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LOW COST MINIATURE PHASE SHIFTER FOR L AND S BAND PHASED ARRAY

APARNA B BARBADEKAR [1], PRADEEP M. PATIL [2]

[1] Department of Electronics and Telecommunication, AISSMS IOIT, Pune, India

[1] Department of Electronics and Telecommunication,VIIT, Pune, India

[2] Department of Electronics and Telecommunication, JSPM/TSSM'S COE, Pune, India

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ABSTRACT

Phase shifters are one of the most critical subsystems of a phased array antenna. The accuracy of the phase shifter depends on how accurately the phase and amplitude are changed without attenuation between the output and input ports. To verify the phase shift parameters such as cost, size, reliability, weight etc. a customized miniature phase shifter is presented with on-chip design using an IC 2484 operating at 2.45GHz frequency. The IC 2484 has outline dimensions of 11.43×20.43mm^2 with a thickness of 0.762mm and operates within 2.150 GHz to 2.484 GHz band. The insertion loss is -5.6dB, Voltage Standing Wave Ratio (VSWR) is 1.5:1, the weight is 3gms and it operates at 2.45GHz frequency. The experimental results show that the insertion loss of -3.71dB and VSWR 1.33:1 are within the specified limits of the IC 2484.A comparison between the reported and presented work at L and S bands demonstrates that the presented work on the phase shifter gives a better performance with lower power consumption.

KEYWORDS: Phase shift, Calibration, Return loss, Insertion loss, VSWR, Radiation pattern.

1. INTRODUCTION

The phase array is a multiple antenna element system design to get a directional pattern without physically moving the antenna itself. Generally electronically controlled phase shifters are used to steer the beam. Due to technological developments there is a remarkable change in the design process of phase shifters. Monolithic Microwave Integrated Circuit (MMIC) phase shifters such as: switched types [1-8], reflection type [9-12] and vector some methods [13-15] are reported recently. Due to less sensitivity to power supply, temperature variations and high insertion loss, their use is limited.

Publications on Ferro electric phase shifters are used to get the phase shifts at radio frequency. They operate on the concept of in-homogeneously filled rectangular wave guides. In these phase shifters poorer performance in comparison to ferrite devices, the expensive fabrication process, require high (~100V) dc –bias. Ferrite based phase shifters have limited applications in mobile and satellite communication devices due to high costs, a complex fabrication process, and frequency limitations.

Radio Frequency Microelectro Mechanical Systems (RF MEMS) developed a series of phase shifters such as switched line [16-19], loaded line [20-23], reflection type [24-27], distributed line [28-32] phase shifters. However these phase shifters have distinct limitations such as a large size, unreliable operations and temperature instability, and packaging is perhaps more critical. Because of these drawbacks RF MEMS phase shifters have limited use in the consumer market.

There are a large number of articles and research papers released on phase shifter circuit topologies. However it is necessary to find the best possible circuit solution which can satisfy the requirements in the most efficient way.

The proposal is to design a miniaturized, custom based IC 2484 as a phase shifter which is small in size, has a wide phase range and is reliable. A design 3dB Wilkinson power divider is used to provide an RF signal from a Voltage Control Oscillator (VCO) to each of the phase shifters with equal amplitude and phase. A 1:4 phased array dipole antenna is used in the experimental setup to verify the radiation pattern. The expected results of the proposed phase shifter are insertion loss 3.7dB, VSWR 1.35 and phase shift ± 5%.An operating frequency of 2.45GHz, insertion loss ranging from 2 to 5.6dB, VSWR 1.50:1 and phase shift from 0 to 180 ° are the design specifications of the proposed phase shifters.

The paper is systemized as: Section 2 is a comparison of phase shifter technologies. Section 3 presents a phase shifter layout of IC JSPHS-2484. Section 4 presents a proposed system block diagram. Section 5 presents the experimental setup for measurement of S- parameters using Vector Network Analyzer (VNA). Section 6 presents the experimental setup for the radiation pattern. Section 7 includes results and discussions between the proposed and existing phase shifters. Conclusion based on our research is given in section 8.References are given at the end of the paper.

2. COMPARISON OF A PHASE SHIFTER TECHNOLOGIES

A fixed phase shifter provides a constant phase change between two ports while an adjustable phase shifter will provide a phase change between ports that can be controlled mechanically or electrically. Table 1 shows adjustable electronic phase shifter topologies in brief.

