Wideband 94 GHz On-chip Dipole Antennas for Imaging applications

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***Abstract*—Microstrip on-chip dipole antennas with L and T shapes are designed and implemented to operate at W band with large bandwidths for imaging applications. On-chip antennas are manufactured using IHP SiGe BiCMOS run and localized back etching technique for removal of lossy silicon under the antenna. Measured return losses are in good agreement with simulated ones and antennas operate at 95.5 GHz with 15 GHz and 25 GHz (or more) 10dB-bandwidth for L and T antennas, respectively.**

I. Introduction

Dipole antenna has very simple structure and is of great interest of designers since it can resonate in wide verity of designs with providing its length to half wavelength [1]. Integrating most components of transceiver radar inside a chip has taken high effort of designers to use higher frequencies and various designs to minimize chip size and cost. Microstrip dipole antenna can be used in applications such as passive millimeter-wave cameras, imaging and collision-avoidance radars at W-band. It is important to have wide band operation of antennas/circuits for increased resolution in temperature measurements.

High dielectric constant (like Si substrate) and thick substrate excite substrate waves which cause to power lost in substrate, antenna radiation efficiency dropping and also redundant side lobes in radiation pattern of the antenna [2] inside the chip. Removing the silicon substrate beneath the antenna and leave it on thin layer of silicon dioxide with lower permittivity will reduce surface wave energy and improve the antenna performance [3].

II. Antenna design

The strip dipole antenna which is connected to two 50 ohm microstrip lines is tuned to operate at 94 GHz. Localized backside etch (LBE) technology is processed for etching the substrate below the antenna to reduce the power lost by the substrate and increase the antenna radiation efficiency. A lumped LC balun is designed to transmit the unbalanced 50 ohm signal to the balanced differential 100 ohm (two 50 ohm ports of the antenna) terminal. The feeding GSG pad will impose a parallel capacitive (signal pad with ground pads and ground plane) load to the input port and accordingly shift frequency of the reflection coefficient which is alleviated by optimizing the antenna length, inductance and capacitance of the balun circuit.

Both antenna and balun circuit are designed on the 450 um height Si ($\varepsilon_r \approx 11.9$) substrate and 11.4 um thick silicon dioxide ($\varepsilon_r \approx 4.1$). Top metal 2 (metal 5) is used to design the strip dipole antenna on SiO_2 layer and Si substrate beneath the antenna is etched away [4]. However, the balun circuit is implemented using top metal 1 (signal line) and 2 (ground plane) inside the SiO_2 layer.

A. L ShapeAntenna

The antenna with the shape of L, shown in Fig. 1 (a), is designed using the embedded top metal 2 in SiO2 layer. The antenna and etching part dimensions are optimized for operating the antenna at 94 GHz by exciting two 50 ohm microstrip lines which are connected to the antenna arms with a differential 100 ohm port. All simulations are performed in presence of a large ground plane (20×20 mm^2) under the Si substrate ($\lambda_0 \approx 3.2mm$). Some frequency shift will happen in antenna resonance by inserting the top metal 1 as the ground of RF circuit which is attributed to the coupling between strip antenna and RF ground. Effect of the coupling is also considered by optimizing antenna length, spacing between strips and RF ground and etching dimension. The current flows on the bent arms at two sides of the RF ground plane are in opposite direction, and consequently the corresponding parallel radiated electric fields will be canceled. Furthermore, the coupling between two parallel adjacent strips is reduced when the antennas are handled together in an array in y direction (shown in Fig. 1). This property will help the designer to bring the antennas in an array close to each other to decrease the size of chip.

B. T Shape Antenna

An antenna with two T shaped arms is shown in Fig. 1 (b) is designed to resonate at 94GHz. The visual difference between L and T shaped antenna is in their shapes. In T antenna, the bent parts have moved up and coupling between these parallel strips and RF ground plane is decreased. Total length of the strip line T shape antenna is more than the length of L shape one that can be attributed to the length of the etched area and coupling between top metal 1 and strips. Dimensions of the different parts of the antenna an etched area are shown in Fig. 1.

C. Balun Design

A lumped component balun circuit is designed to transmit the RF signal from a 50ohm input port to the differential output

