Design of an E-plane Ring Hybrid Coupler in a Rectangular Waveguide

Tsend Shijirbaatar*, Dong-Kook Lee*, Otgonbaatar Gombo*, Jae-Hoon Bang*, and Bierng-Chearl Ahn*

Abstract

Rectangular waveguide ring hybrid couplers are often used in combining, subtracting and dividing microwave signal in waveguides. In this paper, we present the optimum design and experimental verification of an E-plane 180° ring hybrid coupler in a rectangular waveguide. Using an electromagnetic simulation tool, the optimum dimensions of the ring hybrid coupler are obtained for a wideband performance at various operating frequencies of the standard WR-28 rectangular waveguide. The resultant design data can be used for an E-plane ring hybrid coupler in any standard rectangular waveguide. To verify the validity of the design, a ring hybrid coupler operating at 35GHz is fabricated using the split-block technique and its performance is measured. Measured results agree well with the simulation. Measurements of the fabricated coupler show a reflection coefficient less than -20 dB, an isolation greater than 20dB, an amplitude deviation within +0.3/-0.6dB and phase deviation within +6.5°/-5.5° over 33.4-37.2GHz(10.8% bandwidth).

요 약

사각형 도파관 링 하이브리드 커플러는 도파관 내의 마이크로파 신호의 합 또는 차를 구하거나 신호를 나누는 데에 사용된다. 본 논문에서는 사각 도파관 전계면 180° 링 하이브리드 커플러의 최적설계 방법과 실험 결과를 제시하였다. 전자기장 해석 툴을 이용하여, WR-28 표준 도파관의 여러 동작 주파수에서 최적 특성을 가지는 하이브리드 커플러의 치수를 도출하였다. 설계의 타당성을 확인하기 위해, 35GHz에서 동작되는 하이브리드 커플러를 블록분리 기법으로 제작하여 그 특성을 측정하였다. 측정결과는 시뮬레이션과 잘 일치하였다. 제작된 커플러는 33.4-37.2GHz(10.8% 대역폭) 주파수 범위에서 -20dB 이하의 반사계수, 20dB 이상의 격리도, +0.3/-0.6dB 이내의 진폭편차, +6.5°/-5.5° 이내의 위상편차 특성을 보였다.

Keywords
ring hybrid coupler, waveguide components, 180-degree coupler, optimum design

Ⅰ. Introduction

A rat-race ring or 180-degree hybrid coupler in a rectangular waveguide is widely used in power divider or combiners, mixers, and monopulse comparators for high-power systems[1]-[2]. A ring hybrid coupler is a four-port device that has two inputs and two outputs[3]. When the coupler is used in the power-

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dividing mode, the sum channel input is equally divided into two output ports in the same phases, while the difference channel input divided in the opposite phases. Conversely, when two signals are applied at respective ports, a sum of them appears at the sum port while the difference of them appears at the difference port.

A waveguide 180° hybrid can also be realized with a quadrature hybrid coupler[4] and a phase shifting section[5]. Though printed-circuit counterparts have been extensively studied[6]-[7], ring hybrid couplers in a rectangular waveguide have not received much attention[8]-[9]. Also in waveguide ring hybrids, sophisticated miniaturization and widebanding techniques are not usually applicable since small and complicated circuit elements are not realizable due to the space restrictions inherent in waveguide structures. The theory of operation of the ring hybrid coupler is treated in microwave textbooks[3]. Optimum design of an *E*-plane ring hybrid basically involves the determination of the ring region dimension[8]. A slightly wider bandwidth is obtained when angles between ports are varied and impedance-matching steps are used[9].

In this paper, we present the optimum design of a rate-race ring hybrid coupler in the *E*-plane of a rectangular waveguide. The radius and width of the ring region is optimized using the widely-used Microwave Studio^{TM} by CST. The WR-28 standard rectangular waveguide[3] is used. The design data presented in this paper can be applied to a ring hybrid coupler in any standard rectangular waveguide by frequency scaling. To verify the design, a ring hybrid coupler operating at 35GHz is fabricated, tested and compared with the simulation.

