Journal of Scientific & Industrial Research
Vol. 69, November 2010, pp. 823-829

A novel miniaturized loaded line phase shifter

V K Manoharan[1], S Sindhuja[1], S Deepak Ram Prasath[2], S Raju[2] and V Abhaikumar[2]
[1]PSG College of Technology, Coimbatore, India
[2]Thiagarajar College of Engineering, Madurai, India

Received 14 June 2010; revised 12 August 2010; accepted 16 august 2010

This study proposes a novel design of phase shifter for WLAN applications, by using Koch fractal curves to reduce size of conventional loaded line phase shifter (PS). Proposed PS provides an area reduction (41.88%) in comparison with conventional PS.

Keywords: Bluetooth, FR4, Koch fractal, Loaded line, Microstrip, Phased array, Phase shifter, WLAN

Introduction

Phase shifter (PS) in a phased array antenna shifts phase of incoming RF signal depending on control input[1], enabling antenna main beam to be steered at a faster rate without rotating antenna mechanically. Demand for high performance WLAN system at low cost has necessitated development of a miniaturized PS with reduced loss at low cost[2]. Design and development of various types of PSs (switched line, reflective line, loaded line and high-pass and low-pass types) are reported[3-10]. Out of different types of PSs, loaded line PS offers simplicity and low insertion loss[8]. Practical design of C-band MIC PS using pin diodes is reported[9]. Miniaturized PSs have been reported using MEMS technology[12], MMIC technology[13,14] and metamaterials[15]. In addition, fractal technique has been used to reduce size of antenna[16]. Also, usage of Koch fractal in miniaturizing a branch line coupler and a hybrid coupler is reported[17,18].

This paper presents a reduced size Koch fractal based 3-bit loaded line PS, of which a single bit loaded line section was fabricated and its performance was tested with conventional PS.

Loaded Line Phase Shifters (PSs)

Each section of a loaded line PS (Fig. 1) consists of a λ/4 transmission line symmetrically loaded at its ends by small susceptances for mutually canceling reflections due to λ/4 separation. Susceptance values are controlled by semiconductor switches such as pin diodes. Desired PS is obtained by changing electrical length through switching pin diodes. Loaded line PS is designed using well known closed form expressions[10] as

$$Z_0 = Z_0^1\left(\frac{\cos(\Delta\Phi/2)}{\sin\theta}\right) \quad \ldots(1)$$

$$\frac{B_i}{Y_0^1} = \frac{\cos\theta}{\cos(\Delta\Phi/2)} \pm \tan(\Delta\Phi/2) \quad \ldots(2)$$

where Z_0, characteristic impedance of transmission line; θ, electrical length of transmission line; $\Delta\phi$, required phase shift; Z_0^1, characteristic impedance of equivalent circuit; B_i, shunt susceptances, where i=1 when diode is in on condition and i=2 when diode is in off condition.

Microwave Associates MA4P789-287 pin diodes were used as a switch. Diode parameters for equivalent diode model were Cr=0.35 pf @ 20V reverse bias voltage and Rf=1.5Ω @ 10 mA forward current. Switching between two susceptace values of each bit is done by applying proper bias voltages to PIN diodes. Co-simulation of 3-bit conventional loaded line circuit (Fig. 2) is to produce a phase shift of 157.5° (a cascade of 22.5°, 45° and 90° bit sections). During cascade of 3-bit sections, matching between sections is taken care of for low insertion losses.

Miniaturization Using Koch Curves

Fractals are fragmented space-filling containers used to pack electrically large features efficiently into small

