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소형 하이브리드 커플러를 이용한 고조파가 억압된 저손실 위상 변위기

A Low-loss Phase Shifter with Harmonics Suppression Using Compact Hybrid Coupler

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요 약

본 논문은 T 형태의 미엔더 선로를 적용한 브랜치 라인 커플러를 이용하여 고조파가 억압된 소형 저손실의 반사기 형태인 위상 변위기에 대해 제안을 한다. 위상 변위기의 소형 커플러는 22.2×14.9 mm^2의 크기를 갖고 있으며, 기존의 브랜치 커플러는 32.6×27.8 mm^2의 크기를 나타낸다. 본 논문에서 제안된 위상 변위기는 2.1 GHz의 중심 주파수에서 삽입손실 0.19~0.28 dB, 그리고 137° 의 최대 위상 변위를 보여주고 있다.

핵심어 : 소형 크기, 고조파 억압, 미앤더 T 형태 선로, 브랜치-라인 커플러, 위상 변위기

ABSTRACT

In this paper, a compact low-loss reflector-type phase shifter with harmonic suppression using meander T-shaped branch-line coupler is suggested. The compact coupler for the phase shifter has a size of 22.2×14.9 mm^2 while a conventional branch coupler has a size of 32.6×27.8 mm^2. The phase shifter shows insertion losses of 0.19-0.28 dB at the center frequency of 2.1 GHz, and a measured maximum phase shift of 137°.

Key words : compact size, harmonics suppression, meander T-shaped line, branch-line coupler, phase shifter

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Ⅰ. INTRODUCTION

A phase shifter is an essential component in power receiving circuits and array antennas in RF systems [1]. The necessary characteristics for a phase shifter include a low return loss, low insertion loss, compact size, and harmonics suppression [2, 3].

The phase shifter is designed using hybrid branch-line couplers [4]. The branch-line coupler has a large size and some harmonics [5]. To reduce the circuit size of the branch-line coupler, many compact designs have been proposed. The lumped elements approaches were proposed in [6] and this technique shows the combinations of shunt lumped capacitors and short-high impedance transmission lines. In this case, metal-insulator-metal capacitors are needed for the monolithic microwave integrated circuits (MMIC), which increases the cost and the complexity of fabrication.

Photonic-band gap structure is another way to miniaturize the circuit [7]. However, the existence of many defected cells on the ground plane may limit the use of this technique. Furthermore, the conventional coupler has spurious pass-bands at the harmonics of the fundamental frequency, which affects the circuit's performance when used in microwave applications.

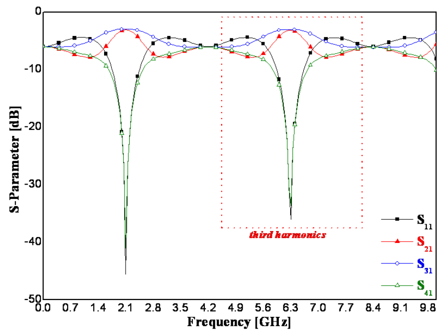
Recently, several design techniques have been reported for size reduction and harmonics suppression. In [8], a defected ground structure (DGS) is used to realize a compact coupler with up to third harmonic suppression. However, the problem is the requirement for a minimum air space volume below the DGS, and also radiation loss due to the DGS. In [9], compensated spiral compact microstrip resonant cell (CSMRC) resonators are used to suppress up to third harmonics, as well as to reduce size. However, the isolation performance is much less than for a conventional coupler, and a further fabrication difficulty arises due to the requirement for a high impedance line for the resonator.

In this paper, a compact size low-loss reflector-type phase shifter is presented, with constant insertion loss over a wide phase tuning range.

Ⅱ. A COMPACT SIZE BRANCH-LINE COUPLER

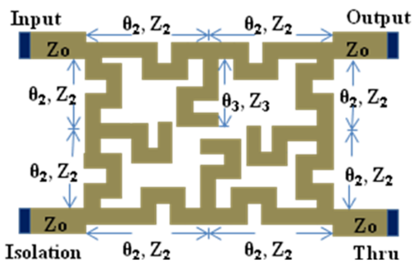
In general, the conventional branch-line coupler of large size [5] has third harmonics as shown in Fig. 1, which has the size of 32.6 × 27.8 mm^2[5]. The compact branch-line coupler, which is adopted to the design of the phase shifter, is composed of a T-shaped meander line as shown in Fig. 2 [5].