Table 1: Comparison of Electronic adjustable phase shifter technologies

Feature	**Electronic Phase shifters**			
	Ferrite	**Semiconductor (MMIC)**	**MEMS**	**Ferroelectric**
Various device OR Components used	Waveguides, Coaxial lines, Strip lines, microstrip lines	Switches((PIN/Schotky/varactor) diodes /(MESFET,HBT)transistors),	Switches, Inductor, varactor	Ferroelectric varactors
Material Used	yttrium iron garnet(YIG), Magnet ferrite, Aluminium.e tc	GaAs , quarts, RT/duroid , silicon, ferrite/garnet, sapphire alumina etc	Ceramic quartz, Glass, high – resistivity silicon, HRS, GaAs, SOI,PCB, BiCMOS, Alumina, apphire.etc	1.Berium Strontium Titanate(BST) 2.Yttrium iron garnet etc
Types (operating mode)	1.Analog(Pas sive) 2.Digital(Act ive)	1.Analog (Passive) 2.Digital (Active)	1.Analog (Passive) 2.Digital(Act ive):	1.Thin Film 2.Coupled-Line Microstrip
Cost	Very expensive	Expensive	Low	Low

Switching Speed	slow	Fast at low power	Slow 1-20µs	Intrinsically fast, controller limited if high voltage
Operating Frequency Range GHz	26.40 to 70 (X band)	26.5 to 40(Ka band) RF sampling at 1 to 2 (L band) and 2 to 4 (S-Band)	26.5 to 40 (Ka band)	18 to 26.5 (K band)
RF Loss	<1dB	˜ 2 dB	˜ 2.3 dB	˜ 5 dB
Size(mm^2)	Large(~few cm)	PIN based switch Small (1 to 5) FET based switch (0.1)	small (~nm/µm)	Large(~few cm)
Applications	Phased array radars	military high-performance RF and microwave applications	Cell Phone, Biotechnolog y and healthcare	Phase array

3. **PHASE SHIFTER LAYOUT OF IC JSPHS-2484**

The phase shifter is implemented with analog variable voltage IC 2484 from mini circuits. The chip is mounted on TB-122B authorized layout PCB from the same company is as shown in Figures 1(a-c). It is mounted on a test board that utilizes grounded co planar wave guides for input-output RF excitation and narrow conductive traces for DC bias and control. The substrate used in the test board PCB is Rogger-R0 4350 with dielectric constant 3.5 and a thickness of 0.762mm.All traces on the test board are fabricated using 1 oz. Copper with Electroless Nickel, Electroless palladium emersion Gold surface finish to allow the addition of wire bonds is used. The RF input and output pads of the chip are wedge wire bonded to the test board with two parallel 18 µm diameter gold wires. Female SMA Connectors are attached to both the input and output RF ports to facilitated measurements.