Ⅱ. Ring Hybrid Design

Fig. 1 shows the structure of an *E*-plane ring hybrid coupler in a rectangular waveguide, where port designations, electric field reference directions and nominal lengths of the ring sections are denoted. The mean radius(r_0) and width(c) of the ring are the principal design parameters. For the simulation of the ring hybrid with Microwave Studio^{TM}, the waveguide bends are used to make the port plane parallel to a rectangular boundary.

The nominal distance between port 2 and port 4 is $3\lambda_g/4$, while all other nominal distances between any two ports are $\lambda_g/4$, where λ_g is the guided wavelength of the dominant TE_{10} mode. In the combining mode, ports 3 and 4 are input ports. The sum and difference output ports are port 2 and port 1, respectively. In Fig. 1(a), the directions of the electric field are denoted to show the operating principle of the ring hybrid. The scattering matrix of an ideal ring hybrid is given by the following equation (1), where a perfect impedance matching at all ports and an infinite isolation between any two ports are infinite[3].

$$[S] = \frac{-j}{\sqrt{2}}\begin{bmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & -1 \\ 1 & 1 & 0 & 0 \\ 1 & 0 & -1 & 0 \end{bmatrix} \quad (1)$$

Optimum design data for a ring hybrid coupler is obtained using the standard WR-28 waveguide at six different frequencies of the *Ka*-band(26.5-40.0GHz). The WR-28 standard rectangular waveguide with a cross-sectional dimension of $7.112\times3.556mm^2$ is used [3]. The ring's mean radius and width are adjusted for the best performance at the design frequency. The ring radius is sensitive to resonance frequency while the ring width only improves the impedance matching. The final optimized design values are listed in Table 1. The optimum value of the ring width ranges from $0.62b$-$0.75b$, where b is the waveguide narrow-wall height. The mean circumference of the ring normalized by the nominal length of $1.5\lambda_g$ at the center design frequency ranges from 0.90-1.08.

The bandwidths for -20dB reflection, 1dB amplitude balance, and 10° phase balance range from 6.1% to 11.8%, 13.2% to 20.5% and 10.8% to 34.7%, respectively.

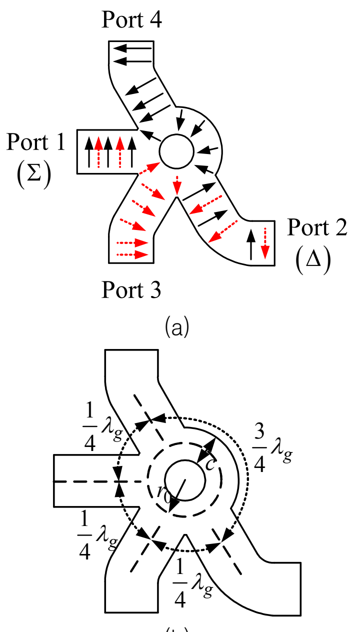
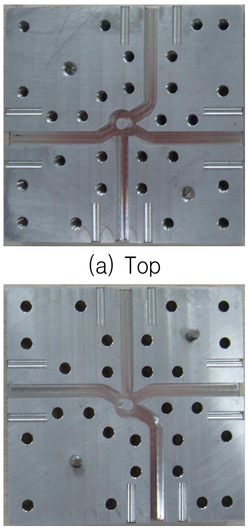


Fig. 1. (a) Reference directions of the electric field in the ring hybrid and (b) Nominal dimensions of the ring sections

Although optimum dimensions in Table 1 are given for the ring hybrid couplers in the standard WR-28 waveguide, they can be used for other standard waveguides where the narrow wall height b is one half of the broad wall width a.

Ⅲ. Fabrication and Measurement

To check the accuracy of the design, a ring hybrid coupler operating at 35GHz with dimensions given in Table 1 is fabricated. Fig. 2 shows the photograph of the fabricated ring hybrid coupler. The split-block technique is employed in the fabrication, where the structure is divided in half at the center of the E-plane of the rectangular waveguide. Two symmetric halves of the block are tightly joined by bolts. For precise alignment, two guide pins are used. Sharp corners are replaced with a corner of 0.3mm radius for end mill machining. In Fig. 2, six screw threads for the mating of waveguide flanges can be seen.



