A 77 GHz On-chip Strip Dipole Antenna Integrated with Balun Circuits for Automotive Radar

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***Abstract*—In this paper, design and implementation of a 77 GHz on-chip strip dipole antenna integrated with both lumped and transmission line based balun circuits are presented. The on-chip antenna is realized by using IHP's 0.25 µm SiGe BiCMOS technology with localized back-side etch (LBE) module to decrease substrate loss. The strip dipole antenna is fed by both a lumped LC circuit and strip line tapered baluns integrated on the same substrate and occupies an area of 1x1.2 mm^2 including the RF pads. For increased directivity, the antenna sits on a grounded silicon substrate. Experimental results show that antenna is well matched around the design frequency and achieves 7 GHz impedance bandwidth (minimum return loss of 17 dB) for the LC balun circuit. The antenna and its feeding structure are well suited for 77 GHz single chip automotive radar applications.**

I. INTRODUCTION

With the advance of silicon based technologies (CMOS circuits up to 100 GHZ, SiGe Circuits reaching to almost 1 THz), we see more civilian use of millimeter wave radar especially in navigation, traffic control and safe highway driving. Inline with these developments, ETSI has developed standards for ''short range'' radar for automotive applications in 24 – 77 GHz bands. In 77 GHZ band, there is a 2 GHz bandwidth allocated for an application of a short range automotive radar for the purposes of stop and go, blind side detection, crash avoidance, braking if crash cannot be avoided and to keep safe driving distance with the traffic ahead, [1]. As the frequency is increased, the size of the antenna becomes comparable to the chip size (less than 1 mm) and this brings the opportunity for a highly integrated single chip transceiver integrated with the antenna or antenna arrays.

There is extensive research on on-chip antennas for 77 GHz band for unbalanced type of antennas (such as slot or microstrip patch type of antennas) as well as feeding balun structures for circuit application. In [2], single-ended fed antennas for 77 GHz operation are reported. In [3-4], balun structures are shown for 77 GHz band for small chip area. In [5], a small chip size balun circuit is mentioned to be used with the antenna; however, antenna design is not specified. Especially, when wire/strip type antennas and feeding balun structures on the same chip are in the vicinity of each other, the radiation properties of the antenna is highly affected by the metallic structures of the balun circuit. Hence, this requires the design of both the wire/strip antenna and the balun structure, together. For full integration of mm-wave circuits with the properly designed antenna, the overall chip size is still a problem and has to be small. In this paper, a strip dipole on-chip antenna is designed with the integrated balun structures (both lumped and stripline distributed) to obtain a small sized chip. A standard BiCMOS process with an additional LBE module is used to realize the antenna. Silicon substrate below the antenna is etched away to eliminate the substrate loss, while a ground plane is placed below the silicon substrate for increased directivity/gain.

II. ON-CHIP STRIP ANTENNA AND BALUNS

A microphotograph of the on-chip dipole antenna integrated with the strip line balun is shown in Fig. 1, which is optimized for 77 GHz operation using HFSS version 12.0. The length of the strip dipole antenna is 1100 µm and it has a width of 100 µm with a metal thickness of 3 µm. The feed gap between the arms of the dipole is 40 µm. The dipole arms are deposited on a SiO_2 layer of 11.4 µm, which is placed above a low resistivity substrate Si (20 Ohm-cm) with a thickness 670 µm. The silicon substrate is grounded and the silicon volume under the dipole antenna is removed.

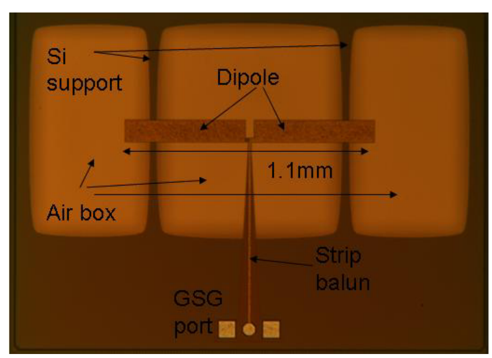

Fig.1 77 GHz dipole antenna and the strip balun

The silicon area which are closer than 400 µm to the arms of the dipole antenna are removed by etching process and three air boxes are formed under the dipole antenna except two blocks of silicon substrate as mechanical supports. Fig. 1 also shows the strip line balun formed by linearly tapering the ground plane of a regular microstrip line. Microstrip line length is 800 µm and has a width of 15 µm. The width of the microstrip ground line is 100 µm at the RF port and achieves 15 µm at the antenna feed point. Vertical profile of the antenna and the substrate etching is shown in Fig. 2.