The T-shaped meander line is used to replace the series quarter-wavelength connecting line, and its electrical length is 90° [5]. Then, the T-shaped line works like a band-stop filter (BSF) at the second and third harmonic frequencies [5].



〈그림 1〉 고조파가 발생된 브랜치 라인의 커플러
〈Fig. 1〉 Harmonic responses of the conventional branch-line coupler

Therefore, the compact branch-line coupler has better characteristics with the third harmonics rejection than the conventional coupler [5]. It also has improved characteristics of third harmonic suppression and compact size. On the other hand, since the T-shaped line is designed to show rejection at the third harmonic of the coupler, θ_3 is assigned to be 30° at



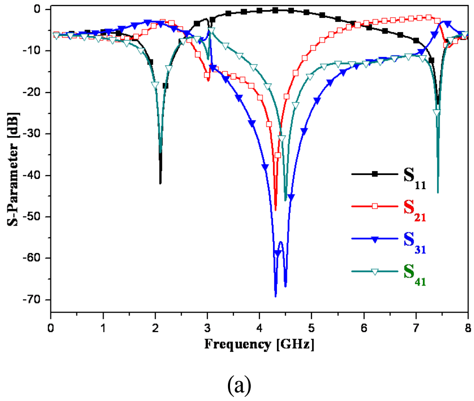
〈그림 2〉 소형 브랜치 라인 커플러
〈Fig. 2〉 A compact branch-line coupler

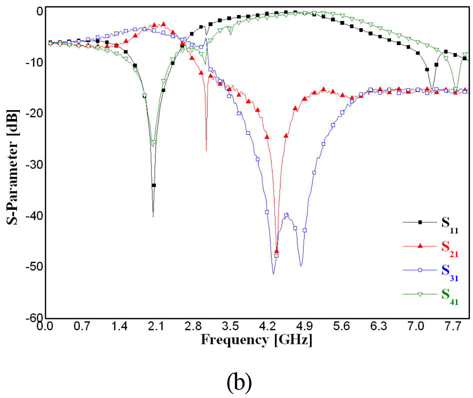
the fundamental frequency. Also, Θ_2 is 30° instead of 90° [5].

Fig. 3 shows the simulation and measurement results for the compact branch-line coupler with third harmonic suppression using the T-shaped meander line. From the figure, the simulation results for S_{21} and S_{31} are better than 3.08 dB and 3.19 dB and the S_{11} and S_{41} are 46.9 dB and 35.6 dB, respectively.

Also, measurement results for S_{21} and S_{31} are less than 2.85 dB and 3.94 dB and the S_{11} and S_{41} are 25.2 dB and 22.1 dB, respectively at the center frequency of 2.1 GHz. The simulation and measurement results for S_{21} of third harmonic suppression are 15.4 dB and 15.9 dB, respectively at 6.3 GHz. The simulation and measurement results for S_{41} which is the isolation characteristic, are 35.6 dB and 26.4 dB in the 3 dB coupling area, respectively.

The simulation and measurement results for the phase difference of the compact branch-line coupler are 89.0° and 90.3°, respectively. Fig. 4 shows the simulation results for phase response of the compact branch-line coupler with third harmonic suppression using the T-shaped meander line. The size of the compact coupler is 22.2 × 14.9 mm^2.

