BSTO 강유전체에 기반한 Meander-Type 가변 위상 천이기

채동규* · Mai Linh* · 임문혁* · 윤기완*

BSTO Ferroelectric-Based Meander-Type Tunable Phase Shifter

Dongkyu Chai* · Mai Linh* · Munhyuk Yim* · Giwan Yoon*

This work was supported by Korea Research Foundation Grant
(KRF-2002-003-D00229)

요 약

본 논문에서는 강유전체 기반, 마이크로스트립 라인을 이용하여 13~17GHz에 걸친 넓은 주파수 범위에서 삽입 손실이 2dB 이하, 반사 손실이 10dB 이상인 4-coupled 가변 위상 천이기를 제안한다. 특히, 15 GHz에서 위상 천이 편이(DPS)는 0V를 인가하였을 때 89°이었고, 인가 전압을 150V로 증가시켰을 때 115°이었다. 그러므로 위상 천이 편이의 가변성은 26°에 달한다.

ABSTRACT

In this paper, we propose a 4-coupled ferroelectric-based meander-type microstrip-line tunable phase shifter which has less than 2dB of insertion loss (IL) and larger than 10dB of return loss (RL) over 13~17GHz. Particularly at 15GHz, the differential phase shift (DPS) is observed to be 89° at zero bias and it increases up to 115° when 150V is applied. This indicates a DPS tunability of 26°.

키워드

DPS, ferroelectric, tunability, insertion loss, return loss

Ⅰ. Introduction

The role of the phase shifter is to complement the phase error occurring between the transmitter (TX) and receiver (RX) stages, mainly in phased array antennas. Several ways were reported on the implementation of the tunable phase shifters [1,2]. Tunability can be achieved by using ferroelectrics. One of the most widely used ferroelectrics is Barium Strontium Titanate Oxide (BSTO) that can stably operate in room temperature [3-5]. The BSTO/MgO composites offer some advantages over other candidates for the field-tunable technologies such as pure BST

*한국정보통신대학교

접수일자 : 2002. 10. 18

ceramics, Barium Strontium Titanate (BST) thin films, strontinum titanate, and high-temperature superconductors. In other words, the BSTO/MgO composites show a smaller dielectric constant, allowing for the easier impedance matching to air in high-frequency applications in addition to its higher tunability.

In this paper, we propose a novel tunable phase shifter, consisting of CFD (conductor/ferroelectrics/dielectrics) structure and meander-type microstrip-lines. As a result of simulation, the insertion loss (IL) is less than 2 dB and the return loss (RL) is larger than 10 dB in the frequency range of 13 ~ 17 GHz. Particularly at 15 GHz, the differential phase shift (DPS) is observed to be 89° at zero bias and it increases up to 115° when 150 V is applied, which indicates a DPS tunability of 26°. The dimension of the phase shifter is 4.5 mm × 1.4 mm × 0.5 mm.

II. Basic theory of tunable phase shifter

The relative dielectric constant of ferroelectrics decreases as the bias voltage increases. Equations (1), (2), (3) explain how the tunable phase shifter proposed can be achieved. Here, β V-applied is the propagation constant when the positive bias is applied, while β0V is the propagation constant when 0 V is applied. ε r(0V) is the relative dielectric constant for 0 V bias and ε r(V-applied) is the relative dielectric constant for positive bias. Also, L and $\Delta\varphi$ represent the coupling length and DPS, respectively.

$$\beta_{0V} = 2\pi \frac{\sqrt{\varepsilon_{r(0V)}}}{\lambda_o} \quad (1)$$

$$\beta_{V-applied} = 2\pi \frac{\sqrt{\varepsilon_{r(V-applied)}}}{\lambda_o} \quad (2)$$

$$\Delta\phi = (\beta_{0V} - \beta_{V-applied}) \cdot L \quad (3)$$

As ε r(V-applied) tends to decrease with both polarities biasing [3], βV-applied also decreases. Therefore, the DPS ($\Delta\varphi$) increases positively when a voltage is applied. In other words, the $\Delta\varphi$ varies with the applied voltage. On the other hand, equations (4), (5) are needed to calculate the widths of input and output stages for 50 Ω matching [6]. Here, Zo is the matching impedance to air, W is the width of signal line, S is the gap between two signal lines, h is the total height of dielectrics, and ε eff is the effective dielectric constant. It is noted that as h decreases, W also needs to be reduced for 50 Ω matching. Thus, considering the fact that smaller W is more desirable for smaller devices, the smaller components can be easily realized simply by reducing the dielectrics thickness.

$$Z_o = \frac{377}{\sqrt{\varepsilon_{eff}}(1.393 + \frac{W}{h} + \frac{2}{3}\ln(\frac{W}{h} + 1.444))} \quad (4)$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}(1 + 12\frac{h}{W})^{-0.5} \quad (5)$$