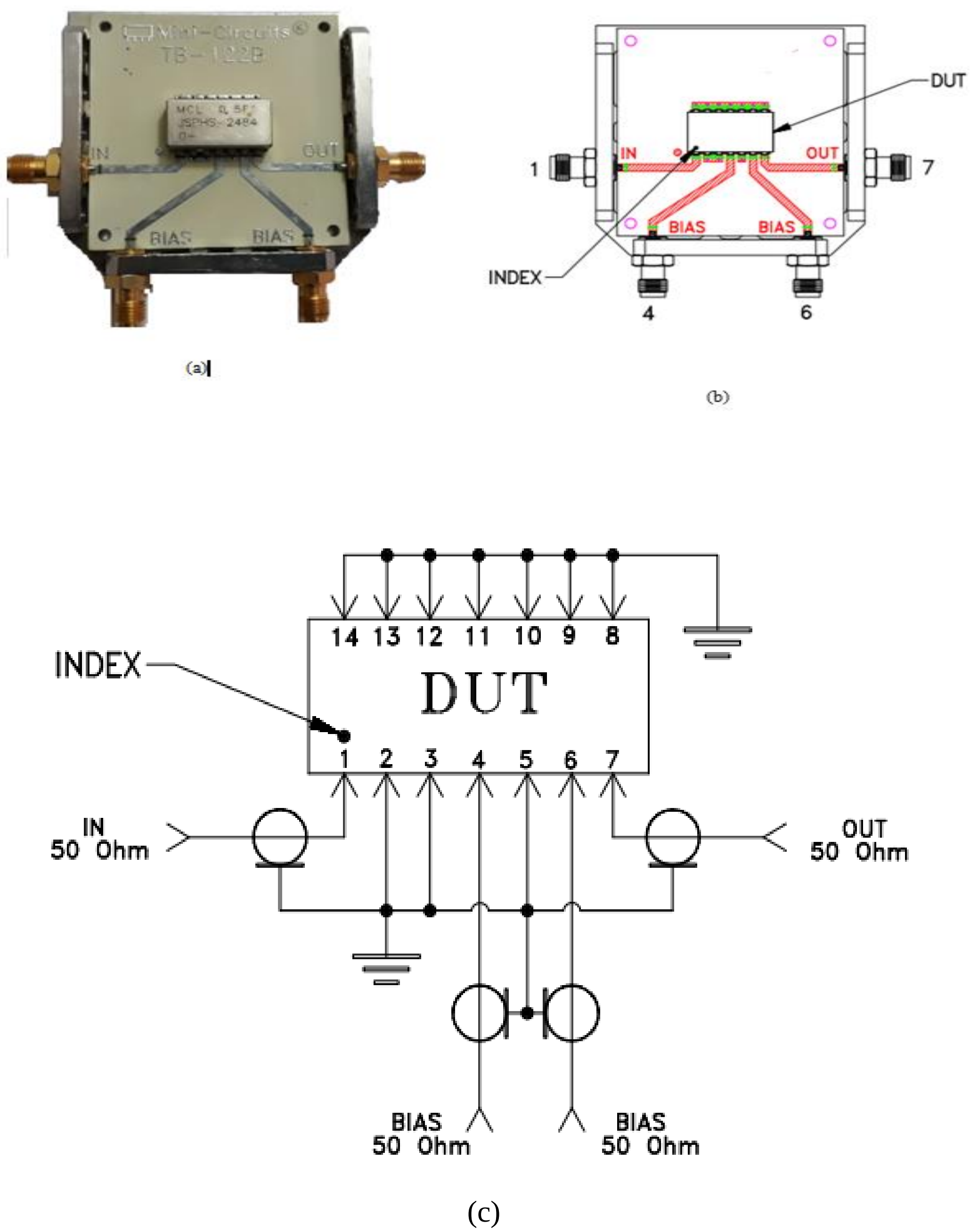

Fig. 1: (a) fabricated layout of IC 2484 ,(b) Evaluation board and circuit of IC 2484,(c) Schematic diagram of IC 2484

The dc bias is provided at the top of the board. The typical specifications of the IC are: frequency 2.15-2.484GHz,phase range 180°(min), insertion loss 5.6dB(max), control voltage 0 to 15 Volts, control bandwidth Dc-50 KHz, VSWR 1.5:1,operating temperature -40° to 85°,outline dimensions

11.43×20.40mm^2 and weight is 3gms.The presented phase shifter is designed based on the specifications listed above.

4. PROPOSED SYSTEM BLOCK DIAGRAM

The four phase shifter ICs are connected in the system layout as shown in Figure 3 such that the RF input from the VCO given to 1:4 WPD equally divides the amplitude and phase and provides the same as input to each of the phase shifter IC 2484. The control voltage from the power supply of 0-12 Volts is controlled through a control switch and is given to each control pin of the IC 2484. A fine control is also provided to tune the control voltage so as to adjust the required phase shift.

The graph between phase V's control voltage for each phase shifters is plotted so as to understand the behavior of individual phase shifter when connected in the system. Calibration of the progressive phase shift against the control voltage is given in Table 2.