*Author for correspondence
E-mail: vkmanoharan@ece.psgtech.ac.in

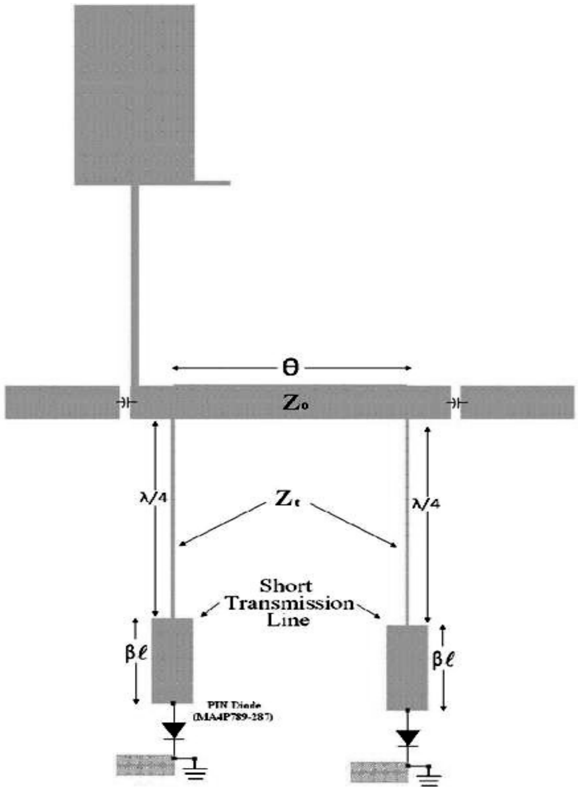

Fig. 1—Layout of a section of conventional loaded line phase shifter

physical areas. Koch fractals are characterized by iteration factor and iteration order. Iteration factor represents construction law of fractal geometry, and iteration order depicts how many iteration processes are to be carried out. Fractal geometries were utilized as reported[17]. Generation law of Koch curve facilitates to begin with a specified initiator. Then a generator is applied repeatedly in a lower scale to form fractals. For a straight microstrip line of λ/4 electrical length, Fig. 3 shows generation process of a Koch-shaped microstrip line with iteration factor of 1/5. The condition that must be satisfied to get a reduced size micro strip line by applying Koch fractal curve is as[17]

$$\text{Line width} \leq \frac{\text{Line length}}{6} \qquad \ldots(3)$$

Koch fractals are applied to shunt quarter wave transmission line and bias line of conventional loaded line PS with 0.2 iteration factor with iteration of one. Layout of 22.5° section Koch loaded line PS is shown in Fig. 4. Conventional 3-bit loaded line PS is miniaturized using Koch fractal technique (Fig. 5). A reduction in area (44%) is achieved by application of Koch technique for 3-bit loaded line PS circuit.

