RESEARCH ARTICLE OPEN ACCESS

Modelling And Miniaturization of A 2-Bits Phase Shifter Using Koch Fractal Shape Microstripline

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Abstract
Phase shifter is a key component in phase array antenna for the Radar application and the wireless communication system. This paper presents a novel design of miniaturised 2bits phase shifter using Koch fractal shapes of one iteration orders. The 3-section branch line coupler is used to extend the bandwidth of the phase shifter,this type of coupler is characterised by a low cost and simplicity of fabrication.Using the Koch fractal geometry the circuit size of the coupler is reduced to 6.36cm ×2.14cm at 2.4GHz. The simulation results show a good performance. So, over 2.1GHz-2.7GHzThe novel design of 2bits fractal reflection phase shifter based on the 3section show a return loss less than -20dB and the phase error varied between 0.1° and 0.4°for the four output phases . The circuit size of the phase shifter is reduced to9.5cm×2.1cm.
Index Terms—Digital phase shifter, phased antenna array, Directional coupler, Koch fractal geometry.

I. INTRODUCTION

In the modern application, the broadband and the compact size are the essential factors. So, size and weight of phase shifter are the major problems for developed array system. Therefore miniaturization and widening of the bandwidth have become important objectives. Many techniques have beendeveloped to miniaturize the structures of RF phase shifter such as monolithic microwave integrated circuits MMIC, micro electro mechanical systems (MEMS) and Fractal geometry.

MMIC technology is characterised by expensive cost and complexity of fabrication;Such as in [3] when a 6bits Digital Phase Shifter is fabricated using GAETEC Hyderabad 0.7um GaAs MESFETSwitch model to handle 30dBm peak power.Measured results show a 9dB insertion loss and a return loss better than -15dB and a compact size of 7.0mm ×2.35mm.

MEMS technology has a limited life and yield. Generally this technology have been used at frequency above20GHz and it requiresa high bias voltage. In [4]2and 4bits phase shifter operate over 40-70GHz has been developed based on micro-machined capacitive shunt switch.The tow phase shifter present a compact size equal receptivelyto 6.3mm×1.5mm and7.9 mm ×1.5 mm.In [9] a 3 bits distributed MEMS phase shifter is developed forthe ku frequency band based on fractal Koch geometries. This phaseshifter is set up by cascading a distinct number of MEMS switch. The insertion loss is less than -3.7dB, the return loss is better than -20 dB at 12GHz.

Fractal technique is used to implement many RF systems (filters, couplers, power dividers......). This technique can reduce the size and increase bandwidth. Why many phases shifter summers have developed using fractal geometry.

In [1]a miniaturised 3 bits loaded line phase shifter is realised using Koch fractal curves the results obtained from the fabricated circuit show a good performance over a narrow bandwidth (2.4GHz- 2.5GHz) and an area reduction of (41.88%) compared to the conventional phase shifter.

Then, in [2] a 2bits loaded line phase shifter is implemented using the Koch curve fractal geometry for reduced the size. The phase shifter designed operate at 2.4 GHz using FR4 substrate. The simulation results show reflection loss less than -20dB and insertion loss better than -0.8dB over a narrow bandwidth (2.35GHz-2.45GHz).

So, in [10] Manoharan developed a Koch fractal reflection type phase shifter based on -3dB branch line coupler this phase shifter is fabricated on an FR4 substrate at 2.45 GHz. Measured results show a return loss less than -10dB an insertion loss less than -6.5dB an error phase shift varied between 2° and 10° of four phase shift over 2.4GHz-2.48GHz . The Koch fractals are applied to the matching and bias transmission line the circuit size is reduced by 32%.

This paper reports on the design of 2bits Koch fractal reflection phase shifter using a 3-section branch line coupler The paper is organizedaround four sections:

In section 2, we present design and simulation of 3 section branch line coupler. Then, we present the miniaturisation of the structure using Koch fractal geometry.