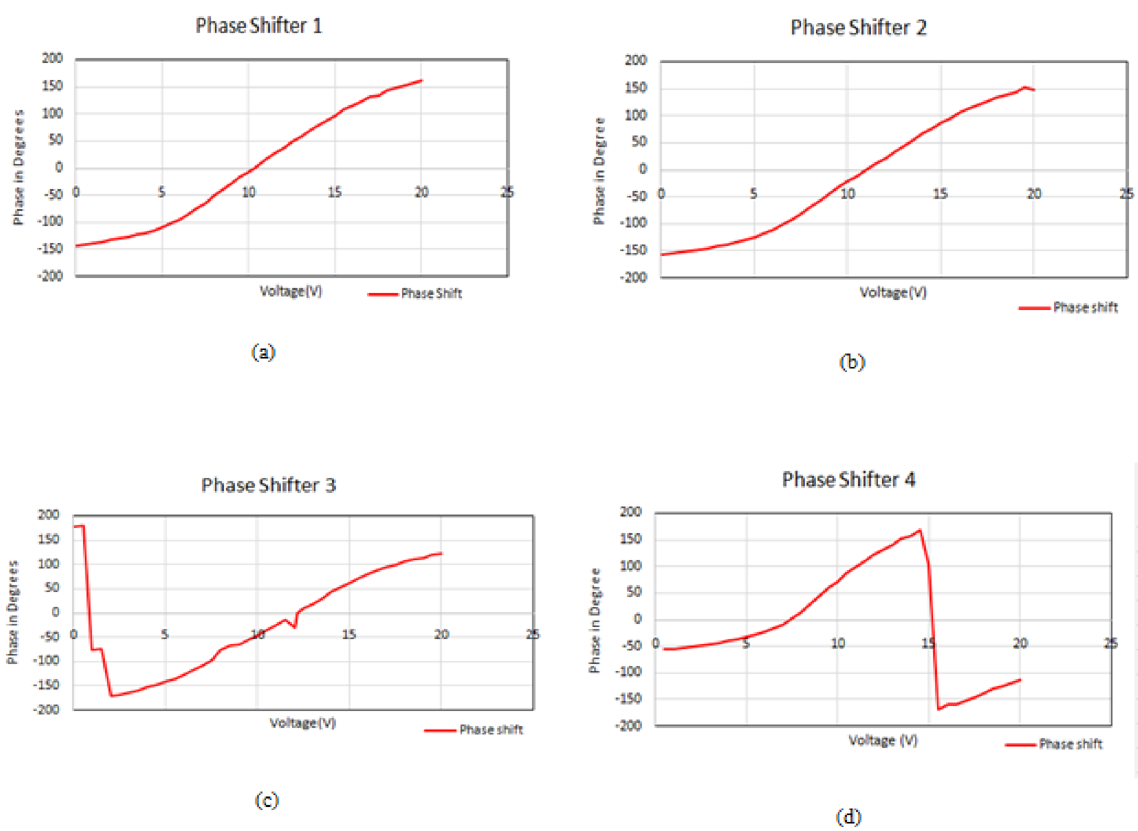

Fig. 2 :(a- d) calibration of phase shifter IC 2484

The graphs plotted in Figures 2(a-d) show the variation of the control Voltage V's phase shift. Before plotting the graphs the number of phase shifts is measured for each phase shifter IC 2484 with a variation of control voltage which is varied in steps of 0.5Volts.From the datasheet provided for the IC 2484, it is observed that the individual phase shifter always gives a positive phase angle when the voltage is varied from 0 to 15 Volts. But from the graphs it is observed that when all four phase shifters operate below 10Volts range, they yield negative phase angles and positive phase angles above 10Volts range. The variation of phase angles from -150 ˚ to 0˚ is observed for phase shifters 1 and 2.

Table 2: Calibration of phase shifters

Sr.No	Biasing Voltage for phase shifters				Progressive Phase Shifts(degree)			
	V1	V2	V3	V4	Φ1	Φ2	Φ3	Φ4
1.	12	14	17	12	36˚	65 ˚	93 ˚	120 ˚
2.	10.5	8.5	7.5	4	0	-60 ˚	-90 ˚	-120 ˚
3.	0	10.2	7.5	0	90 ˚	180 ˚	-90 ˚	-180 ˚

The behaviour of phase shifter 3 is erratic, that is, it gives 175 ˚ phase shift for 1Volts and immediately drops to -175 ˚ at 2.5 Volts. Phase shifter 4 takes -50 ˚ to 0 ˚ for variation of control voltage from 0 volts to 9.5 volts. All the phase shifters namely 1, 2, 3 and 4 attain +100 ˚, +100 ˚, +60 ˚ and +60 ˚ at 15 Volts control. Adjusting the fine control the progressive phase could be calculated accurately. Some of the sample readings of progressive phase shifts are marked against the control voltage in Table 2.