(b) Bottom halves

Fig. 2. Fabricated ring hybrid coupler

Table 1. Optimum dimensions of the ring hybrid coupler

Center frequency(GHz)	c/b	$2\pi r_0/(1.5\lambda_g)$	Frequency(GHz) for reflection coefficient < -20dB	Frequency(GHz) for amplitude balance within ±1dB	Frequency(GHz) for phase balance within ±10 deg
26.5	0.75	1.07	24.77-26.33 (6.1%)	24.50-27.96 (13.2%)	24.50-27.31 (10.8%)
30	0.66	1.08	28.63-31.24 (8.7%)	27.00-32.16 (17.4%)	26.75-31.17 (15.3%)
33	0.62	1.01	31.80-35.13 (10.0%)	30.21-37.12 (20.5%)	29.47-35.87 (19.6%)
35	0.63	0.99	33.65-36.96 (9.4%)	32.20-39.50 (20.4%)	30.80-38.50 (22.2%)
37	0.62	0.99	35.22-39.09 (10.4%)	33.61-41.14 (20.1%)	31.62-40.71 (25.1%)
40	0.62	0.90	37.60-42.27 (11.7%)	35.45-41.62 (16.0%)	33.80-48.00 (34.7%)

The reflection and transmission properties of the fabricated ring hybrid are measured using a vector network analyzer. Since laboratory network analyzers measure the scattering parameters between two ports at a time, one has to repeat scattering parameter measurements many times to fully measure the hybrid's performance.

Fig. 3 shows the reflection coefficient at each port of the fabricated ring hybrid coupler. All of the measured reflection coefficients are less than -20dB over 33.4-37.2GHz(10.8% bandwidth). Agreement between the measurement and the simulation is excellent.

Fig. 4 shows the amplitudes of the transmission coefficients between the orthogonal isolated port(port 1 - port 2 and port 3 - port 4). Over 32.2-37.5GHz 15.1% bandwidth), all of the transmission coefficients are less than -20dB.

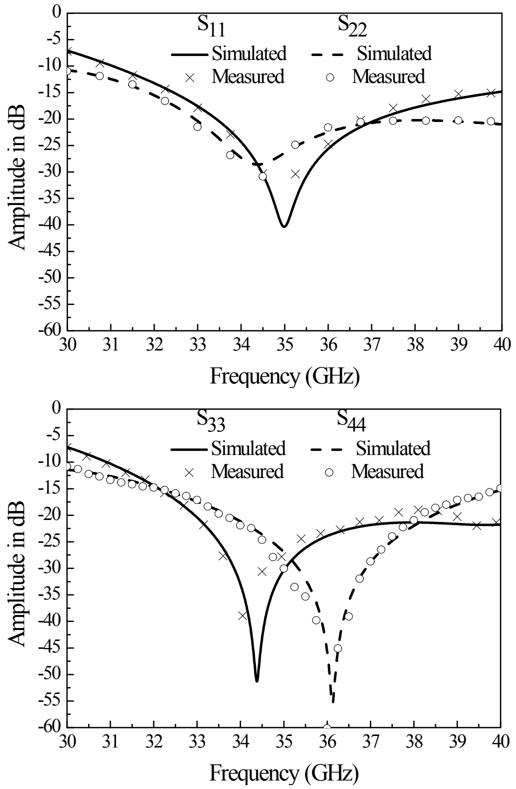


Fig. 3. Reflection coefficients of the fabricated ring hybrid coupler

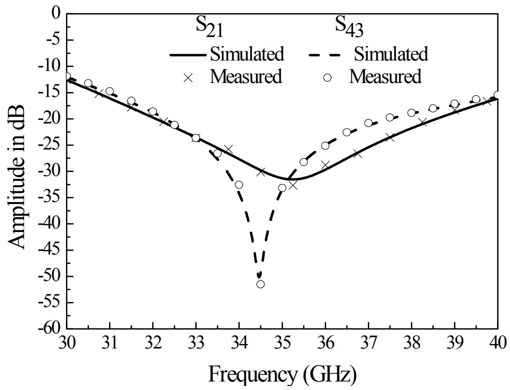


Fig. 4. Transmission coefficients between isolated ports of the fabricated ring hybrid coupler