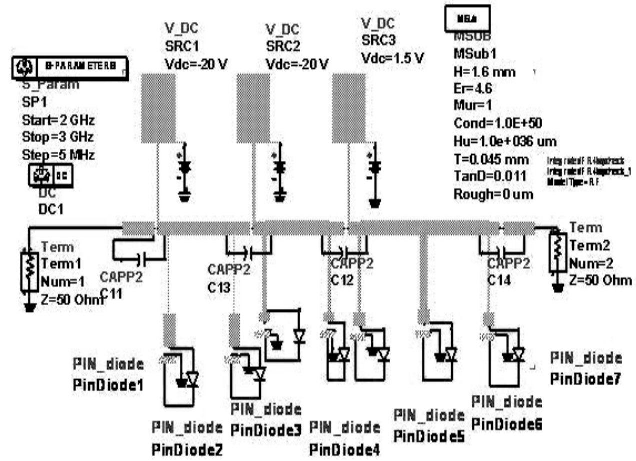

Fig. 2—Co-sim of conventional loaded line phase shifter

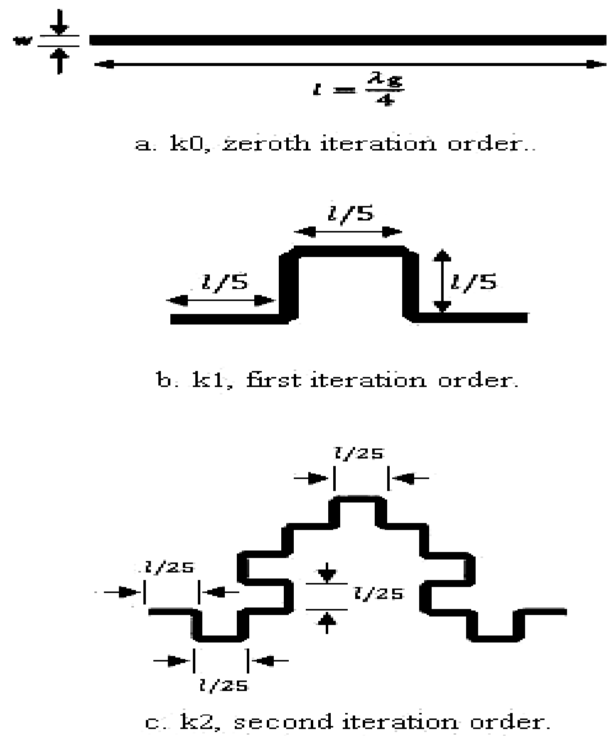

Fig. 3—Koch-Fractal-shaped microstirplines whose iteration factor is 1/5

Fabrication, Testing and Simulation

Single bit (22.5° section) of conventional (Fig. 6) and Koch (Fig. 7) designs were fabricated using a copper etching process. Substrate was FR4 (thickness, 1.6 mm; ε_r, 4.6). PIN diode (MA4P789-287 with SOT-23 package) and capacitors were soldered on PCB after fabrication. PIN diodes were grounded through via holes. PSs were tested using E5062A ENA series vector network

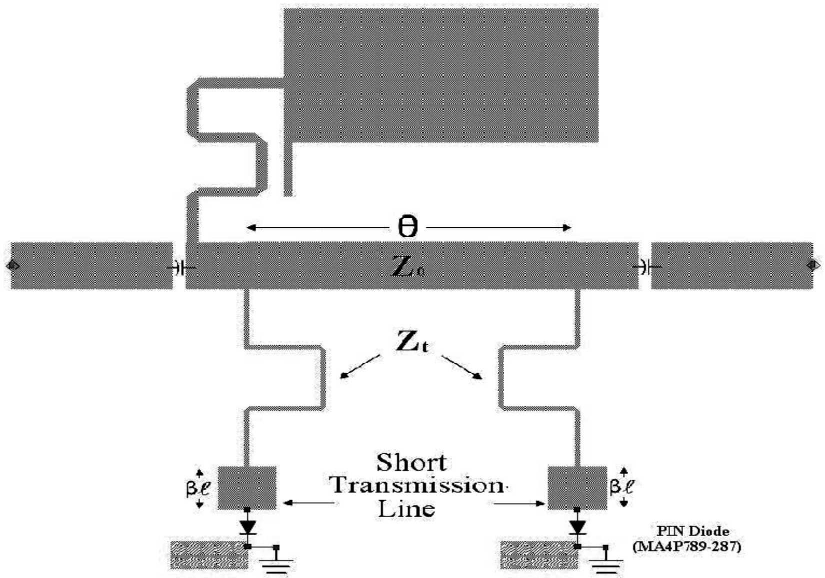

Fig. 4—Layout of 22.5° section of Koch loaded line phase shifter

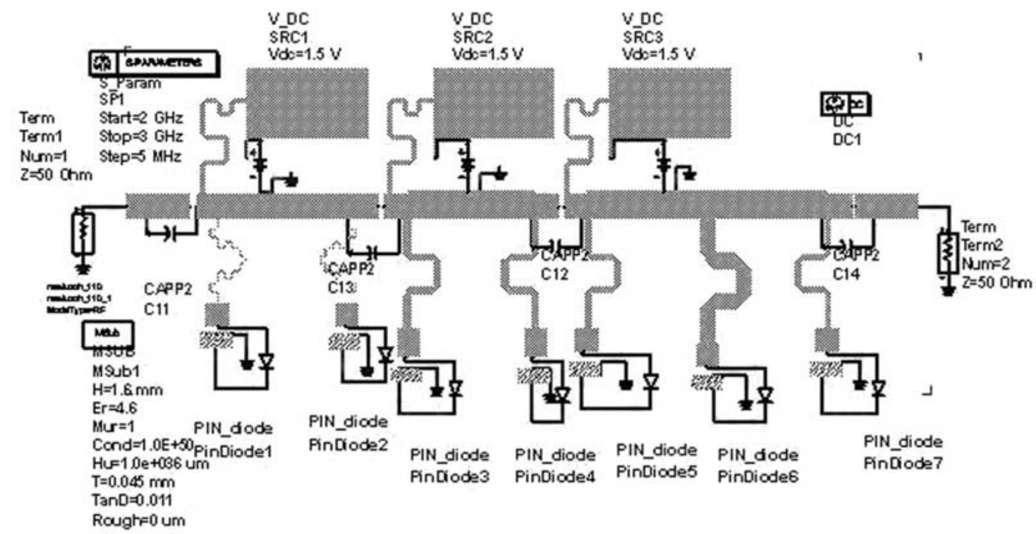

Fig. 5—Layout of 3-bit Koch loaded line phase shifter

analyzer. Both conventional and miniaturized loaded line PSs were designed for single bit and 3-bit sections on FR-4 substrate (thickness, 1.6 mm; ε_r , 4.6). Design was simulated using Agilent-ADS 2008 (Advanced Design System).