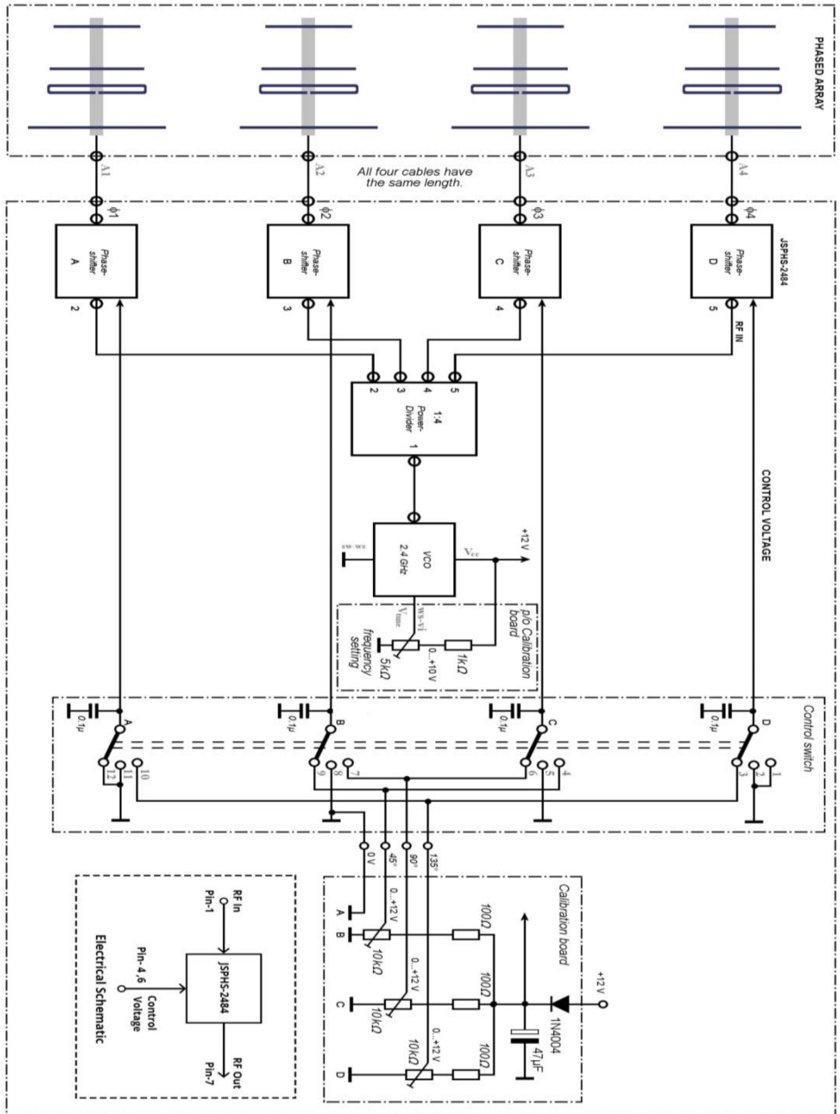

Fig.3: Proposed system block diagram

5. EXPERIMENTAL SETUP FOR MEASUREMENT OF S-PARAMETERS USING VNA

The S parameter is a domain which quantifies the behavior of the RF system. The S parameter can represent two types of losses: insertion loss and return loss for any RF system. The insertion loss indicates the amount of the signal reflected back at a port in comparison with the amount of signal sent through it. The return loss is a parameter which quantifies the amount of attenuation or gain the signal sent from one port to other experiences. The VSWR shows the mismatch at each port. Subscripts one and two respectively refer to the phase shifters input and output ports. All these S- parameters can also be measured with a vector network analyzer (VNA) as shown in Figure 4 .The S parameters are measured and tabulated in the Table 3. The graphs of S-parameters are shown in Figure 5 and Figures 6(a-d).

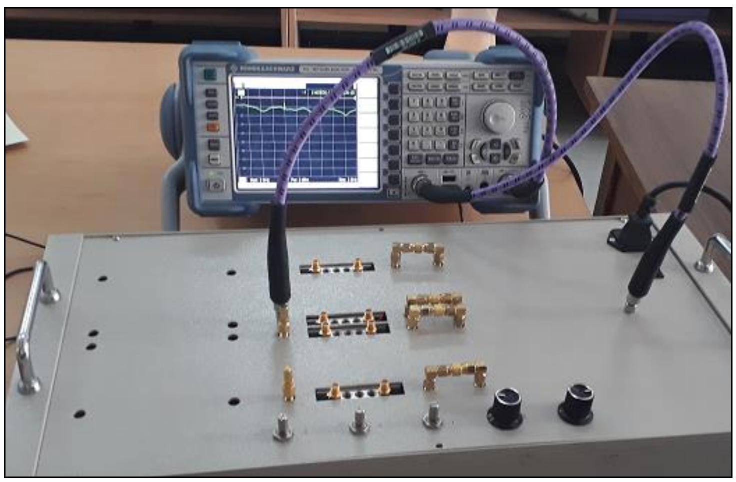

Fig.4: Experimental set up to measure S- parameters of phase shifter IC 2484 using VNA

