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High Resolution Tunable MEMS Phase Shifters for Radar Phased Array Antenna

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Abstract: The paper proposes a high resolution tunable MicroElectroMechanical Systems (MEMS) phase shifters for radar phased array antenna to steer the beam. Two phase shifters are considered the first is a switched line phase shifter; the second is a reflection type phase shifter. The resolution of the designed phase shifters is two degree phase shift using 8 bit control circuitry. The proposed circuit is based on dividing the tuning range into coarse and fine tuning sections which change the phase by 30^o and 2^o steps respectively to achieve the desired phase. A microstrip phase shifters have been designed at 3 GHz suitable for surveillance radar applications. The development of RF MEMS switches over the past years has enabled system designers to consider replacing the GaAs phase shifters with RF MEMS phase shifters. MEMS phase shifter exhibit excellent characteristics, including low insertion loss and low DC power consumption. The designed phase shifters are simulated and tested using Advance Design System circuit simulation package (ADS) and the results demonstrated using the graphics capability of Matlab Program. The results show that the worst case insertion loss is less than 0.17 dB and 0.05 dB for switched line and reflection type phase shifters respectively. The return loss for the two proposed phase shifters is less than -60 dB.

Keywords: Phased Array Antenna, MEMS Switch, Switched Line Phase Shifter, Reflection Type Phase Shifter, ADS, Radar.

1. Introduction

Phased array antennas use electronic, mechanical, or material switches to alter the phase of individual radiating elements across an antenna, and in so doing, enable the radiated beam to steer [1]. Radar systems incorporating phased arrays will enable greater efficiency and elevation while azimuth scanning. In the past decade, RF MicroElectroMechanical (MEMs) switches have been widely used in phase. The use of MEMS phase shifters in a phased array offers some advantages. First, MEMS phase shifters have low-loss performance with nearly zero dc power consumption compared to semiconductor-based counterparts [2-3]. Moreover, MEMS phase shifters are suitable for monolithic phased-array designs with their reduced cost and volume compared to semiconductor- and ferrite-based counterparts. Phase shifters have been published on various materials, including silicon and GaAs. Various switching elements have been used including FETs, PIN diodes, and in recent years MEMS [4-8]. This paper is

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devoted to design and simulate high resolution tunable phase shifters for radar phased array. The designed phase shifters are switched line phase shifter and reflection type phase shifter. The resolution of the designed phase shifters is two degree phase shift using 8 bit control circuitry. The designed phase shifters are simulated and tested using circuit simulation program (ADS). Advanced Design System (ADS) is an electronic design automation software system produced by Agilent EESOF EDA [9], a unit of Agilent Technologies. It provides an integrated design environment to designers of RF electronic products such as, satellite communications, radar systems, and high-speed data link.
The results show that the proposed phase shifters perform the phase shifting mechanism with high degree of accuracy and low insertion and return loss.

2. Phase Shifters Theory

Switched Line Phase Shifter:

Switched-line phase shifters are time delay circuits. Phase shift is achieved by passing the signal through different transmission line lengths. The phase delay $\Delta\phi$ between the two States is $\beta(L_1-L_2)$ where $\beta = 2\pi/\lambda$ is the propagation constant of the transmission line and L_1 and L_2 are the physical lengths. A simple switched-line phase shifter is shown in Fig. 1. The phase shift can easily be computed from the difference in the electrical lengths of the reference arm and the delay arm. The phase of any transmission line is equal to its length times its propagation constant; typically we use electrical degrees for this, not radians. Single Pole, Double Throw (SPDT) switches can be realized in a wide variety of ways, using FET, diode, or MEMS (micro-electro-mechanical systems) switches. The combined isolation of the two switches must exceed 20 dB in the design frequency band, or there will be ripple in the amplitude and phase response due to leakage of the "off" arm, sensitivities to FET parameters, etc. [10].

