INTEGRATING 77GHZ LNA/PHASE SHIFTER CHIP WITH PCB MICROSTRIP PATCH ANTENNA FOR ARRAY APPLICATIONS

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Abstract - *For mm-wave radar applications, integrating the antenna element with active components on a single chip, occupies more die area and increases the cost of manufacturing. In an array application, required spacing between the neighboring antennas also causes to employ much larger chip area to handle overall system on a single chip. In this paper, we propose to embed the on-chip LNA/active phase shifter component on the PCB board to combine with the designed microstrip patch antenna and decrease the cost of fabrication. The antenna and passive components are implemented on 130um thick RO3003 board with dielectric constant of 3 at 77GHz, while the on-chip LNA/phase shifter is manufactured on 11.4um height silicon dioxide located on silicon substrate manufactured by IHP 0.25 um SiGe BiCMOS process. The size of the patch antenna which is operating at 77GHz is 1.050mm×1.41mm. The size of the CPW including the chip area and CPW/u-strip transition is 1.8mm×4.7mm. This circuit is a preliminary prototype to examine the effect of wire bonding and mm-wave on PCB board for applying multiple antenna/phase shifter circuits in a beam-steering array.*

INTRODUCTION

Applications of the mm-wave at 60 GHz for wireless communication, 77 GHz automotive radar and imaging at 94GHz and 140GHz have been increased in recent decades [1]. Radar sensors operating at 77 GHz are used for collision avoidance at long range; since it can penetrate through fog and heavy dust and has high resolution, while the sensors at 24 GHz are employed for short range applications; such as vehicle parking [2]. Automotive cruise control systems and especially 77 GHz automotive radar is coming up with new features every day [3-4]. Open literature presents improved low noise amplifiers, phase shifters and also methods which results in better antenna performance, gain and directivity [5].

With development of the chip integration technology, radar transceiver modules are being integrated inside a single chip [3-4]. However, when multiple antennas or all components of radar are integrated inside a single chip, the occupied chip size is increased due to large antenna sizes. Each designer proposes new methods to reduce either chip size or cost of his structure. Most of the times, each component is designed individually and then connected to each other [6] to examine the performance of the targeted system. Connecting different modules at lower frequencies may be easier, but as the frequency is increased, the connections are going to be more sensitive and in some cases impossible; at higher frequencies the size and accuracy of the connections have significant effects on transmitted/received signals.

In this paper, we present the integration of a patch antenna to an active phase shifter circuit with transitions between u-strip and CPW transmission lines.

PCB CIRCUIT BOARD

The overall schematic of the circuit, including the patch antenna, active phase shifter, u-strip to CPW transition and the probe is shown in Fig. 1. Microstrip patch antenna, u-strip to CPW transition and the solderless probe are etched on the PCB board and the LNA/phase shifter chip with GSG pads are connected to CPW transmission lines using wire bonding. In this figure, the chip cavity is the etched area on the PCB board in which the chip is located and wire bonded to the adjacent CPW lines. The on-chip active phase shifter is biased using wire bonded DC pads on the PCB (Fig. 1). A u-strip/CPW transition is designed to convert u-strip transmission line signal to coplanar waveguide type. The CPW/u-strip transition is designed in the way to have minimum return loss of better than 20dB. The size of the patch antenna which is operating at 77GHz is 1.050mm×1.41mm. The size of the CPW including the chip area and CPW/u-strip transition is 1.8mm×4.7mm. The wire bonding for transmitting the RF signal from board to chip results in about 2-3dB insertion loss and causes to return loss degradation at input (feeding port) and output (antenna port) ports.

Although the chip is composed of LNA and phase shifter, the effect of phase shifting cannot be seen at the antenna system performance (beam steering) since this design contains only one antenna. This circuit is a preliminary prototype to examine the effect of wire bonding and mm-wave on PCB board for applying multiple antenna/phase shifter circuits in a beam-steering array.

The antenna is matched to a 50 ohm microstrip transmission line using inset feeding method. Microstrip to CPW transmission line transition is optimized and designed for maximum return loss by bending the edge of the ground lines and adjusting the length of the lines. Microstrip transmission line is connected to Vector Network Analyzer (VNA) using Rosenberger solderless surface mount (SSM) PCB connector from probe as shown in Fig.1.