III. Design procedure and operation

The design procedures and operations of the proposed phase shifter are as follows: i) To obtain tunability, BSTO film was selected as a ferroelectrics because of its stable operability at room temperature. ii) To determine the desirable coupling length of tunable phase shifter (L1) and reference guide (L2), the ε eff was selected as 14.1 at 0 V. iii) To increase the DPS tunability, the cascaded multiple couplings (4 couplings) were used. Fig. 1 (a) shows the side view and dimensions of the proposed tunable phase shifter. The thickness of upper microstrip line is 1 ㎛, that of BSTO is 0.5 ㎛, that of MgO is 500 ㎛, and that of the lowest positioned ground plane is 2 ㎛. The relative dielectric constant of MgO ($\varepsilon r2$) is 10, and that of BSTO ($\varepsilon r1$) varies according to the biased voltage [5]. There exist mutual capacitances between the couplings. As the number of couplings increases, so does the number of mutual capacitance. The increase in mutual capacitance widens the tuning range of the phase shifter. To the contrast of the increased tunability, the characteristics of IL and RL become increasingly worse mainly due to the increased loss of conductors. Fig. 1 (b) shows the top view of the phase shifter and reference guide designed. Instead of the straight line structure [5], the meandering-type line without any open stubs was employed in order to reduce the device size as small as possible. The width of the input/output stages for 50 Ω matching is 110 ㎛, L1 is 794.8 ㎛ for 89° with 0 V biased, L2 is 1000 ㎛, and the other dimensions are shown in Fig. 1 (b). The εeff is 14.1 at 0 V, and it decreases up to 13.1 as the bias voltage increases up to 150 V. The conversion between the phase shifter and reference guide is made by an electronic switch with high speed and low loss.

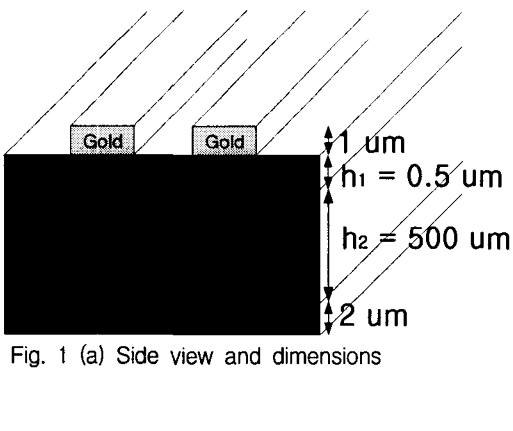

Fig. 1 (a) Side view and dimensions

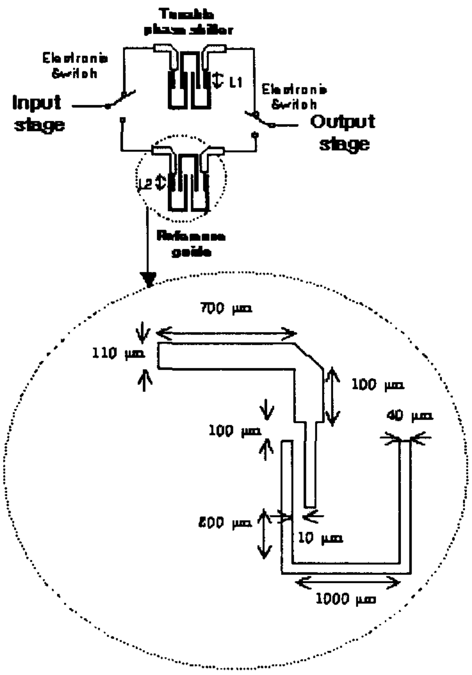

Fig. 1 (b) Top view of the tunable phase shifter and reference guide with 4 couplings (input/output widths = 110 ㎛ for 50 matching; L1 = 794.8 ㎛, L2 = 1000 ㎛ for 89 DPS with 0 V biased)

Fig. 2 depicts the IL characteristics of the phase shifter for the variation of εeff, 14.1 ~ 13.1 with step of 0.2. Overall, less than 2 dB of IL was obtained. The five lines are almost overlapped and indistinguishable, meaning no significant impact of the effective dielectric constant on the IL.

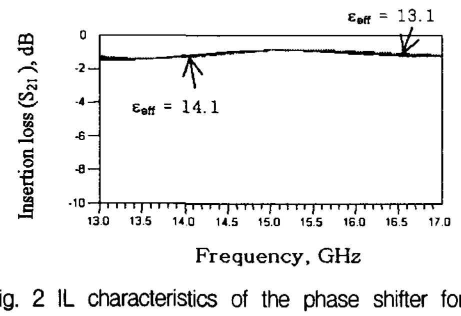

Fig. 2 IL characteristics of the phase shifter for the variations of εeff, 14.1~13.1 with step of 0.2

Fig. 3 illustrates the RL characteristics of the phase shifter where the RL is larger than 10 dB in the frequency of 13~17GHz. The largest value of 30 dB appears near the center frequency (15 GHz). The smaller ε eff results in the higher resonant frequency.

