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Session 1C: Application of information technology convergence

14:45 - 17:50, October 20, 2017. Location: CPA Training Room, No1 Teaching Building, STDU. Session Chairs:

Prof. Jongsik Lim (Soonchunhyang University, Korea)

Dr. Guohui Zeng (Shanghai University of Engineering Science, China)

ID.16. Wide viewing angle negative dispersion retarder by stacking layers with opposite birefringence

*Hee Jung Ryu, Yongchae Jeong, Ji-Hoon Lee**

Chonbuk National University, Jeonbuk, Korea

ID.20. A Design of Impedance Transformer with Wide Stopband and $3f_0$ Harmonic Suppression

Changyu Park, Phirun Kim, Yongchae Jeong, Hyongsuk Kim, and Dongsun Park, Jongsik Lim,

[1]*Chonbuk National University Jeonju-si, Republic of Korea*

[2]*Soonchunhyang University Asan-si, Republic of Korea*

ID.21. A Design of Tunable Phase Shifter Using Capacitive Termination

Boram An, Junhyung Jeong, Girdhari Chaudhary, Seok-Hawn Park, Ji-Hoon Lee and Yongchae Jeong

Chonbuk National University

ID.45. Bidirectional Three-Level DC-DC Converter with Capacitor Voltage Balance Control

Myung-Chul Lee, Min-Kwon Yang, Jun Heo and Woo-Young Choi

Chonbuk National University, Jeonju, South Korea

ID.46. High-Efficiency Transformerless DVR with Bidirectional DC-DC Converter

Myung-Chul Lee, Min-Kwon Yang, Jun Heo and Woo-Young Choi

Chonbuk National University, Jeonju, South Korea

ID.77. Design and Implementation of Enterprise Credit Topic Crawler

Zhang Cuixiao1,Li Xuan[1], **Shao Yunxia*[2], *Wang Yunli*[2], *Gao Jing*[1], *Zhao Guangzhen*[1]

[1]*Shijiazhuang Tiedao University, Shijiazhuang China*

[2]*Hebei Academy of Sciences Shijiazhuang China*

ID.94. Intelligent management system for small gardens Based on Multi-sensor fusion

Xiao-hui ZENG[1,2]*, *Jing-xiang LV*[1,2], *Wen-lang LUO*[1,2]*

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A Design of Tunable Phase Shifter Using Capacitive Termination

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***Abstract*—In this work, we proposed a reflection-type tunable phase shifter using reflection loads. From the analytical analysis, it is shown that the characteristic impedance and coupling coefficient of the coupled line determines the maximum relative phase shift and phase deviation. The fabricated tunable phase shifter shows a maximum relative phase shift of 90.3° with phase deviation and insertion loss of ± 6.3° and 1.7 dB, respectively in 200 MHz bandwidth.**

***Index Terms*—Coupled line, maximum relative phase shift, phase deviation, tunable phase shifter.**

I. Introduction

THE phase shifter is a basic building circuit to control a phase of the signal in RF/Microwave circuits and systems. As systems for handling multiple bands increase, a continuously tunable phase shifter is more required and have been widely studied in literatures [1]-[5]. The reflection-type phase shifter which consists with hybrid coupler and reflection load is widely used because of its good return loss characteristics.

In addition to the return loss characteristics, the ideal phase shifter must simultaneously satisfy a wide phase shifting range, small phase deviation and insertion loss over a wide operating frequency bandwidth (BW). In previous, reflection loads consisting of a transmission line and varactor diodes were proposed [1][2]. To obtain a wide phase shifting range such as 360° or more in [1], many varactor diodes are required, which can increase the insertion loss. Similarly, ladder-type reflection load was used to obtain wide phase shifting range in [2] which increased circuit size and insertion loss.

Several methods of modifying the hybrid coupler to get the wide phase shifting range were proposed in [3] and [4]. However, these works have large phase deviations in the operating frequency band. Although the small phase deviation within the BW of 500 MHz was achieved by using a parallel coupled line in [4], the phase shifting range was limited to 45° and the return loss (< - 6 dB) was poor. Since the practical tunable phase shifter is difficult to design by satisfying all ideal requirements, a trade-off occurs among them.

We propose the tunable phase shifter which consists of hybrid coupler, coupled line, and varactor diode. Both analytical analysis and experimental results are presented to validate the proposed structures. Based on the analytical analysis, it is shown that small phase deviation and wide phase shifting range can be obtained by selecting characteristic impedance and coupling coefficient of coupled line.

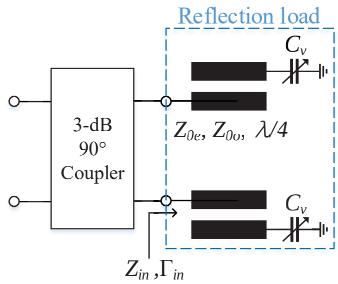

Fig. 1. Schematic of proposed tunable phase shifter.