In section 3, we try to develop a 2bits reflection type phase shifter using a 3section branch line coupler and we reduce the circuit size using the Koch fractal geometry.
Finally, we end up with a conclusion

II. 2 BITS REFLECTION TYPE PHASE SHIFTER USING 3SECTION BRANCH LINE COUPLER

A. 3-section branch line coupler design and simulation

The Branch-line couplers are used in many RF circuits , these couplers have narrow band (<20% bandwidth) and a large size at low frequencies [5]. So, it presents a fundamental component to develop reflection type phase shifter and it has many impacts to the performance of this type of phase shifter. Many techniques are used to enhance their bandwidth and reduce size.Such as in [8] when a miniaturized fractal shaped branch line coupler based on composite right/left handed transmission lines is fabricated and measured. the measured results show a good performance at 0.9 GHz and 1.8GHz . The circuit size is reduced respectively to 49.7%and 64% .In[11]a broadband directional coupler is developed, this coupler is characterised by a compact size and it can provide a coupling over ultra large wide band.
To increase bandwidth, a multi-section branch-line coupler can be used [5].In this section we try to design a 3-section branch line coupler operated at 2.4GHz.The substrate used for designs is the Rogers RT\duroid 5880 with a dielectric constant of 2.2 and athickness of0.508mm.The layout of 3-section branch line coupler is shown in fig.1.

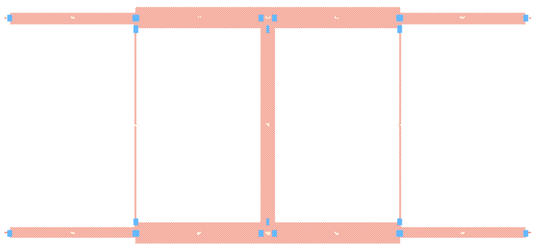


Fig.1. 3-section branch line coupler

To design this coupler the branch and the main line impedances are determined by solving equation (1) and (2) [6].

$$Z_1 = Z_{os}\sqrt{(r-(\frac{r}{t})^2} \quad (1)$$

$$Z_2 = Z_{os}\sqrt{(r-(\frac{t^2-r}{t-r})} \quad (2)$$

$$t = 4\sqrt{1+k^2}$$

Where:

r: impedance transformation ratio

$k^2 = \frac{P_{out3}}{P_{out4}}$: power split ratio

Z_{os}=50Ω

For an equal power division the power split ratio must be equal to k=1. The minimum value of r for non-negative branch impedance is 0.5 [6]. Then, the characteristic impedances of main line and branch lines are 35.35Ω and 120.7Ω and the parameters of the micro-strip-line is calculated using the line calculating tools included in the advanced design system.The return loss, coupling and the isolation of the designed coupler are shown in Fig.2. When, the phase difference between the two output ports is shown in Fig.3