Results and Discussion

Results obtained from fabricated circuits are plotted for magnitude (Fig. 8) and phase (Fig. 9). Simulated (Table 1) and measured (Table 2) values are shown of return loss (S11), insertion loss (S21) and phase shift for conventional single-bit loaded line PS. Corresponding values for miniaturized PS are shown in Tables 3 and 4. Simulation results are also shown for 3-bit loaded line PS of conventional (Table 5) and koch type (Table 6). Measured return loss of both conventional and miniaturized PSs were better than -15dB. Measured insertion losses of conventional and miniaturized PSs were higher than simulated values, may be due to SMA connectors and soldering losses. Simulated and measured phase errors for both conventional and miniaturized PSs were minimal.

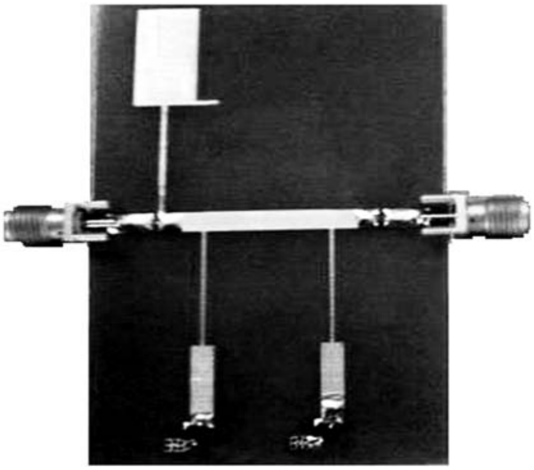

Fig. 6—Fabricated PCB-conventional 22.5° section

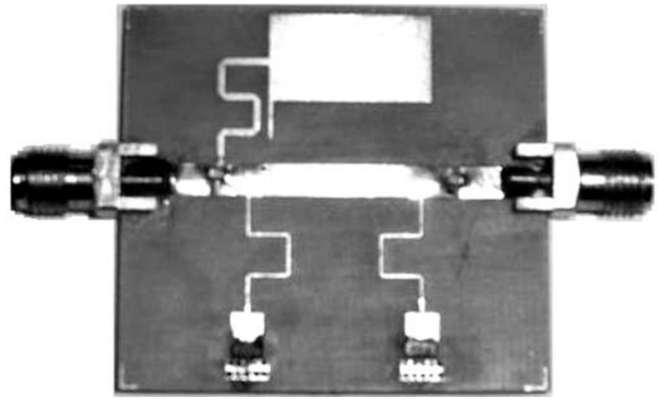

Fig. 7—Fabricated PCB-koch 22.5° section

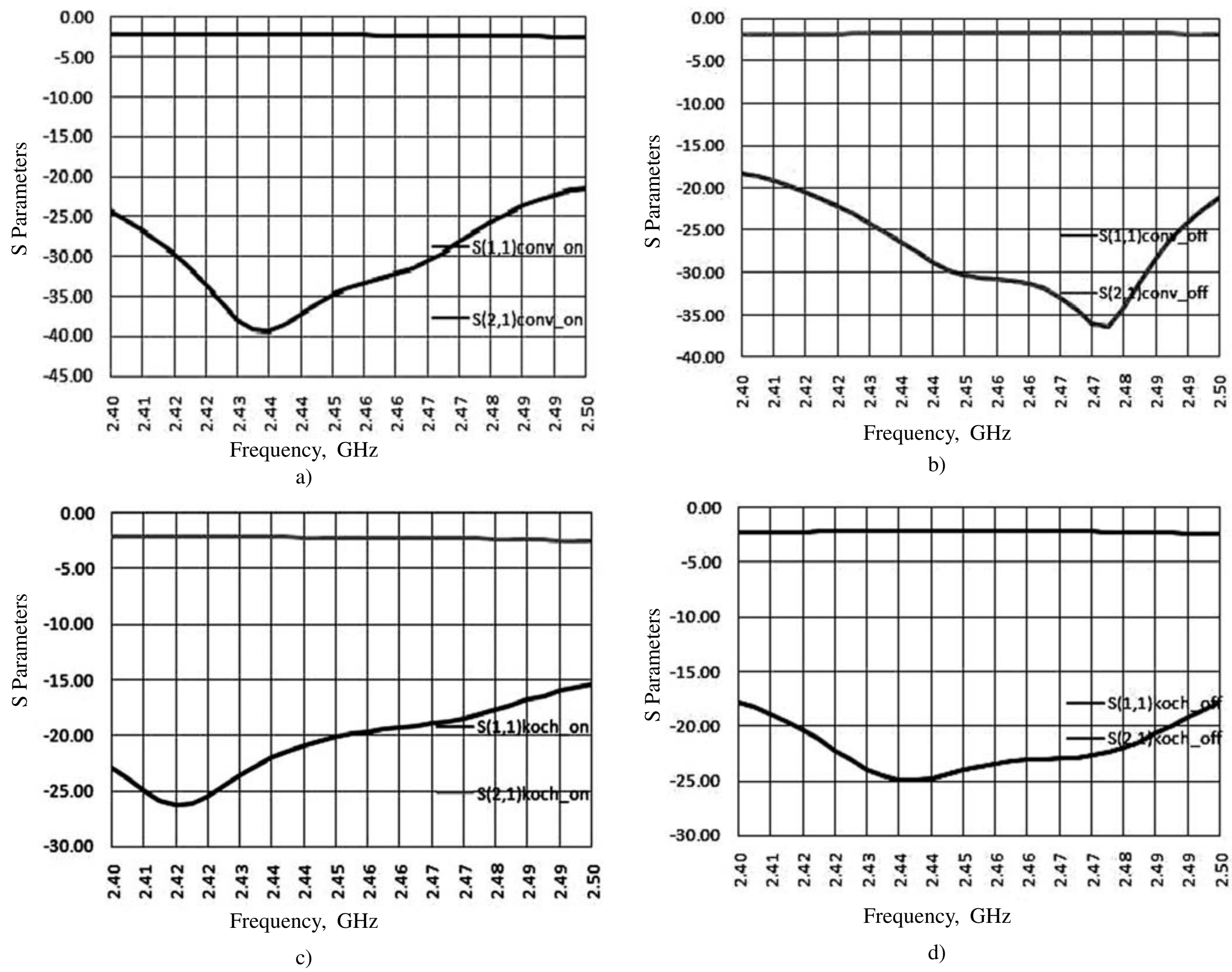

Fig. 8—Conventional & Koch circuit magnitude plot: A) Diode on; B) Diode off

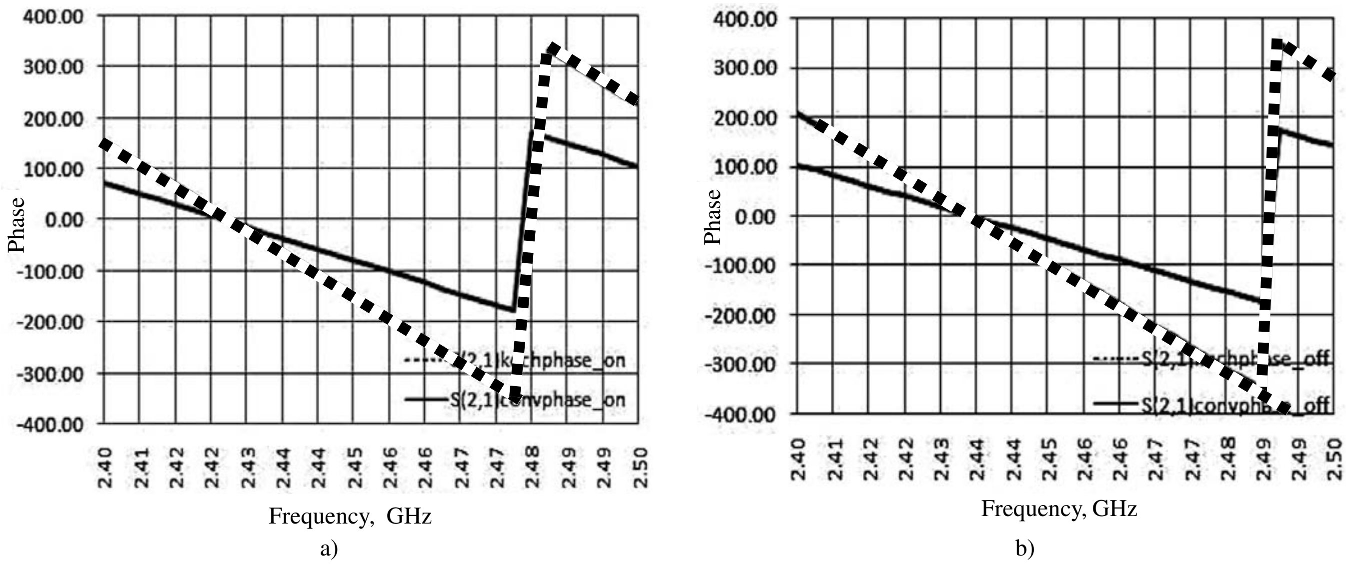