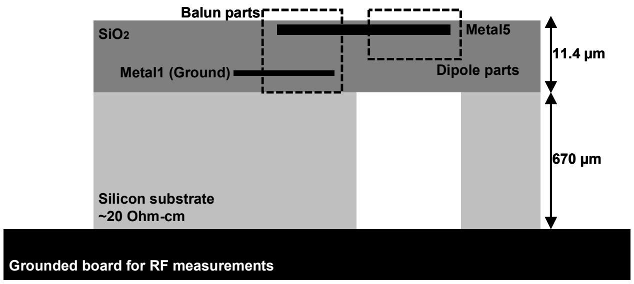

Fig.2. Etched substrate and the metal lines for the dipole

To decrease the total chip area, the on-chip strip dipole antenna is also integrated with the lumped LC balun as shown in Fig. 3. The LC balun converts the single ended signal to differential signals with passive components. The inductors are formed by thin microstrip lines, for capacitances, metal-insulator-metal(MIM) capacitors are used. For 77 GHz, S-parameters and phase simulations are performed using HFSS. An inductor value of 120 pH and a capacitor value of 37 fF are obtained for the balun structure. The balun structure occupies an area of 250 µm x 250 µm (800 µmx100 µm area is required for the strip balun). For measurement purposes, additional 500 µm microstrip line is connected to decrease the effect of RF measurement probe on the antenna radiation. Input impedance measurements are performed with a 110 GHz Agilent Network analyzer with GSG probe.

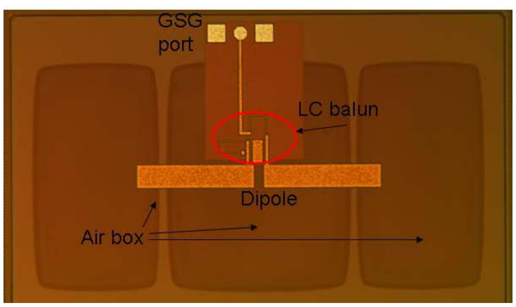

Fig.3 77 GHz dipole antenna and the LC balun

Simulated and measured S_{11} of the dipole antenna with strip balun are given in Fig. 4. Minimum return loss of 15.6 dB is simulated at 75 GHz with a simulated gain of 3.6 dBi. Return loss of 9.7 dB is measured at 79 GHz after deembedding the GSG RF pads. Simulated and measured S_{11} of the dipole antenna with LC balun are given in Fig. 5. Return loss of 21.5 dB is simulated at 75 GHz with a simulated gain of 3.4 dBi. Return loss of 17.9 dB is measured at 74 GHz. Simulated and measurement results agree quite well for the LC balun fed strip dipole antenna. In comparison to strip balun case, the LC balun fed dipole antenna is better matched and achieves 4 GHz impedance bandwidth at 75 GHz. Note that by implementing varactors instead of capacitances, one can tune the center frequency of the LC balun. The antennas are already fabricated and being measured for S11 and radiation patterns at 75/77 GHz. Further detailed results will be presented at the

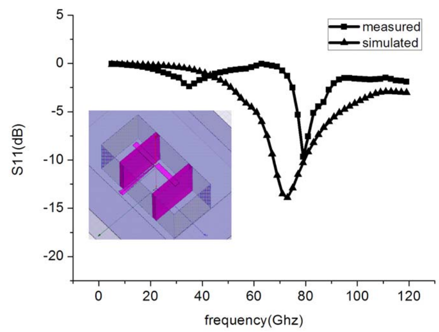

Fig.4 S11 of 77 GHz dipole antenna and the strip balun

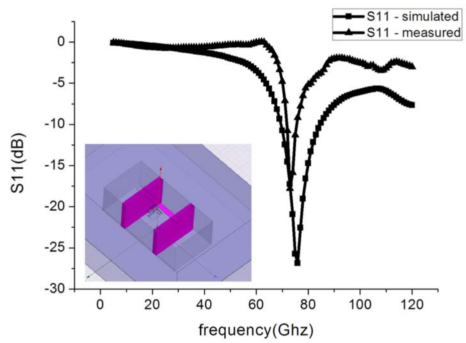

Fig.5 S11 of 77 GHz dipole antenna and the LC balun

ACKNOWLEDGEMENT

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