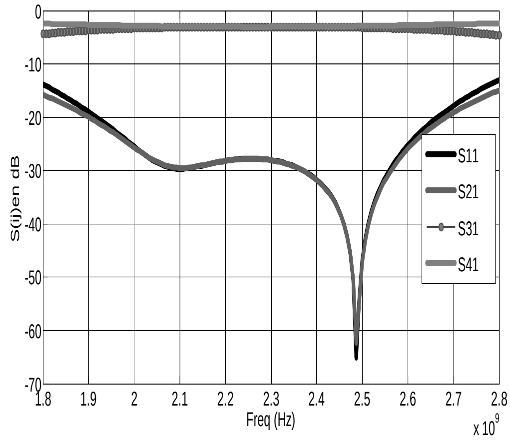


Fig.2. Simulated results of the designed 3-section branch line coupler

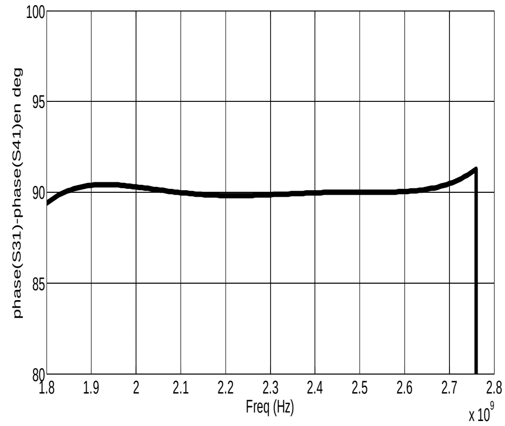


Fig 3. Phase difference between the two output ports

Over 1.8-2.7 GHz , simulation results show a return loss and isolation better than -15dB , the coupling is 3±1dB and the phase difference between the port 3 and 4 is 90°±1°. The structure has a large size equal to 9.3cm×2.9cm.Based on this coupler, a 2bits phase shifter can be designed.

B. 2 bits reflection type phase shifter design and simulation

Digitalphase shifter is benefitedwith their temperature variation and low control voltage noise. Also, using digital phase shifter, array system can switch to different state.

So, it can have a fast and accurate switching between different phase states of the system. Usually, four topologies are used to design digital phase shifter: switched network phase shifter, loaded line phase shifter, reflection phase shifter and vector based phase shifter. In this paper, reflection topology using a 3section branch line coupler is used. Reflection topology is characterized by low fabricationcost and phase error, but it has a narrow bandwidth and a large size due to using the branch line coupler. Then, we proposed to increase the bandwidth of the phase shifter using the 3-section branch line couplerdescribed in the above section. The structure of this phase shifter is designed and simulated at 2.4 GHz using the duroid 5880 substrate. Fig.4 show the layout of the 2bits phase shifter based on 3-section branch line coupler.

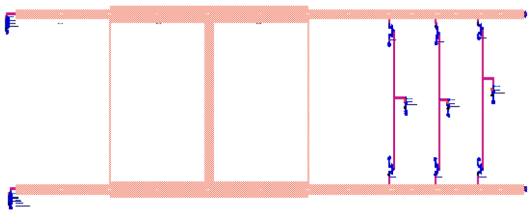
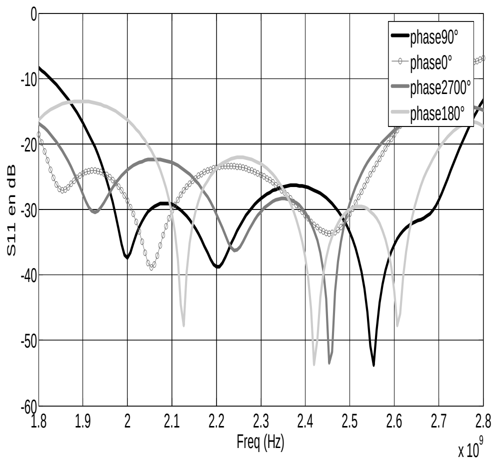
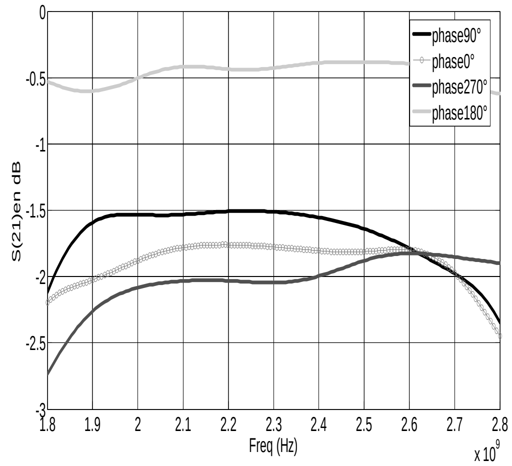


Fig.4. Layout 2bits phase shifter with 3section coupler

The 2 bits phase shifter is composed of a 3-section branch line coupler, Ga As FET switches controlled bya digital command and a delay line. The input signal is first split into two part via the coupler, then, according to the state of the switches the signal pass through a delays line and reflected in the output port. So, the output phase is obtained by selecting the pair of the switches to be switched.



