Design of 4 Bit Digital Phase Shifter at 2.85 GHz Using Lumped Network for Beamforming

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Abstract— This Paper Demonstrates design and simulation of 4-bit digital phase shifter at 2.85 GHz using lumped components for beamforming. The phase shifter is developed using high pass/low pass technique. BAP51-02 PIN diode used to implement Single pole double through switches and Industrial components used as Lumped components. For demonstration purposes, a 45° phase shifter is designed with BAP51-02 PIN diode switches in ADS (Advanced Design System) software.
Key words: Phase shifter, PIN diodes, Lumped Network

I. Introduction

Phase shifter is an important part of phased array antennas, radars and beam forming networks. Phase shifter circuit changes the direction of radiation of the signal passing through it by changing the phase of the signal. Many techniques have been developed to design a phase shifters such as switched line, reflection type, loaded line, lumped Element high pass-low-pass phase Shifter [1].All the phase shifters except the high pass-low-pass phase shifter uses transmission line to provide phase shift in the signal whereas High-pass low-pass phase shifter uses lumped elements like Capacitor ,Inductor. Further high-pass/low-pass phase shifter provides compact size and better bandwidth compared to other type of phase shifters which is useful where size is constraint like phased array antennas used in satellite.

In these phase shifters switches are implemented using either PIN diodes or FET's but PIN diodes have easier biasing and lower cost. The microwave PIN diode's small physical size compared to a wavelength, high switching speed, and low package parasitic reactance, make it an ideal component for use in miniature, broadband RF signal control circuits. In addition, the PIN diode has the ability to control large RF signal power while using much smaller levels of control power. [19]. A PIN diode is a semiconductor device that operates as a variable resistor at RF and Microwave frequencies. A PIN diode is a current controlled device in contrast to a varactor diode which is a voltage controlled device.

PIN Diode and the corresponding Equivalent Circuits is shown in Fig.1

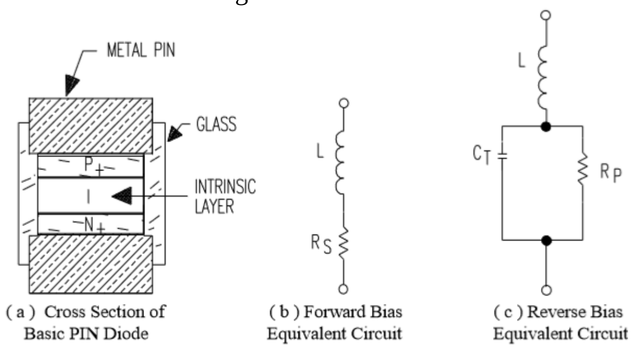

Fig. 1: Schematic showing one-bit section of the 4-bit phase shifter [19]

II. Design Approach

The phase shifter is designed and simulated using high-pass/Low-pass technique at 2.85 GHz for having return loss better than 10 dB, Insertion loss less than 2 dB and Maximum RMS phase error less than 5°.All the simulation and measurements done in Agilent's ADS (Advanced Design System) software 2011.

A. *Topology: High-pass/Low-pass Filter*

This topology was considered suitable for implementation at ISM and S-band frequencies, due to better performance in terms of return loss, insertion loss, and compact size with respect to other phase shifter topologies. Other topologies involving transmission lines for phase shifting resulted in long transmission line lengths at lower GHz frequencies [2].