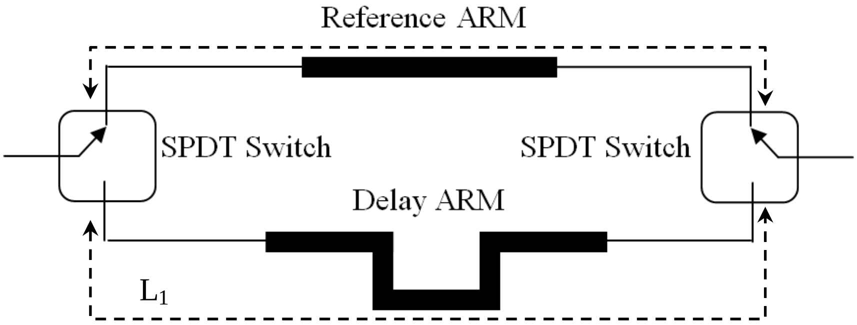

Fig. 1. Switched line phase shifter principle

MEMS can essentially be used to replace PIN diode or FET switches in conventional phase shifters. A typical switch consists of a metal membrane bridge suspended several microns above a lower metal contact. Electrostatic attraction between the flexible membrane and lower contact is used to toggle the switch. Typical actuation voltages are between 20 and 100 V. An interesting advantage of MEMS switches is that they do not depend on the characteristics of the substrate. Hence, they may be fabricated on any material that is compatible with standard IC processing [11]. A photograph of one type of MEMS switch is shown in Fig. 2.

Reflection Type Phase Shifter:

An example of a reflection-type phase shifter is shown in Fig. 3. Changing the state of the switch changes the reflection coefficient of the reflective network. This causes a change in phase delay between the two states. The phase difference $\Delta\phi$, the circulator routes the input signal to the reflective network and the reflection from the network is routed to the output port. For an ideal circulator, the transmission coefficient from the input to the output is equal to the reflection coefficient Γ of the reflective network.

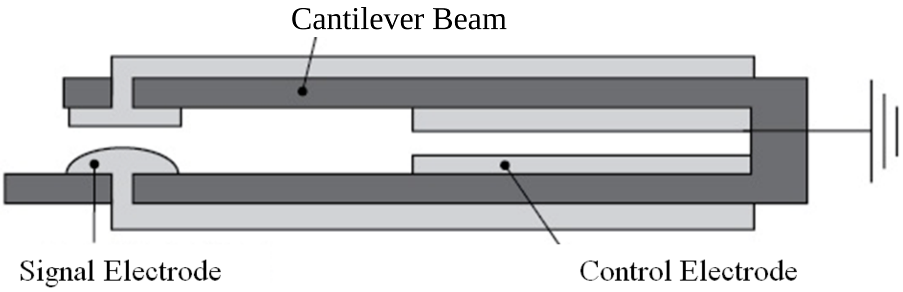

Fig. 2. MEMS switch structure

The simplest design for a real-time-delay phase shifter uses a circulator to provide matched input and output for the switched elements, as shown in Fig. 3. The MEMS switches are used as either short circuits or open circuits over a finite transmission line width. Dependence on a section of line for the time delay causes a bandwidth limitation on this class of phase shifters [12].