(a)



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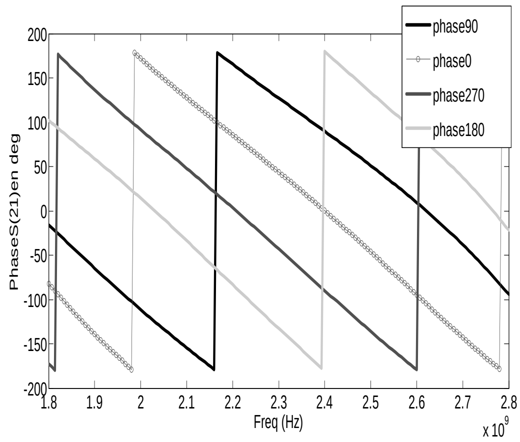


(c)

Fig.5.Simulated results of (a) Input return loss ,(b)Insertion loss, (c) Phase shift of 2bits reflection Phase shifter

The simulation results obtained are plotted in Fig.5. It can be noticed that the return loss is better than -15dB, the insertion loss is varied between -0.5dB and -2dB and the phase error is less than 0.4° for the four output phase over 2-2.7GHz

Using the 3 section branch line coupler, we have succeededto increase the bandwidth of the phase shifter to 50% compared to the bandwidth of the reflection type based on the 3dB branch line coupler (200Mhz) but the size of the structure is increased to 12.3cm×2.9cm. to miniaturise the size of this structure Koch fractalgeometry canbe used.

III. 2 BITS KOCH FRACTAL REFLECTION TYPE PHASE SHIFTER

A. Design and simulation fractal-shaped 3-section branch line coupler

The demand for high performance and low cost system requires a miniaturized structure and increased bandwidth.

The fractal geometry is used to miniaturize and increase the bandwidth of many microwave circuit such as antenna, coupler, phase shifter, modulator. Koch fractal is characterised by two factors: the iteration factors and the iteration order [7].Fig.6 presents the generation process of Koch-shaped micro-strip-line has an impedance of 50Ω and an electrical length of λ_g /4 and with iteration factor of 1/4.Then, the length of micro-strip-line after the first iteration order (K1) and the second iteration order (K2) is determined respectively using equation (1) and (2) [8].

$$l_1 = 2w + \frac{2l}{3} \qquad (1)$$

$$l_2 = 6w + \frac{4l}{9} \qquad (2)$$

To reduce the size of micro-strip-line using the Koch fractal technique ,the condition $w \le \frac{l}{6}$ must be satisfied[4].

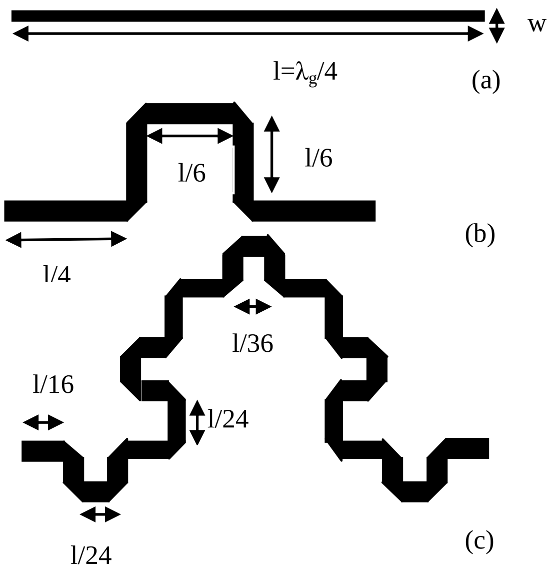


Fig 6. Koch-shaped micro-strip-line with iteration factor of 1/4

In [7], it is demonstrated that with bend structure the return loss is small and the transmission phase shifts to higher negative value. So, the micro-stripe length must be reduced by Δb and will be calculated using the formula3,4,5.