The high-pass filter in π configuration consists of series capacitor and shunt inductors, and the low-pass filter consists of a series inductor and shunt capacitors. The insertion phase undergoes a phase advance in high-pass filter and a phase delay in low-pass network. Phase shift was obtained by switching between the high-pass and low-pass filter. To provide return path for the DC current and for the implementation of PIN diode switches, a large value of DC blocking capacitor can be used in the high-pass filter. Fig. 2 shows the schematic for one complete bit section of the phase shifter

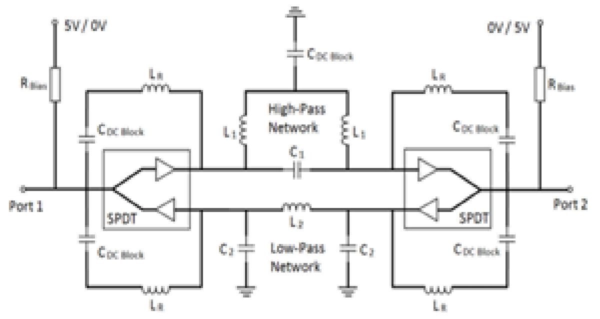

Fig. 2: Schematic showing one bit section of the 4-bit phase shifter [2]

At first High-pass/low-pass filters designed with ideal valued lumped component and then they were replaced with Murata components models from the ADS library. The Murata components model was used because they include the parasitic present in the real components. The Murata component series from which the inductors and capacitors were chosen are Inductors: LQG18 and LQW18 series [17] Capacitors:GQM18 series and GRM18 series(Higher values) [18]

Bit Section	High pass		Low pass	
	L(nH)	C(pF)	L(nH)	C(pF)
22.5°	27	3	1.3	0.1
45°	13	2.2	1.5	0.2
90°	6.8	1.2	1.5	0.6
180°	2.7	1.1	2.7	1.1

Table 1: High-Pass/Low-Pass Component Values

B. SPDT switch

Implementation of the Single Pole Double Throw (SPDT) switch is done with PIN diodes.BAP51-02 PIN diode manufactured by NXP has been modeled and simulated using ADS software with murata resonate inductor to overcome the parasitic capacitance provided by PIN BAP51-02 PIN diode[15].

Fig.3 shows the PIN diode modeling of BAP51-02 Switch in ADS software.PIN diode BAP51-02 provide 190fF parasitic capacitance in OFF state as shown in Fig.4 which can be calculated using Y parameter simulation.

