stage rat-race ring coupler. The insertion loss and isolation is 3.29dB and 33.46dB at the center frequency of 3.5GHz, respectively. Also, the 20dB bandwidth of the isolation is 62.74%. Table 1 shows the compared bandwidth with other results.

Table 1 Comparison of various broadband rat-race ring

Ref.	f_0	*BW*	Techniques
[6]	610MHz	62.3%	Chebyschev function
[7]	1.8GHz	111.1%	Shorted coupled-line
[8]	6.0GHz	36.9%	Stepped impedance line
This paper	3.5GHz	62.7%	Multi-stage

Fig. 7 shows the measured different magnitude and phase between outputs of fabricated multi-stage rat-race ring coupler. The different magnitude and phase is measured 0.04dB and 181.47°, respectively. Also, the bandwidth of 1dB different magnitude is 58.84%.

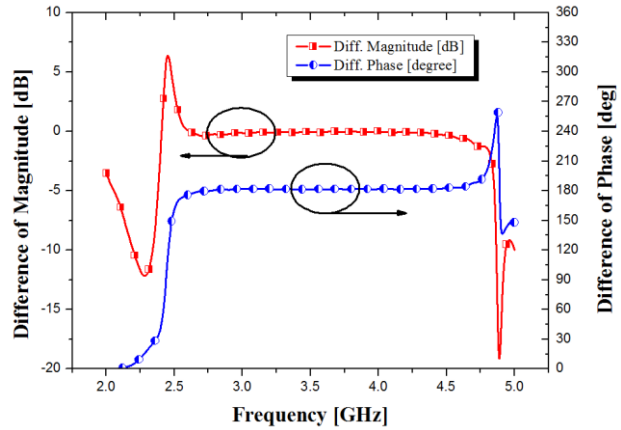

Fig. 7 Measured different magnitude and phase of the multi-stage rat-race ring

IV. CONCLUSION

In this paper, the multi-stage rat-race ring coupler is suggested by overlapping 3 rings for broadband application. The method using by shorted coupled-line has better performance of the bandwidth for the rat-race ring but the realization of the tight coupling is difficult. Suggested multi-stage rat-race ring coupler can be easily realized and can be made more than twice bandwidth compared with the single rat-race ring. For example, the coupler is designed at the center frequency of 3.5GHz. Fabricated multi-stage rat-race ring coupler on the tefron substrate has the bandwidth of 62.7%.

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