Fig. 9—Conventional & Koch circuit phase plot: A) Diode on; B) Diode off

Table 1—Conventional 22.5° loaded line phase shifter- simulation results

Diode state	S11 Magnitude	S21 Magnitude	S21 Phase	ΔΦ (on phase-off phase)	
				Simulated	Desired
ON	-22.282	-0.856	131.43		
OFF	-27.422	-0.659	153.95	22.515	22.5

Table 2—Fabricated conventional 22.5° loaded line phase shifter- measured results

Diode state	S11 Magnitude	S21 Magnitude	S21 Phase	ΔΦ (on phase-off phase)		
				Simulated	Desired	Phase error
ON	-32.522	-2.337	-80.049			
OFF	-28.685	-1.845	-58.295	21.754	22.5	0.746

Table 3—Miniaturized 22.5° loaded line phase shifter- simulation results

Diode state	S11 Magnitude	S21 Magnitude	S21 Phase	ΔΦ (on phase-off phase)	
				Simulated	Desired
ON	-21.311	-0.743	122.89		
OFF	-25.914	-0.628	145.42	22.53	22.5

Table 4—Fabricated miniaturized 22.5° loaded line phase shifter- measured results

Diode state	S11 Magnitude	S21 Magnitude	S21 Phase	ΔΦ (on phase-off phase)		
				Simulated	Desired	Phase error
ON	-17.749	-2.2068	-75.119			
OFF	-21.705	-2.1263	-52.765	22.354	22.5	0.146

Table 5—Conventional 3-bit loaded line phase shifter- simulated results