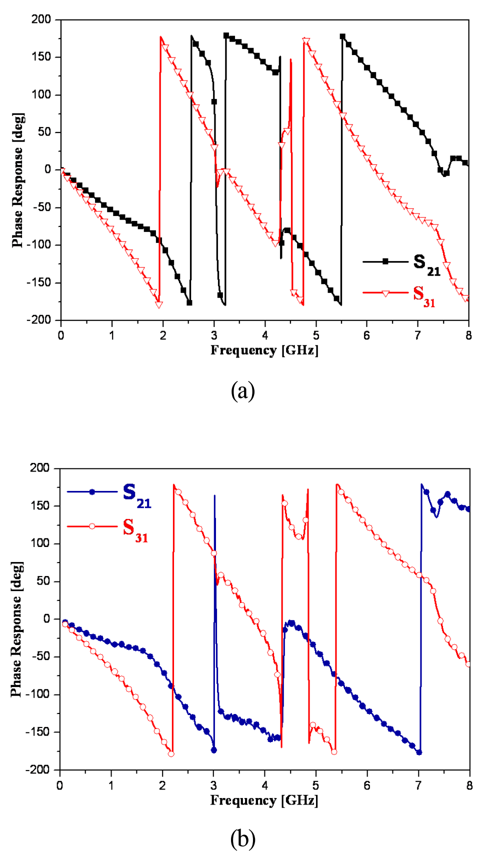




〈그림 3〉 T-형태의 민엔더 선로를 이용한 3차 고조파가 억압된 소형 브랜치 라인 커플러의 실험 결과 (a) 시뮬레이션, (b) 측정치
〈Fig. 3〉 Experimental results for the compact branch-line coupler with third harmonics suppression using T-shaped meander line, (a) simulation and (b) measurement

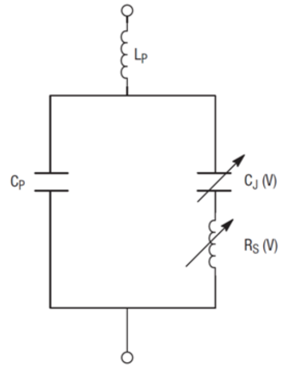
Ⅲ. PHASE SHIFTER WITH VARACTOR DIODE USING THE COMPACT BRANCH-LINE COUPLER

A varactor diode is composed of inductance, capacitance, and variable capacitance and inductance such as an L and C resonant circuit at the P-N junction as shown in Fig. 5 [10], where $C_j(V)$ and



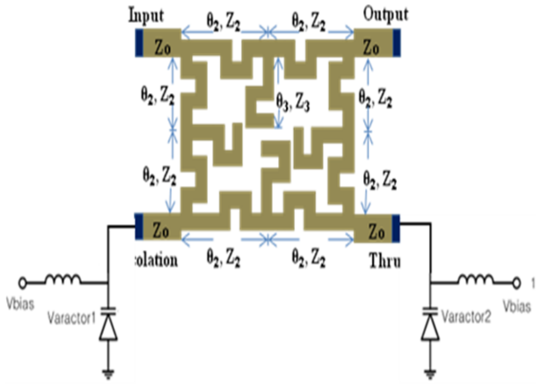
〈그림 4〉 소형 커플러의 시뮬레이션 위상 응답 결과 (a) 시뮬레이션, (b) 측정치

〈Fig. 4〉 Experimental results for phase response of the compact coupler, (a) simulation and (b) measurement



〈그림 5〉 베렉터 다이오드의 등가회로

〈Fig. 5〉 Equivalent circuit of the varactor diode



〈그림 6〉 소형 브랜치 라인의 커플러를 이용한 제안된 위상 변위기

〈Fig. 6〉 A proposed phase shifter with the compact branch-line coupler

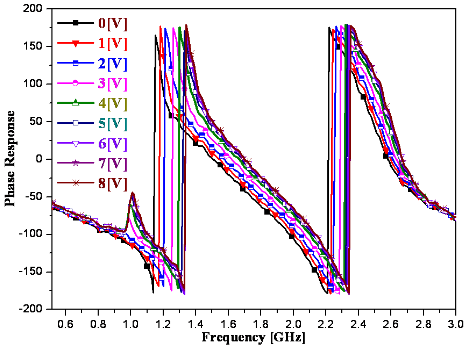
$R_s(V)$ are variable junction capacitance and resistance and C_p and L_p are parasitic capacitance and inductance, respectively [10].

Fig. 6 shows the proposed phase shifter with varactor diode using the compact branch-line coupler. From the figure, the proposed phase shifter has the reflection type and compact size. Port 1 and port 2 are input and output ports, and port 3 and port 4 are thru and isolation ports, respectively. Thus, ports 3 and 4 are coupled to the load and bias circuits of the varactor diodes (1SV306).