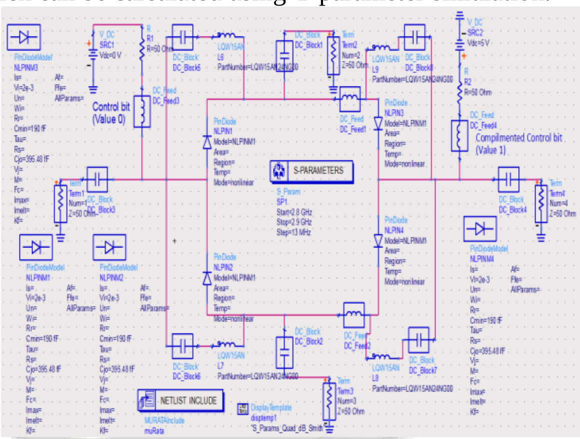

Fig. 3: Schematic setup for BAP51_02 switch with murata resonant inductor

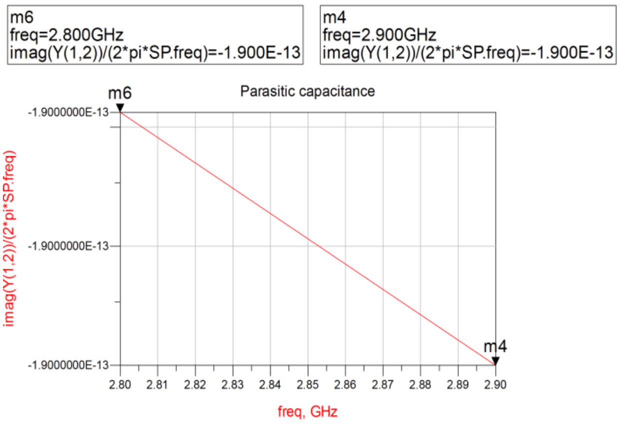

Fig. 4: Parasitic capacitance value of BAP51_02 PIN diode in OFF state

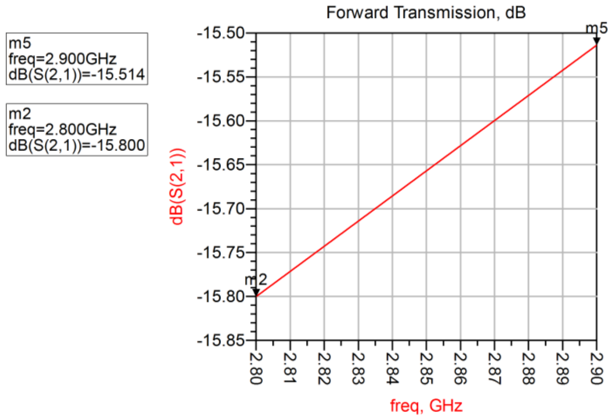

Fig. 5 Insertion loss of BAP51_02 PIN diode in OFF state

The insertion loss is -15.650 dB at 2.85 GHz as shown in Fig.5 which degrading isolation of switch in OFF state.LQW15 series murata Inductor of 24nH is selected as resonate inductor to improve isolation of switch in OFF state.

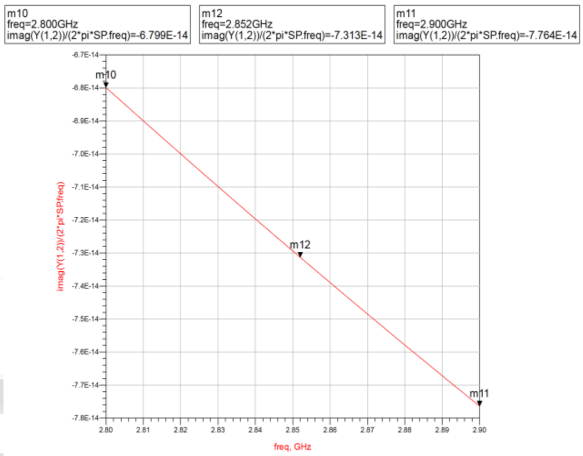

Fig. 6: Reduction in parasitic capacitance with 24nH LQW15AN24NG00 series inductor

Fig. 6 shows that parasitic capacitance is reduced to 73.13fF at 2.85GHz by 24 nH murata Inductor.

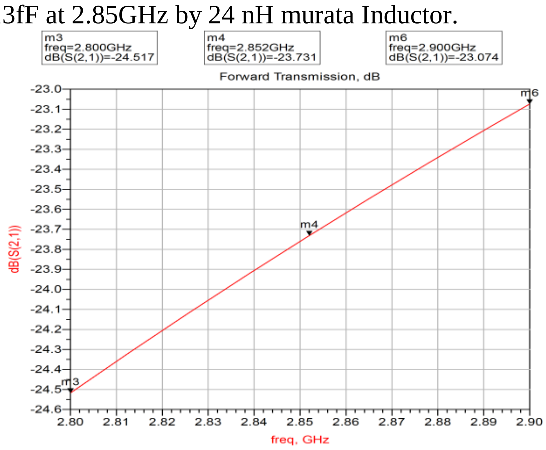

Fig. 7: Increased Insertion loss of BAP51-02 PIN diode in OFF state

Fig.7 shows that Insertion loss of BAP51-02 Increased to -23.731 dB in OFF state which improve the isolation of switch for better switching operation.

III. PHASE SHIFTER DESIGN

The values for L and C obtained from the mathematical calculation using standard formula

$$L1 = \frac{Z0\sin(\phi)}{\omega} \quad (1)$$

$$C1 = \frac{1-\cos(\phi)}{\omega Z0\sin(\phi)} \quad (2)$$

In this work a 45° Phase shifter is designed and simulated using ADS software. The calculated L=1.069 nH and C=0.222 pF for Low-pass filter and L=14.037nH and C=2.291 pF for High-pass filter. Fig. 8 shows the design implementation for lumped network to result in phase shift of 45 degree in ADS.