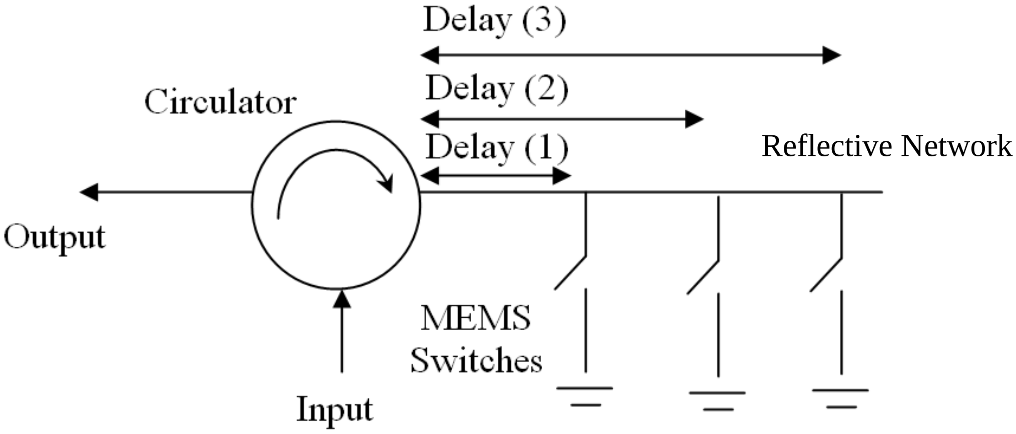

Fig. 3. Reflection type phase shifter (Circulator Type)

3. The Phase Shifters Structure

The proposed phase shifters schematic diagram are illustrated in Figs. 4,5. The switched line phase shifter consists of twelve coarse delay transmission line elements from, 30 to 360 degree with 30 degree step. The fine delay transmission line elements are 2 degree resolution and consist of 15 elements from 0 to 28 with 2 degree step. A couple of MEMS switches for each element control the phase shift value required for steering the antenna beam pattern. A digital control circuit plays an important function during the phase change mechanism. The control circuit is a decoder circuit converts the code word to control signals open and close the MEMS switches. If the required phase is 62 degree then the control circuit choose to close the MEMS switches of the 60 degree element and the other one switch of the 2 degree element, then the total phase shift satisfied is 62 degree. The circulator coupled phase shifter shown in Fig. 5. Consists of two main paths. The first path is the coarse path which introduce phase shift of 30 degree from each element, controlling the switching of these elements implies a phase shift equal to the accumulation of the shifts. Similarly the fine path with 14 phase shift elements 2 degree each of them introduces a total of 28 degree. If the desired phase is 84 degree the control circuit has to close the first two switches from the coarse path and the first twelve switches from the fine path.