II. Design Method

Fig. 1 shows a schematic of proposed tunable phase shifter which consists of 90° coupler and reflection load. The reflection load is composed of a λ/4 coupled line and a variable capacitor which is implemented with varactor diodes. The transmission phase of the entire circuit is obtained from the reflection coefficient Γ_{in} of reflection load as follows.

$$\varphi_{in} = 2\tan^{-1}\left\{\frac{1}{Z_0}\left(\frac{Z_{0e}+Z_{0o}}{2}\cot\frac{\pi f}{2 f_0} - \frac{\left(\frac{Z_{0e}-Z_{0o}}{2}\right)^2 \csc^2\frac{\pi f}{2 f_0}}{\left(\frac{Z_{0e}+Z_{0o}}{2}\cot\frac{\pi f}{2 f_0}+\frac{1}{\omega C_v}\right)}\right)\right\}, \quad (2)$$

where Z_{0e}, Z_{0o}, and C_v are the even and odd mode impedances of coupled line, and the equivalent capacitance, respectively. The Z_{0e} and Z_{0o} can be replaced with the characteristics impedance Z_C and coupling coefficient C as follows.

$$Z_{0e} = Z_C \frac{1+C}{C} \quad (3a)$$

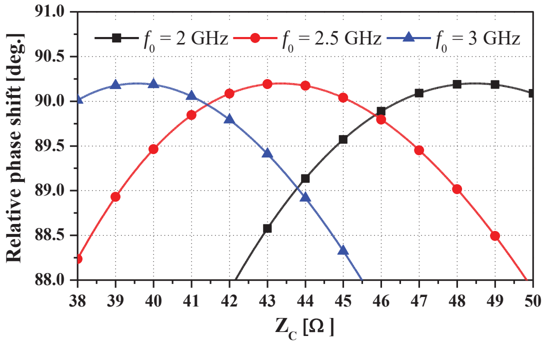

Fig. 2. Maximum phase shifting ranges at each f_0 according to Z_C in conditions of C_{min} = 0.7 pF and C_{max} = 4.1 pF.

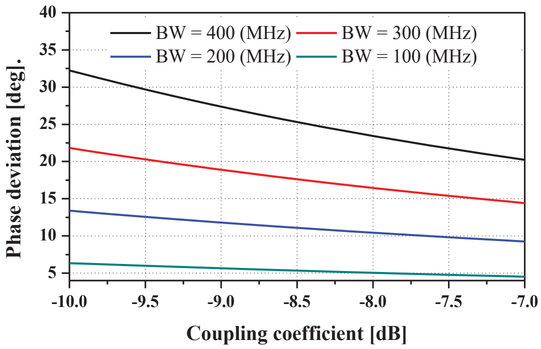

Fig. 3. Phase deviations according to coupling coefficient and bandwidth in phase shifting range of 90°, namely Z_C = 41.46 Ω.

$$Z_{0o} = Z_C \frac{1-C}{C} \tag{3b}$$

By substituting (3a) and (3b) in (2), the maximum phase shifting range at f_0 can be derived as (4) when C_v changes from $C_{\min}$ to $C_{\max}$.

$$\Delta\varphi_{in\_\max}\Big|_{f=f_0} = 2\tan^{-1}\left\{\frac{\omega_0^{\,2} Z_0 Z_C^{\,2}\left(C_{\max}-C_{\min}\right)}{Z_0^{\,2}+Z_C^{\,4}\omega_0^{\,2}\left(C_{\max}C_{\min}\right)}\right\} \tag{4}$$

The phase deviation within operating BW (f_0 - $BW/2 < f < f_0$ - $BW/2$) can be expressed as the difference between maximum and the minimum value of phase shift within the operating BW and mathematically defined as (5).

$$\varphi_{err} = \max\left(\varphi_{in\_\max}\Big|_{f_0-\frac{BW}{2}<f<f_0+\frac{BW}{2}}\right) - \min\left(\varphi_{in\_\max}\Big|_{f_0-\frac{BW}{2}<f<f_0+\frac{BW}{2}}\right) \tag{5}$$

Fig. 2 shows phase shifting ranges at each f_0 according to Z_C. In this calculation, the variation of capacitor is fixed as $C_{\min}$ = 0.7 pF and $C_{\max}$ = 4.1 pF. From this design graph, a designer can choose appropriate Z_C for the required maximum phase shifting range. For example, Z_C is selected as 41.46 Ω in order to obtain the desired phase shifting range of 90° at 2.5 GHz. Then the appropriate coupling coefficient of coupled line for the desired phase deviation with the operating BW can be selected from Fig. 3. As seen from Fig. 3, the phase deviation is small as the BW is narrow and the coupling coefficient is high. However, tight coupling coupled line is difficult to implement in microstrip technology due to very narrow width and spacing between the coupled lines.

