77 GHz PCB Patch Antenna

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Abstract: This paper presents simulation and measurement results of a microstrip patch antenna at W band, fed by using simple solderless surface mount PCB connector. The antenna is designed on Rogers RO3003 board to be operated at 77 GHz, as the antenna of an automotive radar receiver. To calibrate the measurement setup, TRL (Through-Reflect-Line) calibration kit is also designed on the same PCB board. Antenna reflection coefficient is measured at W band with 2.5 GHz shift in resonant frequency due to board lower dielectric constant at the operating frequency. The antenna co-polarized radiation pattern is measured on patch H plane for a span of 100° at 77 GHz. The antenna has a measured and simulated gain of 5 dBi and 5.75 dBi at $\theta = 0°$ and 77 GHz, respectively.

1. Introduction

As the frequency of operation increases to millimeter waves, size of the RF circuits and antennas are decreased. Fabrication of the small size RF circuits and antennas on printed circuit boards (PCBs) are feasible with accuracies up to 1 µm with instruments like CNC controlled and laser circuit-board plotters. When the millimeter wave antennas are implemented, there can be differences between simulated and measured results due to various reasons: low accuracy modeling in simulation, uncertainty in used substrate dielectric constant, fabrication tolerances, calibration and measurement system/operator errors.

Moreover, probing the antenna and specially using GSG type probe can cause uncertainty in the antenna measurement results. It is our experience that Air Coplanar probe (ACP) can couple with the feed surrounding at the probe tip and can change the antenna performance. Therefore, the antenna is designed to be fed using Rosenberger solderless surface mount (SSM) PCB connector which is electromagnetically isolated from its environment up to the probe feeding edge. This perfect shielding of the probe will remove its coupling effects during measurement and act similar to ideal 50 Ω port.

In this paper, a microstrip patch antenna design and measurement results are shown. The antenna is matched to a 50 Ω microstrip transmission line using inset feeding method. PCB dielectric constant is calculated at W band by sweeping ε_r and tuning the simulated antenna S_{11} at its measured resonant frequency. Furthermore, a two port TRL (Thru-Reflect-Line) calibration kit based on two different length transmission lines, open/short and thru standards for Rosenberger SSM probes is designed and manufactured on the same PCB board.

2. Antenna Design

The antenna is designed on Rogers RO3003 laminate with permittivity of $\varepsilon_r = 3$ (< 40GHz) and tan δ = 0.0013 with 130 µm thick dielectric between two copper foils with thickness of 17 µm. The antenna is optimized to be operated at 77 GHz. Initial values of L = 903 µm (resonant length), W = 974 µm (patch width in y direction) [1] and y_0 = 376 µm (feed distance from the edge of patch) [2] are calculated for operation at 77 GHz.

The antenna is simulated and optimized for S_{11} and radiation pattern at 77 GHz using HFSS. Simulations accomplished by setting L = 1049 µm, W = 1412 µm, y_0 = 343 µm and g = 100 µm (gaps around inset feed) to approach the required return loss and gain at the desired frequency. The fabricated antenna fed by Rosenberger probe is presented in Fig. 1. Simulation shows good matching at 77 GHz and maximum gain of 8 dBi at $\theta = 25°$, $\varphi = 0°$ with 5.75 dBi gain at $\theta = 0°$.

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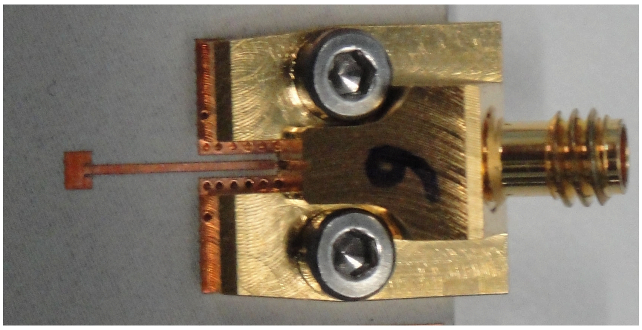

Fig.1 PCB patch antenna and the SSM probe

3. Calibration Kit

The TRL calibration which includes highest accuracy and minimal standard definition is designed for implementation on the RO3003 board and for Rosenberger SSM RPC-1.00 (up to 110 GHz) probe pad. The fabricated kit is shown in Fig. 2. This method requires very good transmission lines with high accuracy in signal trace width and length. The electrical length difference between two transmission lines is not allowed to exceed 180°; to guarantee that the phase difference between two different long lines fall into the confined range, they are designed with electrical length difference between 10° to 170°. Since the frequency changes will change the phase difference between two fixed length lines, the design is valid only for limited band of frequency. Difference in electrical length of two transmission line with Δl difference is given by [3]

$$\Delta\theta = \frac{360 f \Delta l}{v_{ph}}, \quad 0 < \theta < 180$$

v_{ph} is the phase velocity on transmission line with

$$v_{ph} = c/\sqrt{\varepsilon_{r,eff}}.$$

To satisfy the condition on $\Delta\theta$, 9.3 mm and 10 mm long transmission lines are designed. Calculated $\Delta\theta$ for these lines lies between 100° to 150° in W-band.