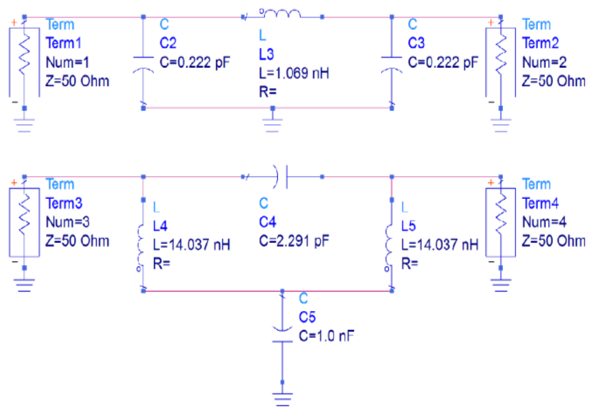

Fig. 8: 45° Phase shifter schematic design in ADS

It is observed from the simulation results shown in Fig.10 and Fig.11 that phase shift achieved is 44.997° with Input and output return loss S(1,1) and S(2,2)better than -73 dB from Fig.9 and insertion loss S(2,1) is -2.124E-7 dB with RMS phase error of 0.4°.

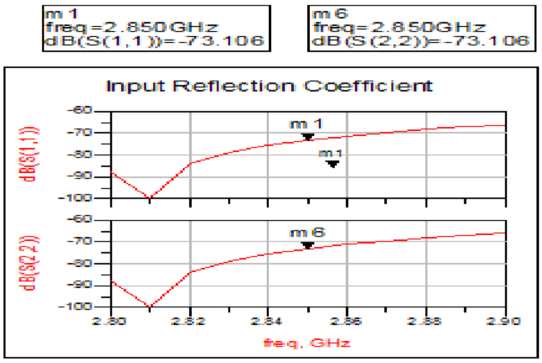

Fig. 9: Input and Output Return loss of 45° Phase Shifter

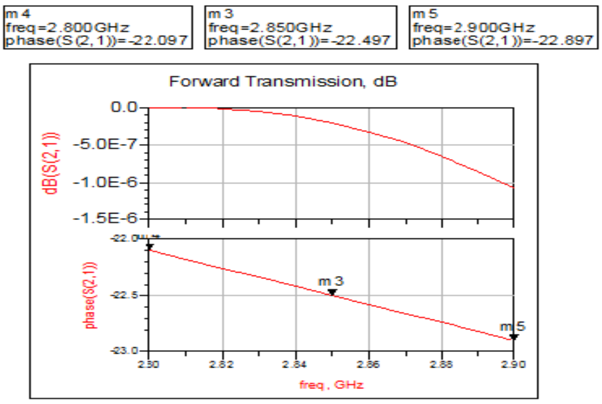

Fig. 10: Phase shift provide by Low pass filter

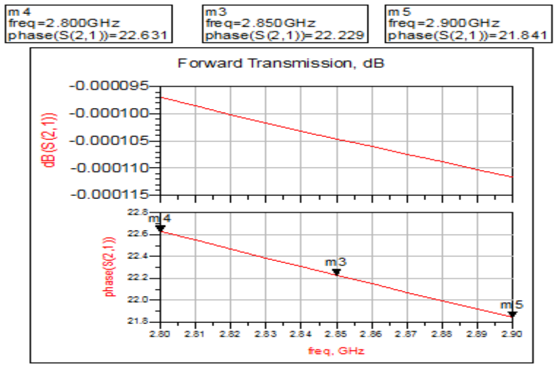

Fig. 11: Phase shift provide by High pass filter

The Lumped components L and C are replaced with Murata components having values from Table I for 45° phase shift