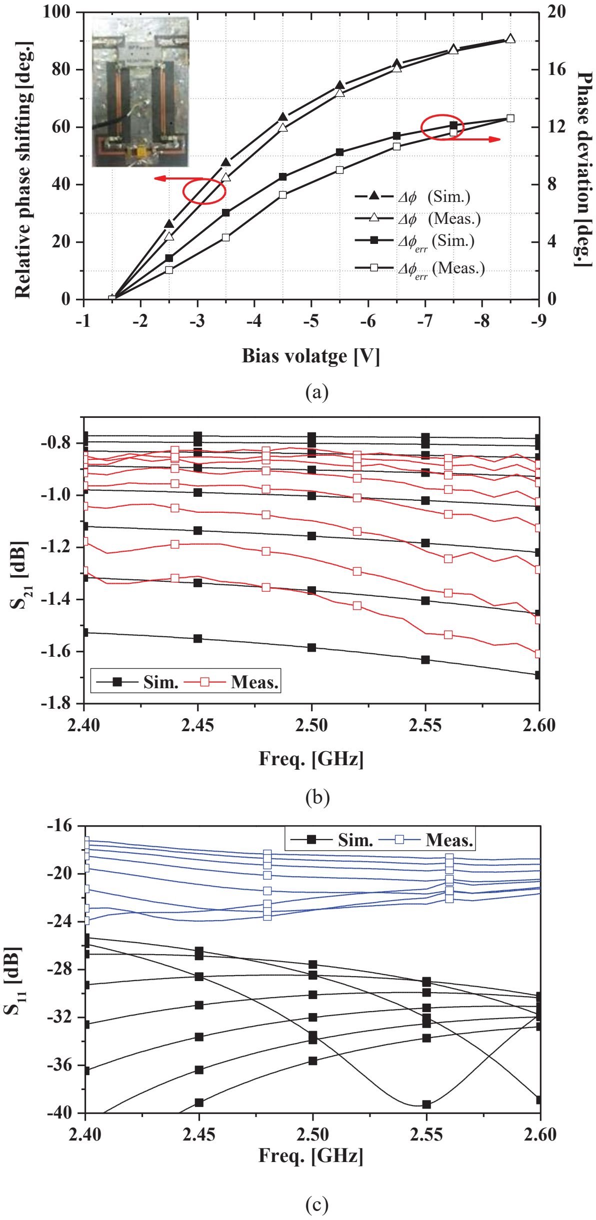

Fig. 5. Simulation and measurement results: (a) phase shifting range at 2.5 GHz and phase deviation within 200 MHz, (b) insertion loss, and (c) return loss.

The variable capacitor can be implemented by using varactor diodes. Since the parasitic components of varactor diode increase the insertion loss, a parallel connection of diodes is a good way to reduce the parasitic components.

III. Simulation and Measurement

For experimental validation, the 90° tunable phase shifter operating at f_0 of 2.5 GHz and having phase deviation less than ± 6° within the BW of 200MHz was designed, simulated, and measured. From Fig. 2 and 3, Z_C and C were selected as 41.46 Ω and - 8.2 dB, respectively. The circuit was fabricated

TABLE I
PERFORMANCE COMPARISON OF PROPOSED CIRCUIT TO THIS IN PREVIOUS WORKS

	Center freq. [GHz]	Phase variation range [deg.]	Bandwidth [MHz]	Phase deviation [deg.]	Max Insertion loss [dB]	Max Return loss [dB]
[1]	2.25	45	500	10	1.5	6
[2-1]	2	201	200	80	1	11
[2-2]	2	385	200	160	1.6	11
[3]	2.05	400	200	100	3.6	13
[4]	2	237	200	80	6.4	13
This work	**2.5**	**90**	**200**	**12.612**	**1.610**	**17.221**

on the RT/Duroid-5880 substrate with a dielectric constant (ε_r) of 2.2 and thickness (h) of 31 mils. In this work, 3-dB hybrid coupler of S03A2500N1 from Anaren Inc. and varactor diode of SMV-1231 from Skyworks were used.

Fig. 5 shows the simulation, the measurement results, and a photograph of the designed tunable phase shifter by varying bias voltage of the varactor diodes from -1.5 to -8 V. As seen from the figure, the measurements results are well agreed with simulations. From the measurement, the phase shifting range is determined as 90.3° at 2.5 GHz with the phase deviation of less than ± 6.3° over the BW of 200 MHz. Similarly, the measured maximum insertion loss and return losses are 1.61 dB and 17.2 dB, respectively, within the operating BW.

Table I shows the performance comparison of the proposed phase shifter with the state of arts. As seen from this table, the proposed structure provides small phase deviation, low insertion loss, and high return loss among the previous works.

IV. CONCLUSION

This work presents a design of reflection-type tunable phase shifter using coupled line. The fabricated tunable phase shifter can adjust the phase shifting range of 90.33° at 2.5 GHz while maintaining phase deviation less than ± 6.3° within 200 MHz bandwidth. In addition, the proposed phase shifter provides low insertion and high return loss characteristics within the operating bandwidth.

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