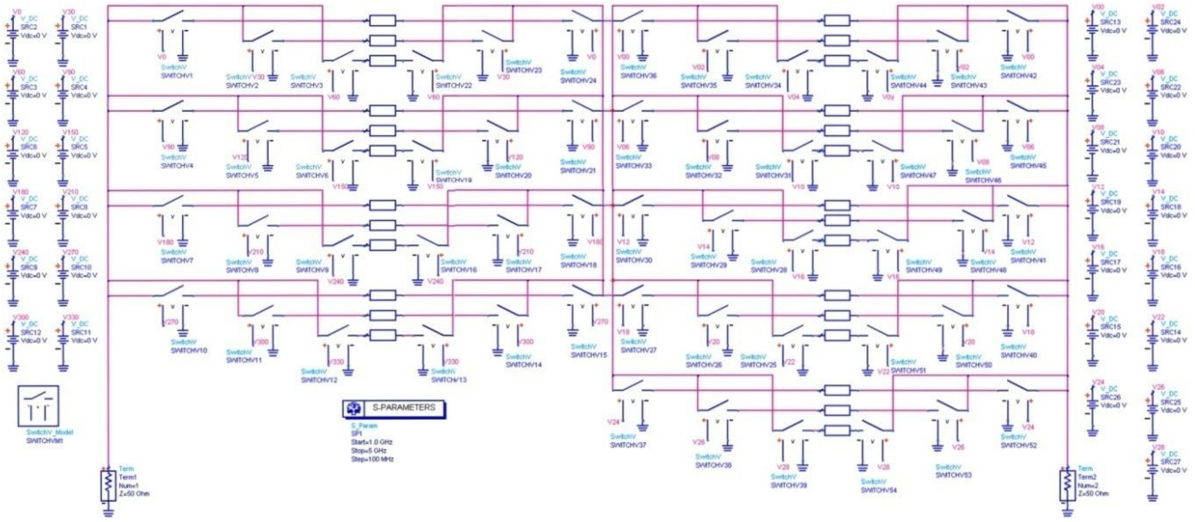

Fig. 4. Switched line phase shifter schematic diagram

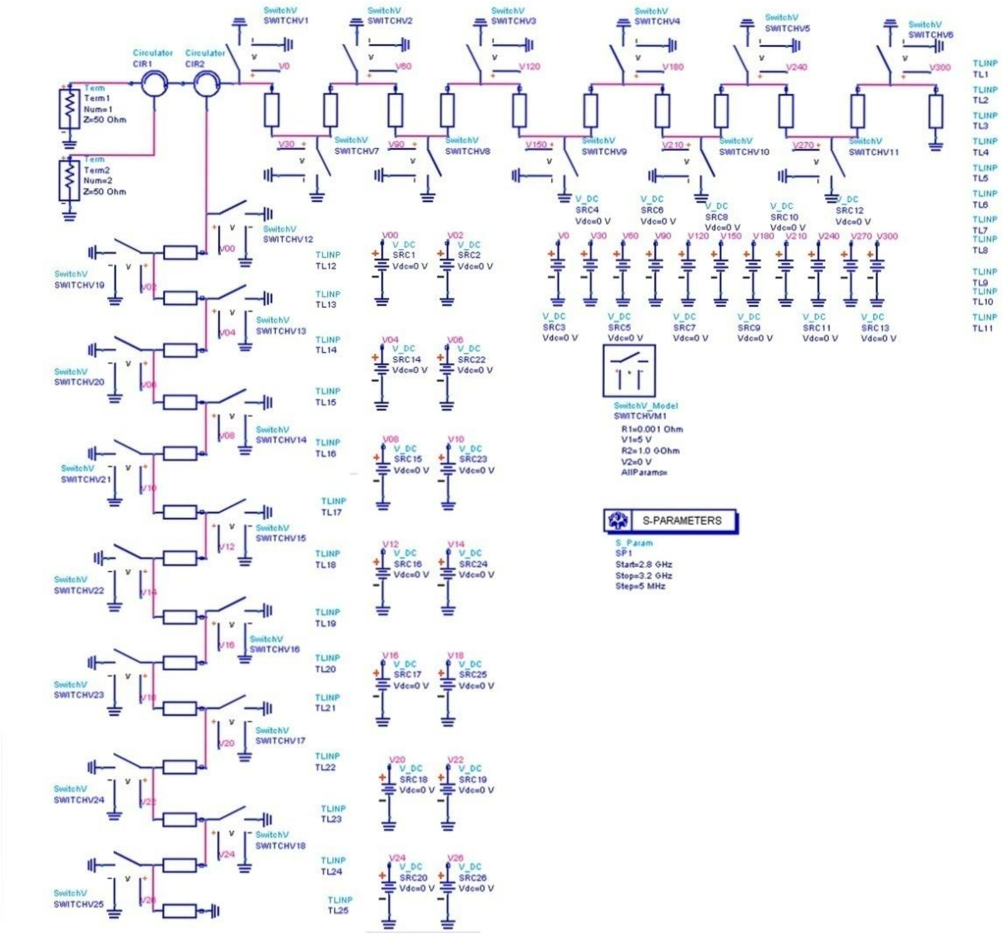

Fig. 5. Circulator coupled phase shifter schematic diagram.

4. Results

Switched line phase shifter (SLPS) is tested at four different phases angles 18, 128, 274, and 324 degree. Total insertion loss of the SLPS is demonstrated in Fig. 6. It is clear that the insertion loss is less than 0.11 for all tested phases. Fig. 7 shows the total return loss of the SLPS, which indicates that, its value less than -60 dB for all testes phases. S21 phase is presented for four tested phases in Figs 8 to11. Circulator couples phase shifter (CCPS) is tested with the same four angles. The total insertion loss demonstrated in Fig. 12 and it is clear that it is nearly 0 dB which behaves better than SLPS. Also the total return loss less than -100 dB for all cases as shown in Fig. 13. S21 phase for two test angles is demonstrated in Figs 14 to 15. A comparison between the insertion losses for the proposed phase shifters is shown in Fig. 16. It is clear that the CCPS outperforms the SLPS by more than -0.14 dB. The total return loss for the phase shifters is shown in Fig. 17. Which indicates that CCPS has lower by more than -40 dB. The reflection coefficient and the transmission coefficient of the phase shifters compared with other phase shifter published [13], which used a FET as switching device and illustrated in Table (1). MEMS phase shifter exhibit excellent characteristics.