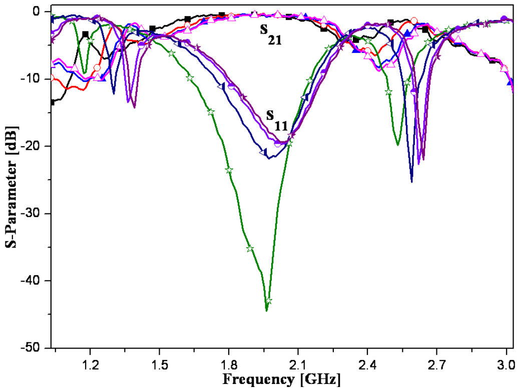
IV. EXPERIMENTAL RESULTS

Fig. 7 shows the experimental results for the proposed phase shifter with a compact branch-line coupler using a T-shaped meander line. From the figure, the measured insertion loss is between 0.19 dB and 0.28 dB at the center frequency of 2.1 GHz. The measured return loss is under 19.2 dB.

The measured maximum phase shift is 137°. The simulation was carried out using Agilent *ADS 2010 tools*, and an HP-8510 C Vector Network Analyzer was used for the measurement of the branch-line coupler and phase shifter [11].



(a)

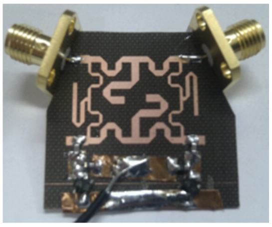


(b)

〈그림 7〉 제안된 위상응답의 실험결과 (a) 시뮬레이션, (b) 측정치

〈Fig. 7〉 Experimental results of the proposed phase shifter, (a) phase response and (b) insertion (S_{21}) and return losses (S_{11})

Fig. 8 shows a photograph for the proposed phase shifter. It uses a Teflon substrate with height of 0.54 mm. The conductor thickness is 0.18 mm and the relative dielectric constant is 2.54. The proposed phase shifter has a lower insertion loss than those of the alternatives, as shown in Table 1. From the table, [12] has a high insertion loss and a large bias voltage. [13] shows a slightly higher insertion loss and much higher bias voltage than this work. On the other hand, [14] has a low insertion loss, but its size is much bigger than the proposed circuit. Therefore, important factors in the phase shifter are low insertion loss, miniature size, and low bias voltage.



〈그림 8〉 소형 브랜치 라인 커플러를 이용한 위상 변위기의 제작 사진

〈Fig. 8〉 Photograph of the phase shifter with the compact branch-line coupler

〈표 1〉 제안된 위상변위기와 기존의 위상 변위기들의 삽입손실을 위한 비교

〈Table 1〉 Comparision for insertion losses of the proposed phase shifter and others

Ref [#]	Frequency [GHz]	Insertion loss [dB]	Phase [deg°]	size [mm^2]	Bias Volt.[V]
This work	2.10	0.28	137	22.2×14.9	3.00
[12]	2.00	4.40	409	810×270	5.00
[13]	2.20	1.50	240	4.90×7.50	20.0
[14]	2.56	0.50	3.7	85.0×36.0	-

Ⅴ. CONCLUSION

In this paper, the compact low-loss reflector-type phase shifter has been demonstrated successfully. The T-shaped meander line was used to replace the series quarter-wavelength connecting line with electrical length of 90°.

The T-shaped line works like a band-stop filter at the third harmonic frequency band. Thus, the proposed compact branch-line coupler has better characteristics with the third harmonics rejection than the conventional branch-line coupler. Also, the proposed branch-line coupler has improved characteristics of third harmonics suppression together with compact size.

The phase shifter is coupled to the compact branch-line coupler, varactor diodes, and bias circuits.

The insertion loss is between 0.19 dB and 0.28 dB at the center frequency of 2.1 GHz. The measurement result for maximum phase shift is 137°.

The proposed branch-line coupler and phase shifter can be applied to LTE (Long Term Evolution) mobile communication for smart phone. Due to the entirely planar structure of this coupler and phase shifter, this technique can also perform adequately in MMIC (Monolithic Microwave Integrated Circuit) device applications with low cost.

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