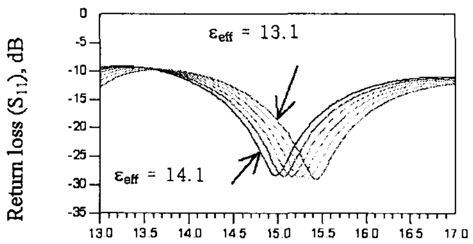

Fig. 3 RL characteristics of the phase shifter for the variations of ε eff, 14.1~13.1 with step of 0.2

Fig. 4 shows the dependence of the DPS characteristics on the effective dielectric constant. At 15 GHz and for ε eff = 14.1, the DPS is found to be 89° . As the ε eff decreases, the DPS also increases. Near the center frequency (15 GHz), the DPS appears flat. When the ε eff decreases to 13.1, the DPS is found to be 115° . Thus, the tuning range of the phase shifter comes up to 26° .

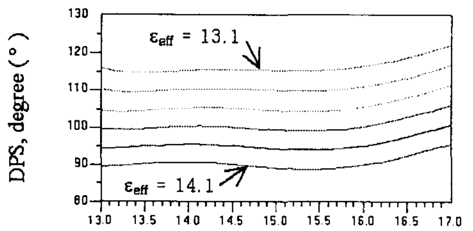

Fig. 4 DPS characteristics of the phase shifter for the variations of ε eff, 14.1~13.1 with step of 0.2

IV. Conclusion

We designed a 4-coupled microstrip line tunable phase shifter using HP ADS. The center frequency is 15 GHz and the frequency range of interest is from 13 GHz to 17 GHz. In this frequency band, the insertion loss is found to be less than 2 dB over the value of ε eff, 14.1 ~ 13.1. In addition, the overall tuning range of phase shifter comes up to 26° . The proposed phase shifter seems very promising for wireless communication applications.

References

[1] B. Acikel, and Liu Yu, "Phase shifters using (Ba,Sr)TiO3 thin films on sapphire and glass substrates", IEEE MTT-S Int. Microwave Symp. Dig., pp. 1191-1194, 2001.

[2] A. Kozyrev, V. Osadchy, and A. Pavlov, " Application of ferroelectrics in phase shifter design", IEEE MTT-S Int. Microwave Symp. Dig., pp. 1355-1358, 2000.

[3] I. Wooldridge and C. W. Turner, "Electrical tuning of passive HTS microwave devices using single crystal strontium titanate", IEEE Trans. Appl. Supercond., vol. 9, no. 2, pp. 3220-3223, 1999.

[4] F. A. Miranda, and G. Subramanyam," Design and development of ferroelectric tunable microwave components for Ku- and K- band satellite communication systems", IEEE Trans., MTT-48, pp. 1181-1189, 2000.

[5] F. W. Van Keuls, and R. R. Romanofsky, " A Ku-Band Gold/$Ba_xSr_{1-x}TiO_3$/$LaAlO_3$. conductor/ thin film ferroelectric microstrip line phase shifter for room-temperature communications applications, Microwave. Opt. Technol. Lett., vol. 20, no. 1, pp. 53-56, 1999.

[6] R. Ludwig, and P. Bretchko, "RF circuit design", Prentice Hall, 2000.

저자소개

Dongkyu Chai

1999: BS in Electronic Engineering, Kyongbook University, Korea

2001~: ICU, Korea

※Area of interest: Thin Film Bandpass Filter/ Phase Shifter, Smart Sensors

Mai Linh

1996: BS in Natural Science, Hanoi University, Vietnam

199: MS in ITIMS, Vietnam

2001~: PhD Course in ICU, Korea

※Area of interest: Smart Sensors, Thin Film BPF

Munhyuk Yim

2002: BS in Material Engineering, Chungnam National University

2002~: MS Course in ICU, Korea

※Area of interest: FBAR, Thin Film BPF

Giwan Yoon

1983: BS in Seoul National University

1985: MS in KAIST

1994: PhD in The University of Texas at Austin, USA

1985~1990: Associate Engineer, LG Group, Semiconductor Research Center

1990~1994: Research Assistant, University of Texas at Austin, Microelectronics Center

1994~1997: Senior Engineer, Digital Equipment Corp. (Presently Intel), USA

1997~2000: Assistant Professor, Information and Communications University, Korea

2000~: Associate Professor in ICU, Korea

※Area of interest: RF Technology, Smart Antenna, Smart Sensors, Bioelectronics