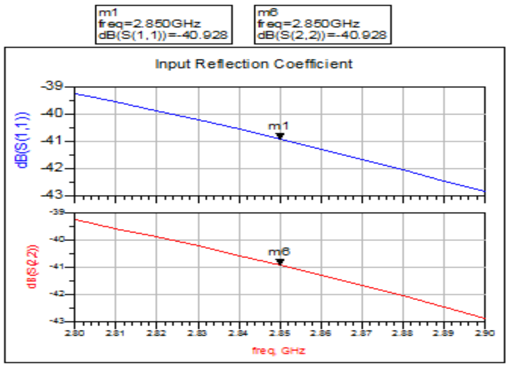

Fig. 12: Input and Output return loss of Murata 45° phase shifter

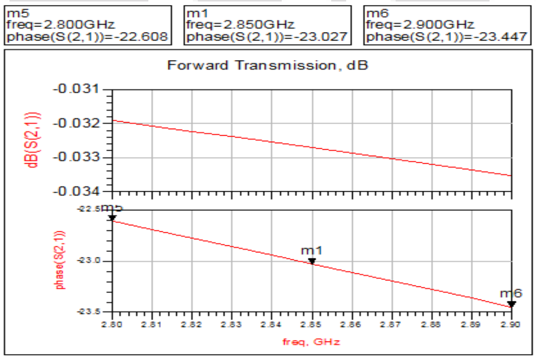

Fig. 13: Phase shift provided by Murata Low pass filter

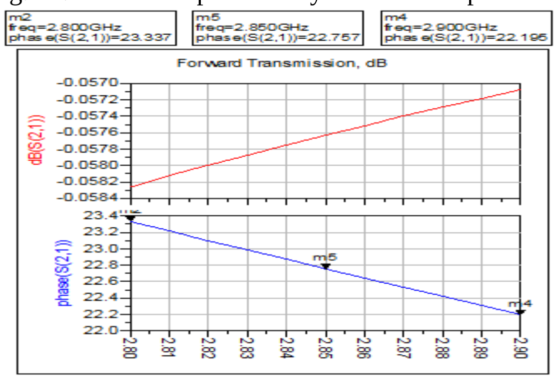

Fig. 14: Phase shift provided by Murata high pass filter

The Input and Output Return loss S(1,1) and S(2,2) is better than -40 dB with replaced Murata Lumped components as shown in Fig. 12.The total phase shift provided by High pass-low-pass phase shifter is 45.784° shown in Fig.13 and Fig.14.Insertion loss S(2,1) is negligible and RMS phase error is 1.3°.

All Simualtion of 45° Phase shifter with BAP51_02 Switch and Murata Components

The complete Phase shifter circuit with Murata High-pass/Low-pass filter and BAP51_02 Switch is shown in Fig.15.

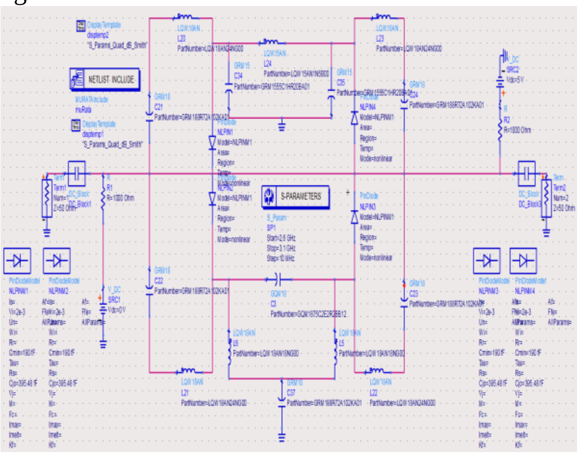

Fig.15 Schematic setup with BAP51_02 switches and HighPass/LowPass Filters biased to select LP filter

Similar circuit can be simulated by applying complementary biasing to select High Pass filter. The Fig.16 shows the S-parameter response of the circuit.