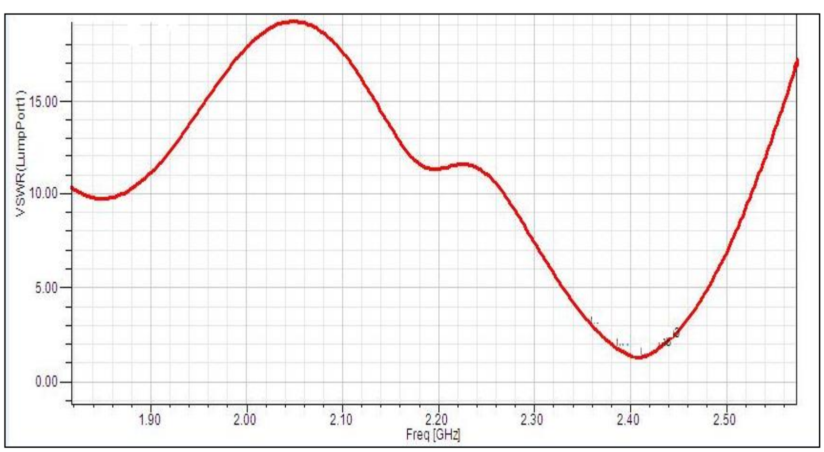

Fig.5:.VSWR of phase shifter IC 2484

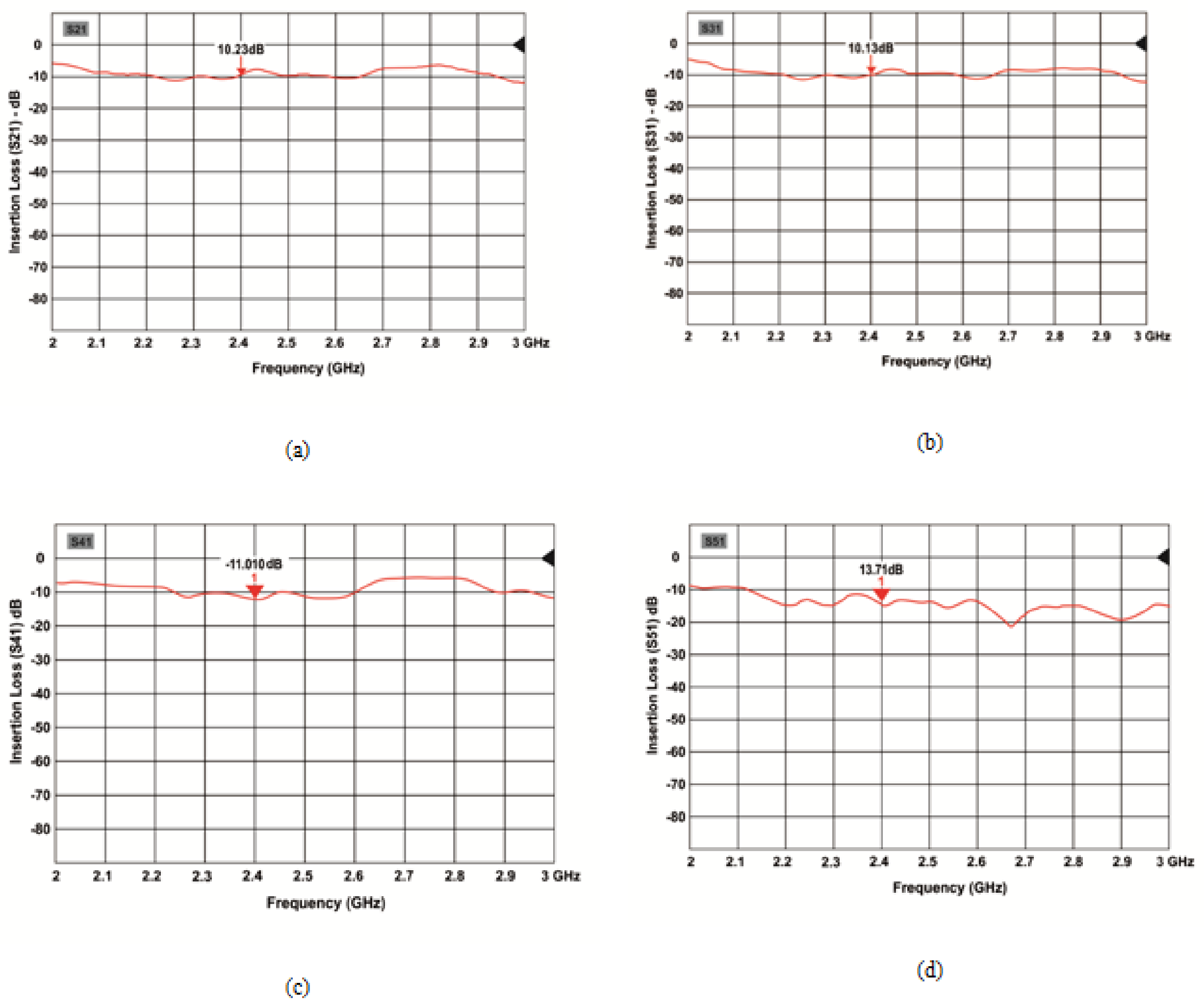

Fig.6: (a-d) Insertion loss of power divider + phase shifter

The variation of insertion loss from port 2 to port 5 is -10.23dB,-13dB,-11.0dB and -13.71dB respectively.These variations are due to a fabricated power divider and SMA connectors.After dedcuting the insertion loss due to the power divider the net insertion losses that occur due to the phase shifter at ports 2,3,4 and 5 are -3.03dB,-2.53dB,-3.4dB and -5.91dB respectively.The average value of the insertion loss is 3.71dB which is well within the specified value that is 5.6dB (Max.).The VSWR is 1.33:1 as compared to 1.5:1 as specified.These results indicate the improved performance of the proposed phase shifter.