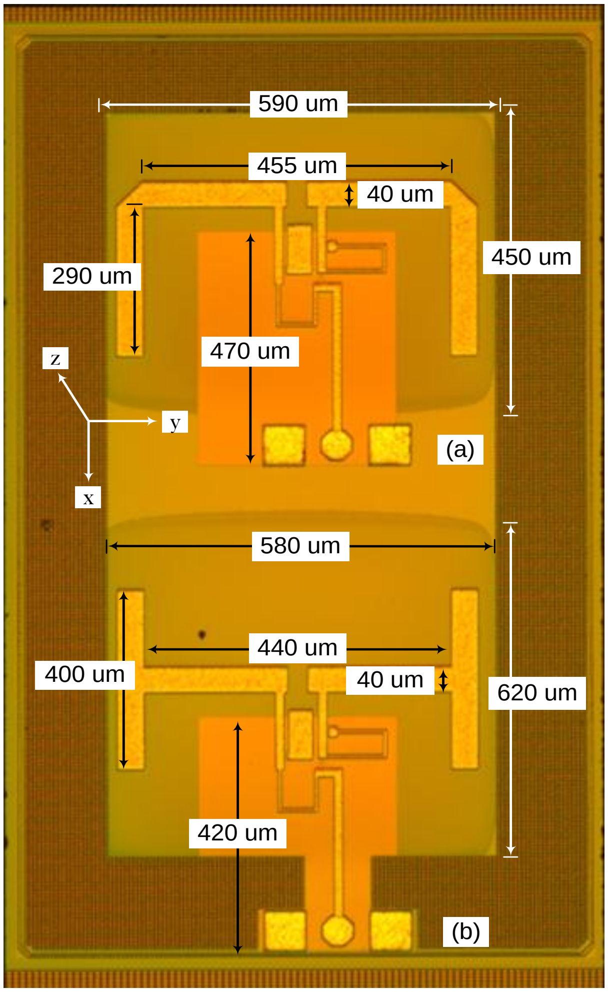

Fig. 1. Micrographic picture of the on-chip (a) L and (b) T shapes strip dipole antennas with different parameters size.

terminal (100 ohm) with 180 degrees phase difference. The input power is divided by two at the output ports and each of the output ports has 50 ohm impedance toward the ground plane. The balun output ports will be matched to the antennas input ports (two 50 ohm microstrip lines) since the antennas are designed by exciting their two 50 ohm ports with a differential 100 ohm port. The calculated values for L (inductance) and C (capacitance) components of the balun at 94GHz are 120pH and 24fF, respectively. The inductors are formed using thin microstrip lines, while the capacitors are realized by the IHP metal-insulator-metal (MIM) technology. The shunt inductor and capacitor of the balun circuit are connected to ground plane by vias. Configuration of the balun circuit is shown in Fig. 1. Although the values of inductors and capacitors are calculated analytically, their values are optimized for achieving the desired outputs in full-wave simulation by including the GSG pads (which applies a capacitive impedance to the input port) into the simulations. After simulations, values of the MIM capacitors are optimized to 20fF for the balun circuits of L and T shapes antennas. Final lengths of the series and shunt inductors [4], respectively, are obtained 140um and 105um for balun circuit of L shape antenna, while these values are 150um and 115um for balun circuit of the T shape antenna.

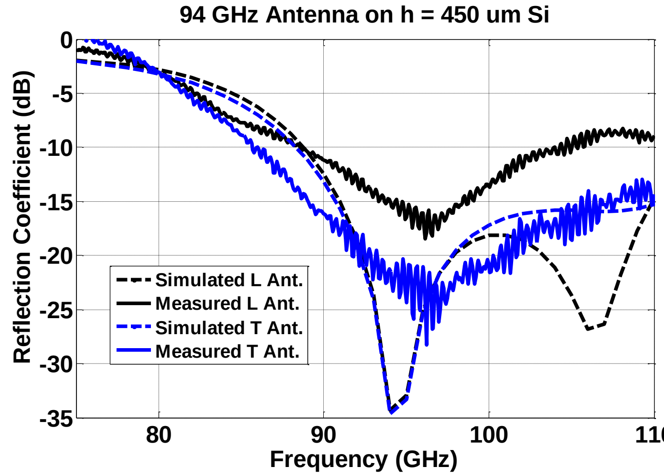

Fig. 2. Simulated and measured reflection coefficient for L and T shapes antennas.

III. Simulated and Measured Results

Micrographic picture of the manufactured antennas are shown in Fig. 1. Both of the antennas are in the single chip. However, the antennas are designed and simulated separately. The simulated and measured reflection coefficient of the L and T shape antennas are displayed in Fig. 2. Both simulated and measured antennas resonate at the same frequencies (94 GHz for designed and 95.5 GHz for measured). The frequency shifts between simulations and measurements may be related to the substrate dielectric constant perturbation, GSG pad modeling and measuring the antennas inside the single chip. The measured results show good performance of the designed antennas in wide bands around resonance frequency. L shape antenna has 15GHz frequency band, where T antenna operates at frequency band more than 25GHz.

IV. Conclusion

Two L and T shaped antenna with balun circuit designed and manufactured to operate at 94GHz. In both of the configurations, the arms of the antennas are bent with 90 degrees and minimize the size of the chip in y direction. The overall chip size for each of the L and T antennas are 790um×750um and 790um×900um, respectively. The antennas fabricated and measured inside a single chip. Simulated and measure result are in good agreement which demonstrate the validity of the simulation results.

Acknowledgement

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