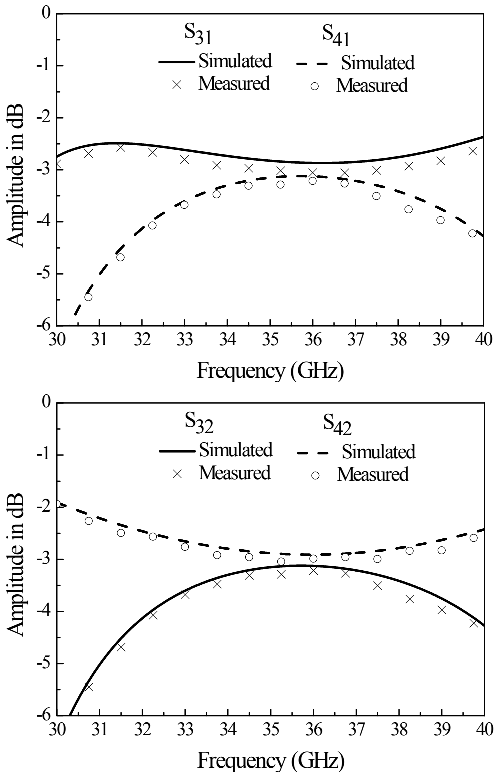
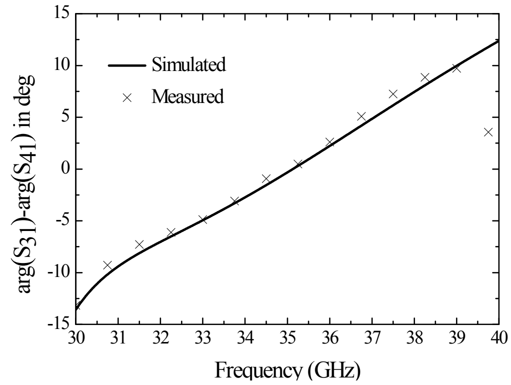


Fig. 5. Amplitudes of the transmission coefficients between coupled ports of the fabricated ring hybrid coupler

The amplitude and phase balance of the fabricated ring hybrid are measured by operating the hybrid in the power-divider mode.

Fig. 5 shows the amplitudes of transmission coefficients between input ports 3 and 4 and coupled output ports 1 and 2, from which the amplitude and phase balances are deduced. From Fig. 5 we find that the amplitude balance is within ±1dB over 32.5-39.5 GHz(19.4% bandwidth).

Fig. 6 shows the phases of the transmission coefficients between coupled ports. The phase balance is within ±10° over 30.8-39.0GHz(23.5% bandwidth). In Figs. 3-6, the agreement between the simulation and the measurement is excellent proving the accuracy of the design data in Table 1. The bandwidth limiting factor is the input reflection coefficient, which can be improved using the stepped impedance transformer as suggested in[9].



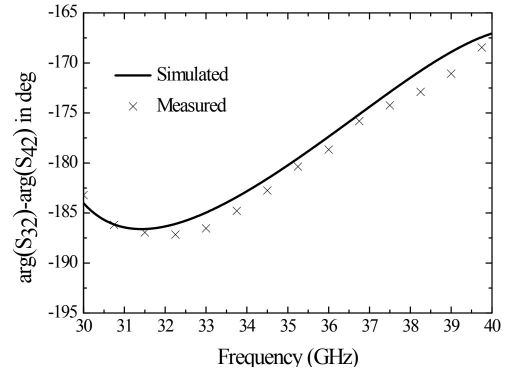


Fig. 6. Phases of the transmission coefficients between coupled ports of the fabricated ring hybrid coupler

Ⅳ. Conclusion

In this paper, we investigated the design of an *E*-plane ring hybrid coupler in a rectangular waveguide. We have designed the rate-race ring hybrid coupler at different frequencies in the WR-28 waveguide and presented optimum dimensions. We have fabricated and measured a rate-race ring hybrid coupler operating at 35GHz. The measured performance of the fabricated ring hybrid coupler agrees well with the simulation proving the accuracy of the design. The ring hybrid design data presented in this paper can be used for the design of a simple ring hybrid coupler in any standard waveguide.

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