Table 3: Measured result for Feed network (power divider and phase shifter)

Experimental Result	**Insertion loss in dB**				**Average Insertion loss in dB**	**VSWR**	**Centre Frequency**
	S_{21}	**S_{31}**	**S_{41}**	**S_{51}**			
Power divider + phase shifter	-10.23	-10.13	-11.0	-13.71	-11.26		
Power Divider	-7.2	-7.6	-7.6	-7.8	-7.55	1.33:1	2.45 GHz
Phase shifter	-3.03	-2.53	-3.4	-5.91	-3.71		

6. EXPERIMENTAL SETUP FOR RADIATION PATTERN

The phase array antenna system is assembled and shown in Figures 7(a-b) where a designed 1:4 WPD is used to input the proposed phase shifters. A four element linear antenna array is used to validate the result of phase shifter.

(a) (b)

Figure 7 (a) Internal layout of antenna array, (b) Antenna measurement system for measuring radiation pattern

The phase shifter is excited by the control voltage and the progressive phase shifts obtained are as shown in Table 2; it is given to each antenna element. The radiation patterns shown in Figures 8(a-c) for different phase shift show that the phase shifters are able to successfully steer the antenna beam in the desired direction. The accuracy of the radiation pattern from Table 4 is ±5%.It shows that the accuracy of calibration of progressive phase angles is within limits.