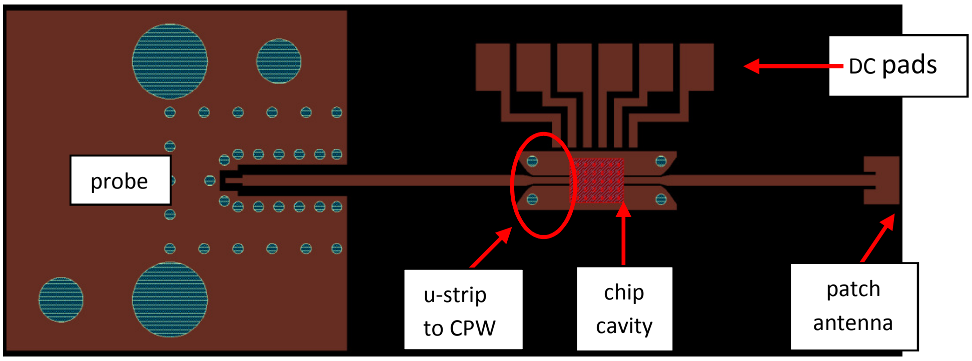

Fig. 1: Schematic of the PCB board

PATCH ANTENNA

The antenna is designed on Rogers RO3003 laminate with permittivity of $\varepsilon_r = 3$ and loss tangent of tan δ = 0.0013 with 130um thick dielectric between two copper foils with thickness of 17um. The antenna is initially designed and optimized at 77 GHz for values of L = 903um, W = 974um and y_0 = 376um in Fig. 2., for the antenna length and width and feed distance from the edge of patch using formulas in [7-8].

Further, the antenna is simulated and optimized for S11 and radiation pattern at 77GHz using electromagnetic simulator software HFSS. Simulations accomplished by setting L = 1049um, W = 1412um, y_0 = 343um and g = 100um to approach the required return loss and gain at the desired frequency. Simulation result for S11 in Fig. 3 shows 39 dB return loss at 77.5 GHz with 2.7 GHz 10dB-bandwith around the resonance frequency. The antenna has maximum gain of 8 dBi at $\theta = 25^0$, $\phi = 0$ with 5.75 dBi gain at $\theta = 0^0$. 3D radiation pattern resulting from HFSS simulator is shown in Fig. 3.

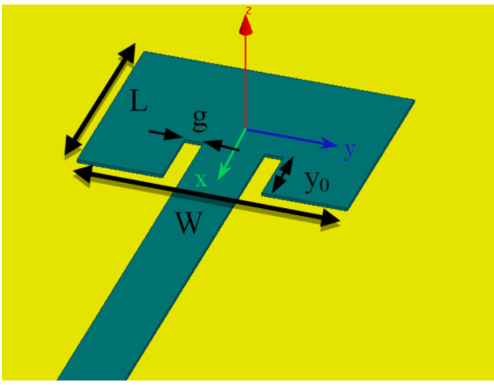

Fig. 2: Patch antenna schematic

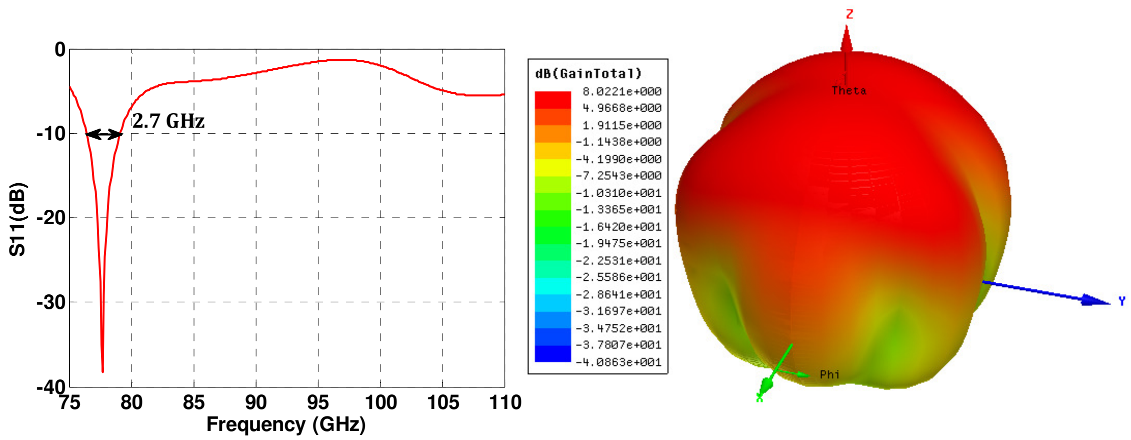

Fig. 3: Simulated S11 versus frequency and 3D radiation pattern at 77GHz.