Table (1)

	SLPS	CCPS	Phase shifter [13]
S_{11} (dB)	-60	-100	-5
S_{21} (dB)	-0.16	-0.06	-17

5. Conclusion

The paper proposes a high resolution tunable MicroElectroMechanical Systems (MEMS) phase shifters for radar phased array antenna to steer the beam. The designed phase shifters are switched line phase shifter and reflection type phase shifter. The resolution of the designed phase shifters is two degree phase shift using 8 bit control circuitry. The proposed circuit is based on dividing the tuning range into coarse and fine tuning sections which change the phase by 30^o and 2^o steps respectively to achieve the desired phase. A microstrip phase shifters have been designed at 3 GHz suitable for surveillance radar applications. The designed phase shifters are simulated and tested using Advance Design System circuit simulation package (ADS) and the results demonstrated using the graphics capability of Matlab Program. The results show that the worst case insertion loss is less than 0.17 dB and 0.05 dB for switched line and reflection type phase shifters respectively. The return loss for the two proposed phase shifters is less than -60 dB.

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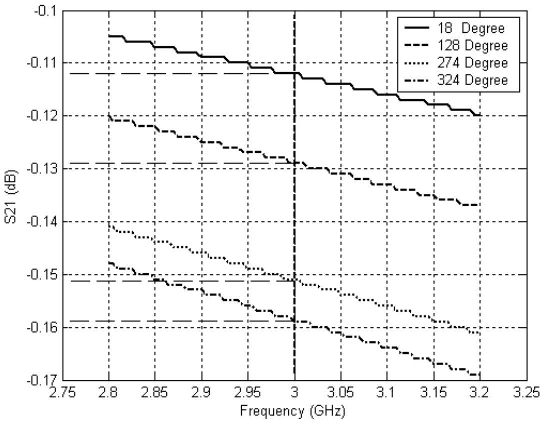