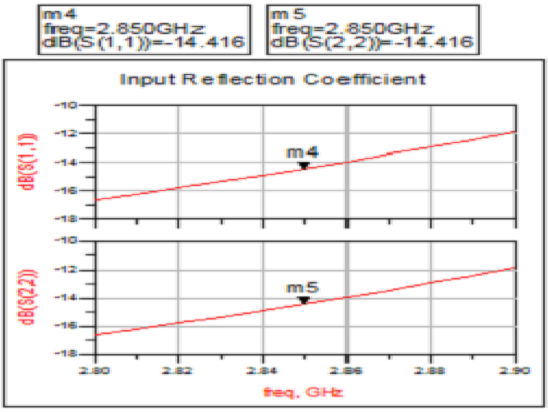

Fig. 16: Input and Output return loss of 45 °phase shifter with BAP51_02 switches and HP/LP Filters

The input and Output Return loss is better than -14 dB as shown in fig.16.

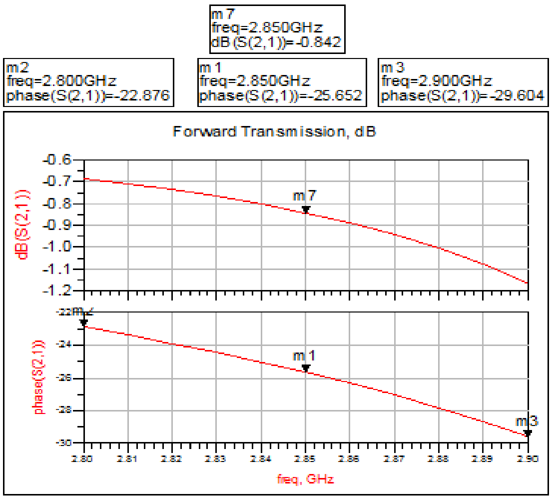

Fig. 17: Phase response of phase shifter with BAP51_02 switch biased to select LP filter

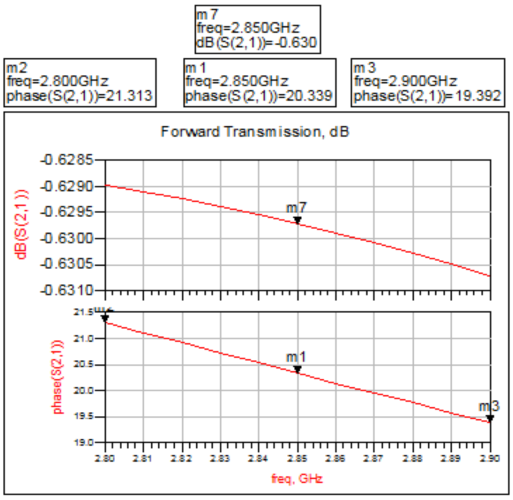

Fig. 18: Phase response of phase shifter with BAP51_02 switch biased to select HP filter

The insertion loss is -0.842 dB and -0.630 dB for Low pass and High pass filter at 2.85 GHz and -25.652° and 20.339° phase shift is provided by Low-pass and high pass filter as shown in Fig.17 and Fig.18 respectively. RMS phase error 4.966° and 2.35° provided when switches biased to select LP and HP filter respectively because of parasitic capacitance in murata lumped components.

IV. CONCLUSION

A Complete bit Section of 45° phase shifter has been designed and simulated in Advanced Design system Software at 2.85GHz for beamforming application.Murata Lumped components are used to implement high-pass/Low-pass filters which gives 45.991° phase shift and RMS phase error less than 5° at corner frequencies. The input and output return loss is better than 14 dB and Insertion loss is 0.8 dB which is pretty good.SPDT designed using BAP51_02 PIN diodes provides good isolation in OFF state and reduced parasitic capacitance of 73 fF using 24nH Murata resonate inductor.

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