LNA/PHASE SHIFTER CHIP

To amplify and change the phase of the received signal from the inset fed patch antenna, a 3-way LNA/phase shifter as shown in Fig. 4 is to be used. The overall aim of this configuration is to scan all 0^0 to 360^0 by dividing it to three equal 120^0 sections. In this method, two branches of three branches in Fig. 4 are turned on by biasing the corresponding LNAs placed on those two branches; and by changing the bias voltages of the LNAs, the gain of the amplifiers are controlled. Each branch value can be shown by a vector in polar coordinates, containing certain phase (one of 0^0, 120, 240^0) and magnitude which is controlled by the bias voltage of the LNA. When two branches are selected by biasing the LNA on those branches, the output phase and magnitude would be the vector summation of the two vectors. As an example, when LNA 1 and LNA 2 are biased, two vectors with phases 120 and 0 degrees and magnitudes which are specified by the LNA 1 and LNA 2 gains are added and the resultant vector phase and magnitude will change between 0 and 120. Consequently, by biasing each combination of LNA1-LNA2, LNA1-LNA3, and LNA2- LNA3, spans of 0-120, 120-240 and 240-360 degrees can be covered. The design and more detailed information for LNAs gain at different bias voltages have been presented in [9].

Layout picture of the chip which will be used is shown in Fig. 5. Three input and output GSG pads at right and left side of the layout are seen in Fig. 5 which will be wire bonded to the CPW transmission line on PCB board, while the located pads on upper and lower parts of the chip are ground and bias pads for LNAs which are wire bonded to the DC pads on the board. The size of the designed chip is 1.5mm×1.1mm which will be located on rectangular cavity at the middle of the CPW in Fig. 1.

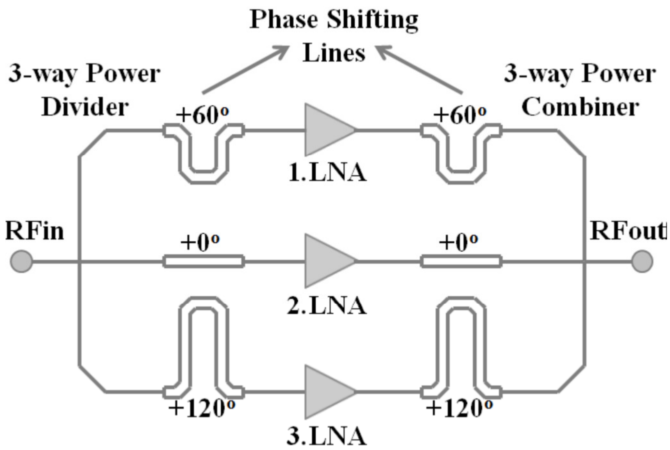

Fig. 4: Schematic of the 3-way chip phase shifter [9]

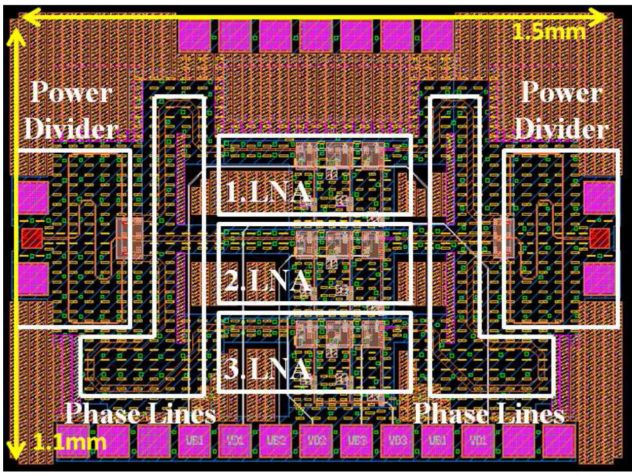

Fig. 5: Layout of the 3-way chip phase shifter [9]