Bit input	S11 Magnitude	S21 Magnitude	S21 Phase	ΔΦ (on phase-off phase)	
				Obtained	Desired
000	-26.064	-1.694	-45.633	-	-
001	-31.937	-1.711	-68.136	22.503	22.5
010	-18.852	-1.876	-90.632	44.999	45
011	-21.338	-1.899	-113.561	67.928	67.5
100	-29.558	-1.710	-135.657	90.024	90
101	-23.091	-1.747	-158.061	112.494	112.5
110	-20.789	-1.849	178.787	135.58	135
111	-27.040	-1.861	`156.012	158.355	157.5

Table 6—Miniaturized 3-bit loaded line phase shifter- simulated results

Bit input	S11 Magnitude	S21 Magnitude	S21 Phase	ΔΦ (on phase-off phase)	
				Obtained	Desired
000	-23.384	-1.658	-77.243	-	-
001	-26.206	-1.673	-99.733	22.49	22.5
010	-22.129	-1.749	-121.517	44.274	45
011	-25.048	-1.762	-143.924	66.68	67.5
100	-19.870	-1.851	-167.314	90.071	90
101	-21.515	-1.867	170.301	112.456	112.5
110	-19.551	-1.951	148.965	133.792	135
111	-23.244	-1.954	126.606	156.151	157.5

Conclusions

Simulated and fabricated results of single bit PSs matched well. Bandwidth of fabricated conventional 22.5° section was 61.75 MHz and that for Koch section was 81.5 MHz. Thus Koch technique facilitates bandwidth improvement of 19.75 M Hz, and area reduction of 41.88 %.