Fig. 6 Total insertion loss of SLPS

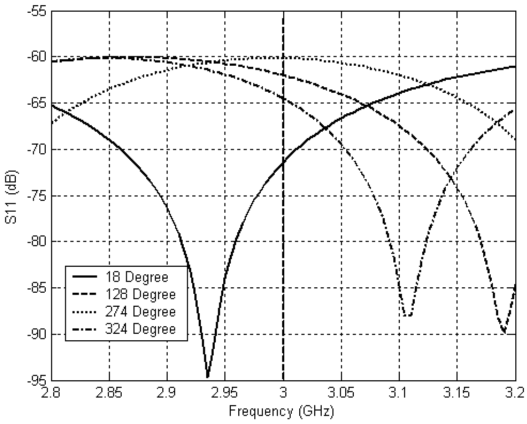

Fig. 7 Total Return loss of SLPS

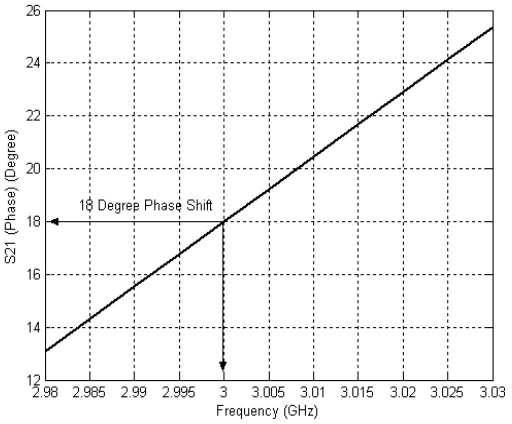

Fig. 8 SLPS Phase at 18 deg. phase shift

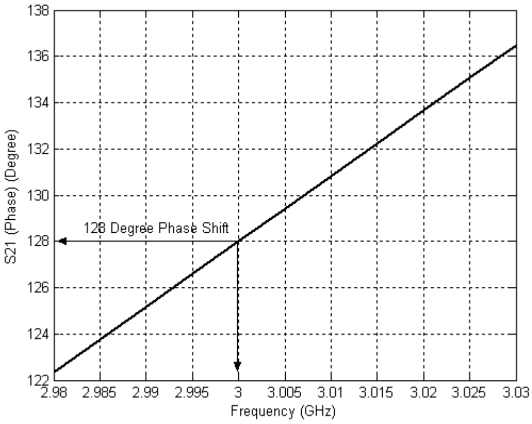

Fig. 9 SLPS Phase at 128 deg. phase shift

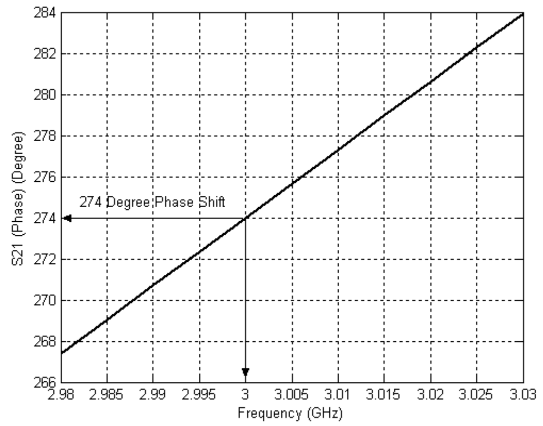

Fig. 10 SLPS Phase at 274 deg. phase shift

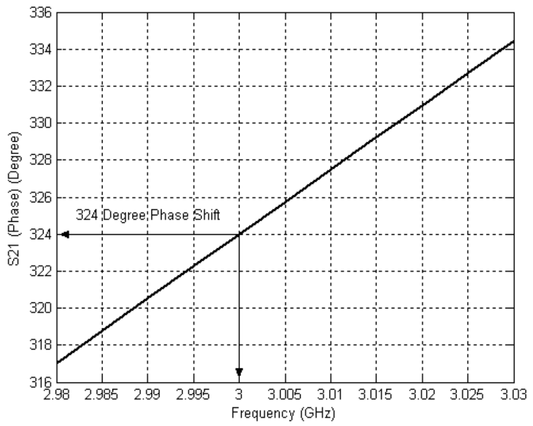

Fig. 11 SLPS Phase at 324 deg. phase shift

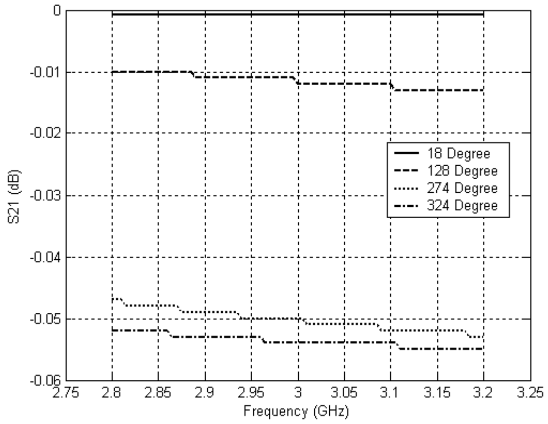