MICROSTRIP AND CPW TRANSMISSION LINE

The designed LNA/phase shifter chip will be manufactured using 0.25 SiGe BiCMOS IHP process. The phase shifter chip in Fig. 5 is terminated by coplanar GSG pads, and is biased by DC pads placed around the chip. To integrate the chip on the PCB board, the RF and DC signals on the chip will be connected to corresponding signal trace and DC pads on the board. To place the chip on the board, a u-strip/CPW transmission line is designed and in the middle of the CPW line, a rectangular cavity is drilled to place the chip. GSG pads of the chip are wire bonded to the RF signal line and ground line on the board. The bias pads of the chip may also be wire bonded to the DC pads on the board. Since the patch antenna and Rosenberger feeding probe are carrying signal using microstrip transmission line, the RF signal on coplanar waveguide transmission line needs to be converted to the microstrip line at both sides. The designed CPW and microstrip transmission lines on RO3003 board have different signal line widths and cannot be connected directly. To reduce mismatching and to have maximum return loss when passing from microstrip to CPW, signal lines of the two structures are connected to each other with linear-slope λ/4 (at 77 GHz) long lines initially, and then the ground plane of CPW, transition length and shape of signal line are optimized to achieve minimum S11. As it is seen in Fig. 6 the structure is optimized with respect to two lumped ports at the edge of microstrip lines and the chip location on middle of the CPW line on PCB board is removed to place and wire bond the chip pads to CPW line. The designed microstrip/CPW/microstrip which is accompanied by optimum lengths for proper matching is presented in Fig. 6. S-parameters for the designed structure is shown in Fig. 7. The S11 in Fig. 7, presents desired matching for two microstrip/CPW and vice versa transitions which demonstrates the return loss for one transition is better than 28 dB. There is 0.9 dB insertion loss between two ports. These S11 and S21 values will degrade on the PCB board due to mismatches from wire bonding.

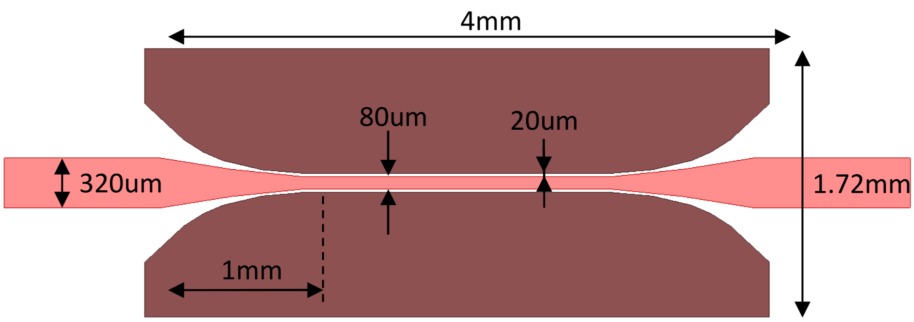

Fig. 6: Schematic of the optimized microstrip/CPW/microstrip

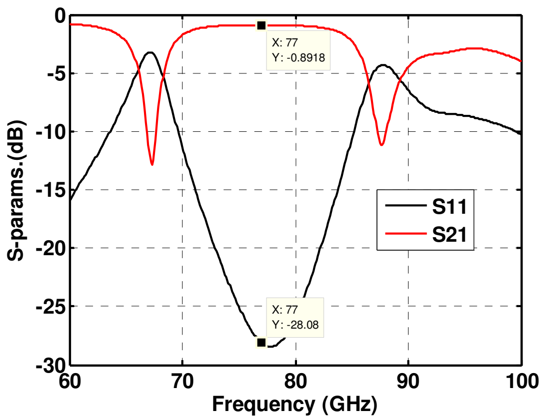

Fig. 7: Simulated S-parameters for microstrip/CPW/microstrip transmission line

SURFACE MOUNT PROBE

To connect the circuit to Vector Network Analyzer and measure the received signal the simple solderless surface mount RPC-1.00 (up to 110 GHz) Rosenberger probe will be used. This type of the probe is easily screwed to the PCB board and stable to any vibration compared to W band needle type GSG probes. The RPC-1.00 Rosenberger probe is shown in Fig. 8.