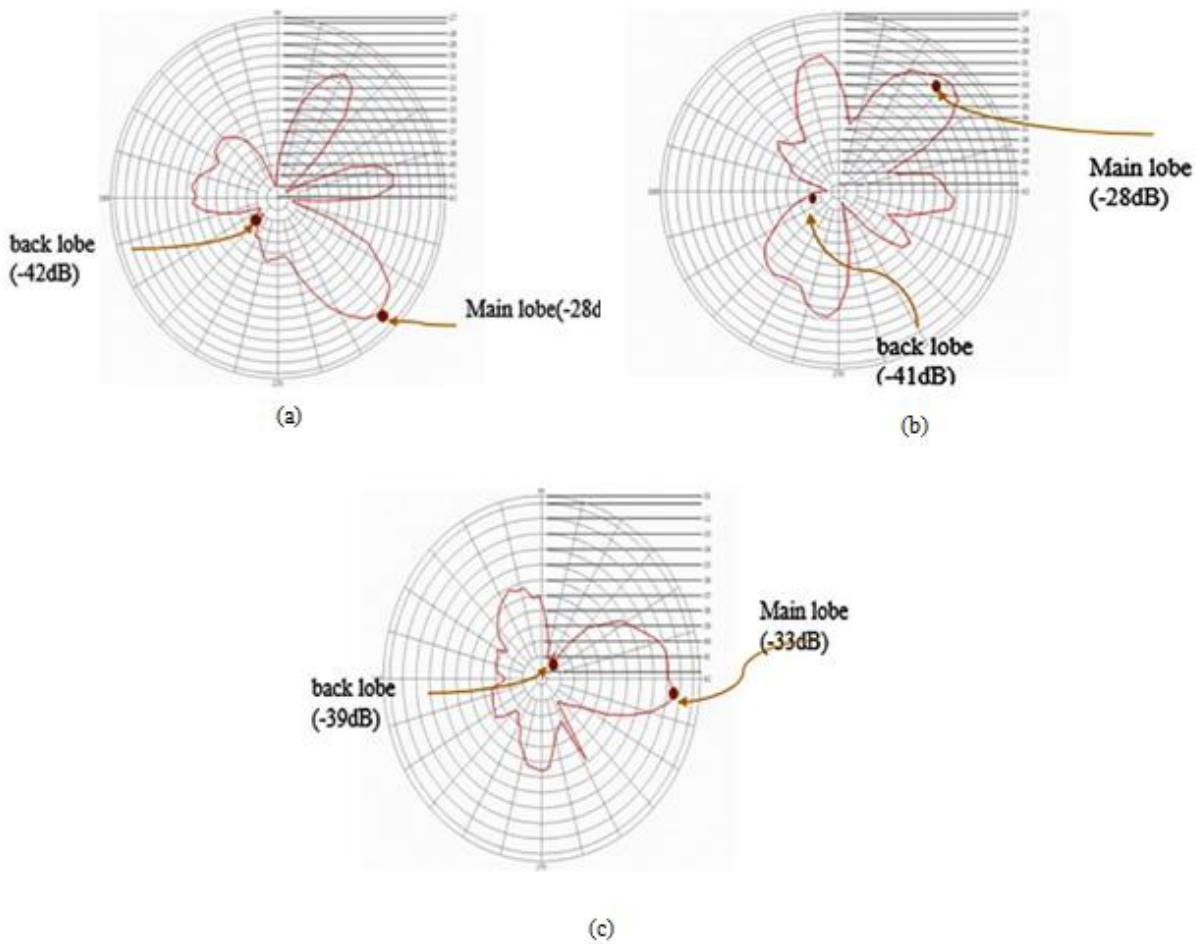

Figure 1Fig. 8: (a) Direction of radiation pattern at 60°,(b) Direction of radiation pattern at 75°, (c) Direction of radiation pattern at 10°

Table 4: Measured values of radiation pattern

Beam Position	Beam Angle	
	Theoretical ΔΘ	Experimental ΔΘ
Centre	0 ˚	10˚
Left	62 ˚	60 ˚
Right	80 ˚	75 ˚

7. RESULTS AND DISCUSSION

The concept of miniaturized phase shifter arose from the fact that there are number of phase shifters presented till date but none is free from limitations such as high cost ,heavy weight, narrow frequency band, less reliability, higher insertion loss and return loss. Hence, based on the market survey, given in Table 1, an analog IC 2484 is considered for the proposed phase shifter which specifies a low insertion loss -5.6dB,VSWR=1.5:1,weight = 3gms,size = 20.40×11.43 mm^2,control frequency of dc 50kHZ,operating frequency 2.15-2.484GHz with a fabricated layout on a substrate Rogar-RO4350 (dielectric constant 3.5 and thickness of 0.762mm).

The calibration of the IC 2484 is very crucial. It is because the control voltage needs to be calibrated in terms of the phase angle in degrees. A detailed layout of the system diagram is drawn to explain the calibration of the phase shifters connected in the system. The control voltage to each phase shifter IC is controlled through a phase control switch. A fine control provided on each control line is used to set the control voltage precisely. A graph of the control voltage versus phase angle for each phase shifter is plotted which helps to set through progressive phase shifts to the input of the phased array elements. The graphs shown in Figures 2(a-d) show that the first and second sets of the calibrated readings for the progressive phase shift as shown in Table 2 operate in the first quadrant and fourth quadrants only. For the third set of readings the first and the second phase shifters operate in the first quadrant and the third and fourth phase shifters operate in the fourth quadrant.

Figures 4(a-d) depict the S-parameters, that is the insertion loss which varies from -2.53dB to -5.91dB.It may be due to the unaccounted losses in connecting the SMA cables and the power divider. The average insertion loss of the 4 ports is -3.71dB which is well within the specified value of -5.6dB. Based on the VSWR (1.33:1), the calculated return loss is -18dB.Hence the obtained parameters quantify the phase shifter behavior.

To validate the accuracy of the progressive phase shift generated by the proposed phase shifter, three radiation patterns are observed which showed that the shift in the radiation pattern is ± 5% which validates the accuracy of the progressive phase shift between the existing phase shifter and the proposed one operated at L and S bands. The performance comparison shown in Table 5 clearly shows that the prototype is superior in terms of bandwidth and insertion loss.

Table 5: Parametric comparison between presented and existing phase shifters

Reference	Technology	Frequency (GHz)	Insertion loss (dB)	Return Loss (dB)
1	HP/LP,PIN diode,PCB	2.4 to 2.5	8.8	13
33	HP/LP, MMIC	2.7 to 3.5	5	15
34	Tl,SW,PCB	1 to 2.0	4	12
35	PIN diode,PCB	2.4 to 4.0	12.5	10
Proposed work	**IC 2484**	**2.15 to 2.484**	**3.7**	**18**

8. CONCLUSION

A high performance 2.45GHz L-band and S-band phase shifter based on IC 2484 is analyzed, calibrated and tested at the center frequency of 2.45GHz.It offers a low insertion loss of -3.7dB and VSWR 1.35:1.The bandwidth varies from 2.15 to 2.484GHz.The degree of deviation in the radiation pattern is ±5% as compared with the theoretical and experimental results. From Table 3 the insertion loss from ports 2, 3, 4 and 5 is -10.23dB,-10.13dB,-11.0dB and -11.26dB respectively. The variation in parameter is due to the unaccounted losses in connecting wires and power dividers. The deduction of insertion loss of power dividers gives the insertion loss due to phase shifters only. It amounts to -3.03dB,-2.53dB,-3.4dB and -5.91dB.Hence the average insertion loss is -3.71dB. This is below the specified insertion loss of IC 2484.Similarly the VSWR is 1.35:1 as compared to the specified VSWR of 1.5:1.

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