$$\frac{\Delta b}{D} = 0.16\left\{2 - \left(\frac{f}{f_p}\right)^2\right\} \qquad (3)$$

$$D = \frac{120\pi h}{\sqrt{\varepsilon_r}\, z_0} \qquad (4)$$

$$f_b = \frac{0.4 z_0}{h} \qquad (5)$$

Now with phase shifting property , we try to design a fractal-shaped 3-section branch line coupler at 2.4GHz using duroid 5880 with a dielectric constant of 2.2 and a thickness of 0.508mm. Moreover, the length and the width of horizontal and vertical transmission line for K0 and K1 are presented in Table I. The Fig.7 show the layout of fractal3-section branch line coupler.

TABLE I. PARAMETRES OF 3SECTION FRACTAL COUPLER

	35.35Ω		120.7Ω	
	W (mm)	L (mm)	W (mm)	L (mm)
K0	2.6	22.4	0.2	23.7
K1	2.6	20.1	0.2	16.2

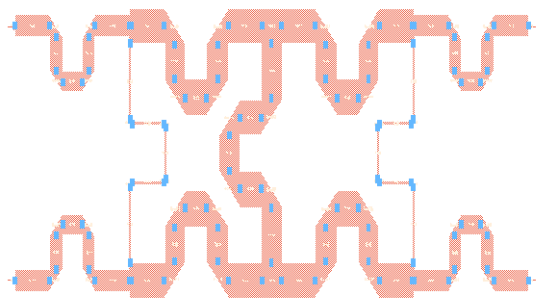


Fig.7. Fractal-shaped 3-section branch line coupler

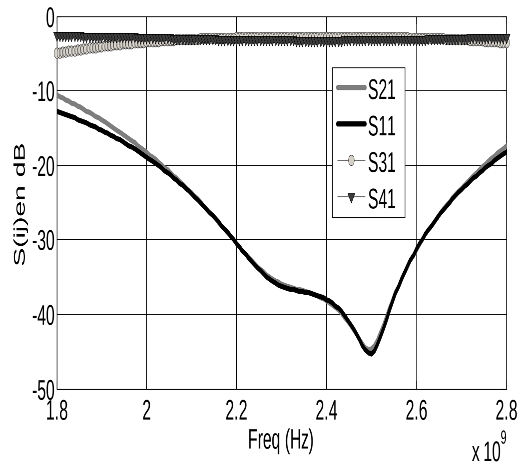


Fig.8. Simulated results of the designed 3-section fractal branch line coupler

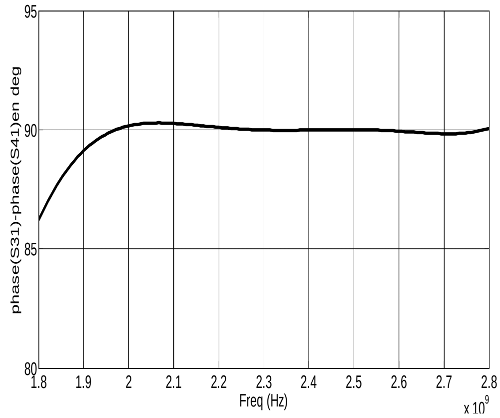


Fig 9. Phase difference between the two output ports

Fig.8, Fig.9presents simulated transmitting parameters and phase difference between direct and coupled ports of the fractal 3-section coupler .it can be noticed that over 1.9-2.8 GHz , simulation results shows a return loss and isolation better than -15dB , the coupling 3±1dB and the phase difference between the port 3 and 4 is 90°±1°. The size structure is reduced to 6.36cm×2.14cm.

B. Design and simulation miniaturised 2 bits reflection type phase shifter

The iteration order is limited to one iteration because the toleration of the circuit. The design of the fractal phase shifter is illustrated in Fig.10. It can be seen that the size of the structure was reduced.