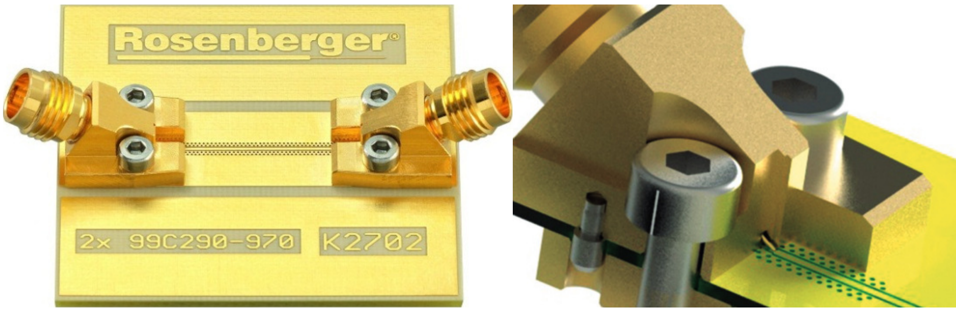

Fig. 8: Surface mount RPC-100 Rosenberger probes [10]

CONCLUSIONS

Integration of a single chip to an antenna on a PCB board is shown for mm-wave frequencies. A single chip containing active phase shifter is connected to a CPW line on a RO3003 PCB board which contains a microstrip patch antenna. A perfectly matched microstrip to CPW transmission line transition with small insertion loss at W band is also presented. The design and simulation results of microstrip patch antenna, CPW to u-strip transmission line transition are shown. The procedure of integrating active and passive components on the PCB board is explained. After manufacturing the PCB board, active phase shifter chip will be wire bonded to the designed circuit using gold wires.

ACKNOWLEDGMENT

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REFERENCES

[1] D. Liu, B. Gaucher, U. Pfeiffer and J. Grzyb, Advanced millimeter-wave technologies: antennas, packaging and circuits, John Wiley & Sons, 2009.

[2] D. Neculoiu, S. I. Ene, A. A. Muller, C. Buiculescu, "Electromagnetic Modelling and Design of 77 GHz Antennas in LTCC Technology," International Semiconductor Conference, pp. 341-344, Oct. 2009.

[3] A. Babakhani, X. Guan, A. Komijani, A. Natarajan, and A. Hajimiri, "A 77-GHz Phased-Array Transceiver With On-Chip Antennas in Silicon: Receiver and Antennas," *IEEE J. Solid-State Circuits*, vol. 41, no. 12, pp. 2795–2806, Dec. 2006.

[4] J. Hasch, E. Topak, R. Schnabel, T. Zwick, R. Weigel, and C. Waldschmidt, "Millimeter-Wave Technology for Automotive Radar Sensors in the 77 GHz Frequency Band," *IEEE Trans. Microwave Theory Tech.*, vol. 60, no. 3, pp.845-860, Mar. 2012.

[5] J. Schoebel and P. Herrero, "Planar Antenna Technology for mm-Wave Automotive Radar, Sensing, and Communications," in *Radar technology,* Croatia: Intech, January 2010, pp.297-318.

[6] S. Beer, B. Gottel, C. Rusch, H. Gulan, T. Zwick, "Off-Chip Antenna Designs for Fully Integrated, Low-Cost Millimeter-Wave Transceivers," *International Workshop on Antenna Technology (iWAT)*, pp.199-202, Mar. 2013.

[7] E. O. Hammerstad, “Equations for Microstrip Circuit Design,” Proc. Fifth European Microwave Conf., pp. 268–272, September 1975.

[8] R. F. Harrington, Time-Harmonic Electromagnetic Fields, McGraw-Hill Book Co., p. 183, 1961.

[9] E. Ozturk and I. Tekin, “A Novel Three Vector Sum Active Phase Shifter Design for W-Band Automotive Radar Applications,” Microwave Opt Technol Lett, Vol. 56, Issue 7, p. 1715–1721, 2014.

[10] http://www.rosenberger.com/en/products/tm/precconn.php