Fig. 12 Total insertion loss of CCPS

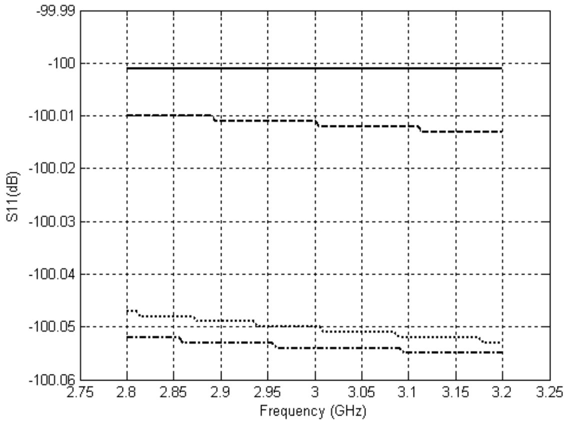

Fig. 13 Total Return loss of CCPS

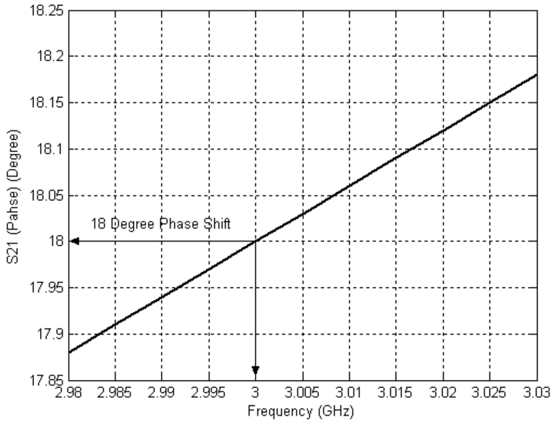

Fig. 14 CCPS Phase at 18 deg. phase shift

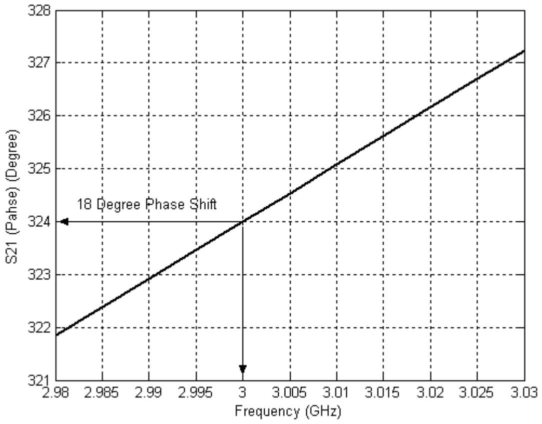

Fig. 15 CCPS Phase at 128 deg. phase shift

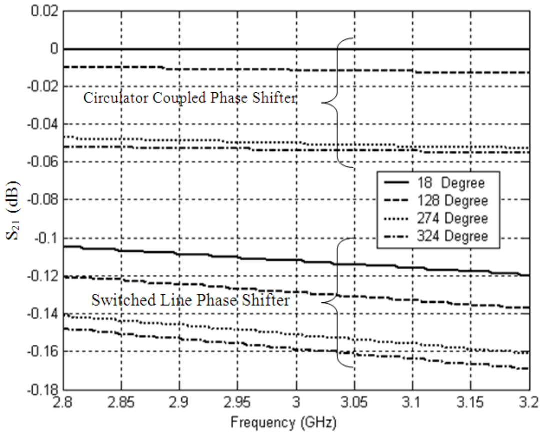

Fig. 16 Comparison of S21 for the proposed phase shifters

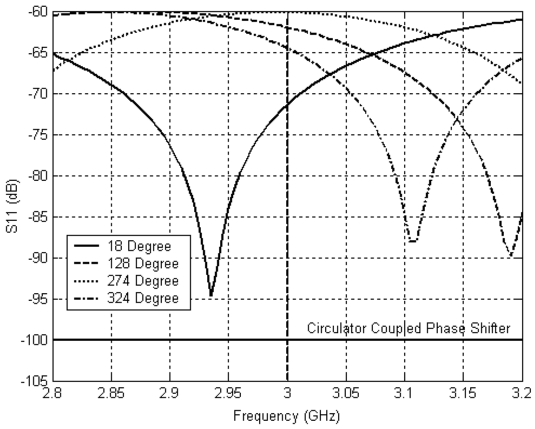

Fig. 17 Comparison of S11 for the proposed phase shifters