Acknowledgments

Authors thank M/S Agilent Technologies for providing license to simulation tool Advanced Design System 2008 under university grants program. Authors also thank Mr Anurag Bhargava and Mr Sreeni Rao from Agilent Technologies Technical support team for their constant technical assistance in this study.

References

1 Nakada K, Marumoto T & Iwata R, Stub switched phase shifter, in *IEEE Antennas and Propagation Society Int Symp*, **vol 2** (salt Lake City, Utah) July 2000, 812-815.

2 Volakis J L, *Antenna Engineering Handbook* (McGraw Hill, New ork, USA) 2007.

3 White J F, High power, p-i-n diode controlled, microwave transmission phase shifters, *IEEE Trans Microwave Theory Tech*, **MTT-13** (1965) 233-243.

4 Opp F L & Hoffman W F, Design of digital loaded-fine phase shift networks for microwave thin-film applications, *IEEE Trans Microwave Theory Tech*, **MTT-16** (1968) 462-468.

5 Garver R V, Broad-band diode phase shifters, *IEEE Trans Microwave Theory Tech*, **MTT-20** (1972) 314-323.

6 White J F, Diode phase shifters for array antennas, *IEEE Trans Microwave Theory Tech*, **MTT-22** (1974) 658-674.

7 Burns R W, Holden R L & Tang R, Low cost design techniques for semiconductor phase shifters, *IEEE Trans Microwave Theory Tech*, **MTT-22** (1974) 675-688.

8 Bahl L J & Gupta K C, Design of loaded-line p-i-n diode phase shifter circuits, *IEEE Trans Microwave Theory Tech*, **MTT-28** (1980) 219-224.

9 Hirai K & Kamihashi S, Practical design of C-band, MIC, PIN phase shifters, in *Int Symp Microwave Digest*, *MTT-S*, **vol 79** (Orlando, Florida, USA) Apr 1979, 229-231.

10 Atwater H A, Circuit design of the loaded-line phase shifter, *IEEE Trans Microwave Theory Tech*, **MTT-33** (1985) 626-634.

11 Salonen P & Sydanheimo L, Analysis and development of 2.45 GHz phase shifters for adaptive antennas, in *Proc Int Conf IEEE Wireless Communications and Networking*, **vol 1** (Orlando, Florida, USA) March 2002, 159-163.

12 Tan G-L, Mihailovich R E, Hacker J B, DeNatale J F & Rebeiz G M, A 2-bit miniature X-band MEMS phase shifter, *IEEE Microwave Wireless Components Lett*, **13** (2003) 333-335.

13 Dai Y-S, Fang D-G & Guo Y-X, A novel miniature 1-22 GHz 90° MMIC phase shifter with microstrip radial stubs, *IEEE Microwave Wireless Components Lett*, **18** (2008) 109-111.

14 Hayashi H, Nakagawa T & Araki K, A miniaturized MMIC analog phase shifter using two quarter-wave-length transmission lines, *IEEE Trans Microwave Theory Tech*, **50** (2002) 150-154.

15 Siso G, Gil M, Bonache J & Martin F, Application of Metamaterial transmission lines to the design of quadrature phase shifters, *Electron Lett*, **43** (2007) 1098-1100.

16 Ze-hai Wu, Sheng-li Lai, Xiao-zheng Lai & Rui-na Zhang, Characteristic investigation of Koch Island fractal patch, in *Proc Int Conf Asia-Pacific Microwave*, **vol 4** (Suzhou, China) 2005, 4-7.

17 Chen W-L & Wang G-M, Exact design of novel miniaturized fractal-shaped branch-line couplers using phase-equalizing method, *IET Microwaves, Antennas & Propagation*, **2** (2008) 773-780.

18 Annaram K, Deepak S, Ram Prasath, Raju & Abhaikumar S V, Reduced size fractal hybrid coupler for IEEE 802.11b/g Wireless applications, *IJMOTI*, **3** (2008) 426-431.