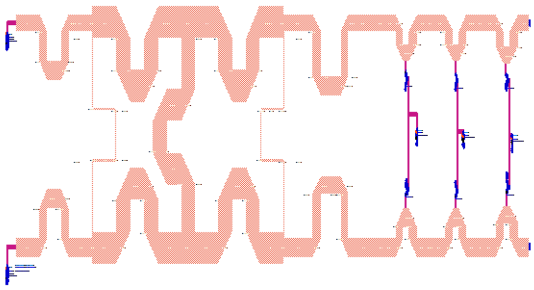
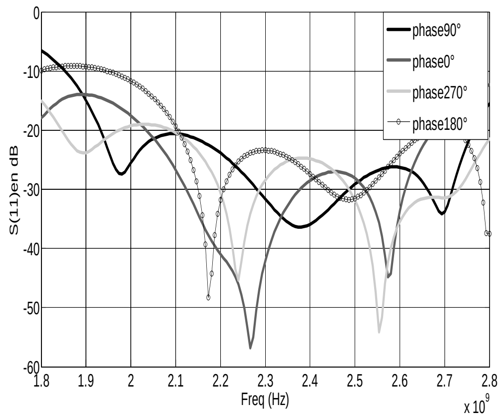
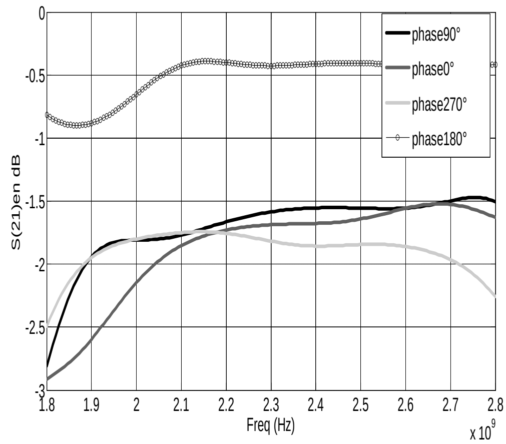


Fig.10. layout 2bits fractal phase shifter



(a)



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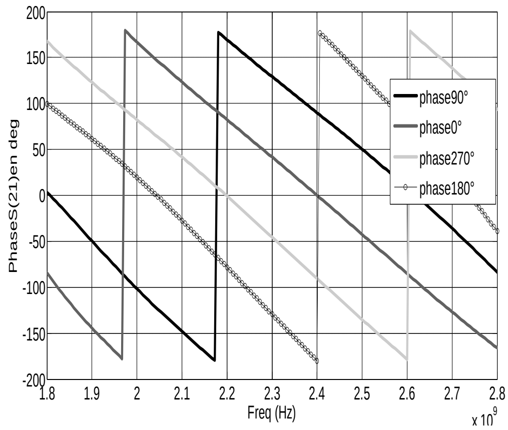

(c)

Fig.11 Simulated results of (a) Input return loss ,(b)Insertion loss, (c) Phase shift of 2bits fractal Phase shifter

The design of fractal phase shifteroperates2.4GHz . So, we can see that the operating frequency bandwidth for the four output phases is decreased compared to the 0 iterations 2bits phase shifter. Well, the reflection performance is decreased because we are using a greater number of bending .The simulation results of the fours output phases are plotted in Fig.11 and it can show that the return loss is better than -20dB, the insertion loss is varied between -0.5dB and -2dB and the phase error is less than 0.4° for the four output phase over 2.1GHz-2.7GHz.

IV. CONCLUSION

In this paper, we have been proposed firstly to increase the bandwidth of two bit phase shifter using a three section branch line coupler. The simulation results show a good performance over 700 MHz of bandwidth, but the circuit size is increased. In the second section, we proposed to miniaturise the structure of phase shifter using Koch-fractal-shaped micro-strip line for one iteration. So, the physical parameters of the fractal 2bits phase shifter is determined by using the length reduction formulae of the chamfered bend. The simulation results show a good performance over 600MHz of bandwidth and a reduction of circuit size.

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