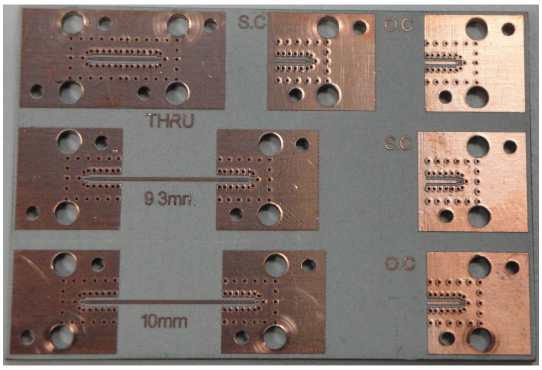

Fig.2 W band PCB TRL calibration kit

4. Measurements

The antenna (Fig. 1) and the calibration kit (Fig. 2) are manufactured using laser plotter with good accuracy. W band extenders are used to increase the frequency of 50 GHz PNA network analyzer to 75-110 GHz. The antenna measured and simulated reflection coefficients are displayed at W band in Fig. 3. The antenna is resonating at 80 GHz with a return loss of 35 dB. A 3 GHz frequency shift between measurement and simulation results can be attributed to the assumed dielectric constant with value of $\varepsilon_r = 3$ during the antenna design/simulations. This value is reported for frequency range of 8 to 40 GHz in the datasheet of the RO3003 PCB board, while the resonant frequency of the measured antenna shows that the dielectric constant of the board is around $\varepsilon_r = 2.8$ at W band. Antenna radiation pattern is measured in patch H-plane (*yz*-plane in Fig. 1) at 77 GHz. Simulated and measured co-polarization radiation pattern in H-plane are shown in Fig. 4. The measured gain of the antenna is around 5 dBi at $\theta = 0°$ which is lower than the 5.75 dBi simulated gain due to shift in fabricated antenna resonant frequency.

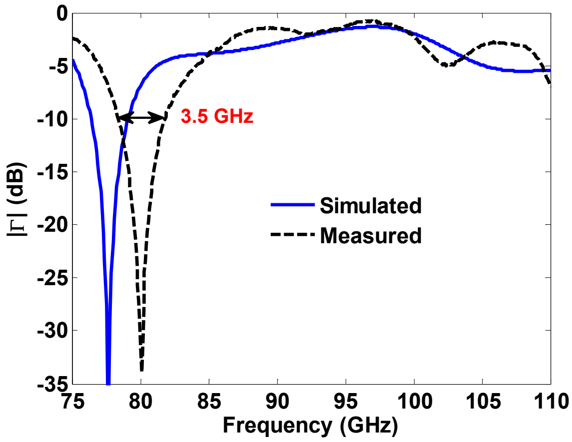

Fig.3 Measured and simulated S11 versus frequency

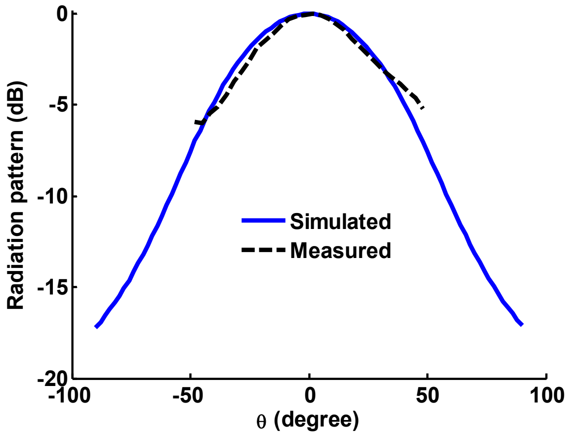

Fig.4 Co-pol radiation pattern on H-plane at 77 GHz

Measurements are done at SUNUM of Sabanci University. Antenna radiation pattern is measured between ±50° using a manually turning setup with a 25 dBi gain horn antenna.

5. Conclusions

A patch antenna for application in automotive radar is designed and fabricated on RO3003 PCB board. A W-band TRL calibration kit and surface mount probes up to 110 GHz are used in measurements. S_{11} results for simulation and measurement after calibration show that the calibration kit is working properly. Experimental S_{11} data shows 3.5 GHz 10-dB bandwidth around the resonant frequency of the patch antenna. The measured and simulated radiation patterns are in good agreement. Some difference in measured radiation pattern can arise from reflection around the antenna and measurement setup which is done without any absorber.

References

[1] E. O. Hammerstad, "Equations for Microstrip Circuit Design," Proc. Fifth European Microwave Conf., pp. 268–272, September 1975.
[2] R. F. Harrington, Time-Harmonic Electromagnetic Fields, McGraw-Hill Book Co., p. 183, 1961.
[3] Application Note, LRL/LRM Calibration Theory and Methodology MS4640A Vector Network Analyzer VectorStar™ VNA.