A 16-Element 77–81-GHz Phased Array for Automotive Radars with ±50° Beam-Scanning Capabilities
Bon-Hyun Ku¹, Paul Schmalenberg², Sang Young Kim³, Choul-Young Kim⁴, Ozgur Inac¹,
Jae Seung Lee², Koji Shiozaki², and Gabriel M. Rebeiz¹

¹ECE, University of California, San Diego, La Jolla, California, 92093, USA
²Toyota Research Institute of North America, Ann Arbor, Michigan, 48105, USA
³Marvell Semiconductor, Inc., Santa Clara, California, 95054, USA
⁴EE, Chungnam National University, Daejeon, 305-764, South Korea

Abstract — This paper presents the first 16-element 77–81 GHz phased array receiver for automotive radars. The silicon phased array chip is packaged using very low-cost techniques, and is attached to a 16-element linear microstrip antenna array. The packaging is designed to result in < -28 dB coupling between the channels even with wirebonds. The measured patterns show scanning to ±50° and agree well with simulations. The 16-element phased array receiver has been implemented with a transmitter and shows detailed images of targets and scenes in outdoor driving scenarios.

I. INTRODUCTION

Silicon W-band automotive radars have been an active areas of research and development in the past 12 years, and are in wide use by the automotive industry for collision avoidance and cruise control [1-4]. Recently, several silicon chips have been developed for automotive radars with scanning (or switch-beam capabilities), and the scanning systems are based on digital or RF beamforming techniques [4, 5]. In particular, a 16-element phased array receiver chip with build-in-self-test capabilities was presented in [6] with state of the art performance in phase and amplitude control. This work expands on [6] by integrating the chip in a low-cost package and demonstrating a W-band automotive radar with wide-angle scanning capabilities.

II. DESIGN

Fig. 1 presents the 16-element phased array receiver chip fabricated in the IBM8HP BiCMOS process. The chip has 8 RF inputs to the left and right side, and LO (38 GHz) and IF (DC-5 MHz) at the bottom. The top connections are DC, digital, SPI, and bias connections. The chip is designed using differential circuitry but the RF input and output ports are single-ended so as to lower the pad count on the sides of the chip. The LO port (38 GHz) is differential to reduce the coupling between the LO and the RF pads. The entire chip is 5.5 x 5.8 mm² and consumes 500–600 mA from a 2 V supply, and the RF performance is presented in [6].

The phased array chip is packaged using a two board design: A top RF board (Rogers 3003, 5 mils thick) and a bottom DC/Control board (FR-4, 20 mils thick). A 5 mils thick mechanical board is also used so that the silicon chip, placed in a 10 mil cavity to reduce the bond-wire lengths, be at the same height as the top board. The CPW lines
close to the chip are 100/100/100 μm which is the smallest size that can be etched reliably on the Rogers board, and result in an impedance of 76 Ω. Also, this allows for a 300 μm (12 mils) ground via between the different channels and results in a grounded-CPW line which greatly increases the isolation between the channels.

The entire half-side of the silicon chip and the CPW feed network is simulated in ANSYS-HFSS. On the silicon side, the balun is included in the HFSS analysis, and therefore the ports are single-ended on the CPW line and differential on the silicon chip. Note that the RF ground are on-top of the silicon chip and the 12 mil via transitions the top silicon ground to the Rogers 3003 ground. A shorted-stub inductor is used to match S11 for each channel since the bondwire have an approximate inductance of 0.25 nH (+10 Ω at 80 GHz). The simulated insertion loss is ~2 dB at 80 GHz and includes the 1.5 dB balun loss on the silicon substrate. The simulated isolation between two adjacent channels, including all the bondwires and via hole effects, is > 28 dB at 60–80 GHz. The achieved low isolation is due to the selection of the spacing between the channels, the grounded-CPW lines, and the short bondwires due to placing the silicon chip in the cavity. In fact, a lot of optimization between HFSS, board-design rules and silicon chip-size was done in order to result in a layout which is compatible with low-cost board fabrication rules (4 mil lines, 12 mil vias, etc.). (The optimization procedure will be presented at the conference if the paper is accepted.)

III. MEASUREMENTS

The phased array chip is first connected to a linear microstrip antenna array using meandered 50-Ω G-CPW transmission lines with a measured loss of 1.2 dB/cm at 80 GHz. The antennas are spaced 2.34 mm apart (0.6λg at 79 GHz) resulting in an amplitude taper due to the different feed lengths of ~2 dB across the array. The 5-bit phase shifters on the silicon chip are first set to compensate for the different feed lengths and to result in a single beam at broadside with -17 dB sidelobes. After this initial setting, the phases are set according to the standard equation:

\[ \Delta \phi = -nkd \sin(\theta_g) \]  

(1)

where \( \theta_g \) is the scanning angle from broadside, and \( n \) is the element number. The measured E-plane patterns (azimuth scan) show ±50° scanning with an average sidelobe level of < -16 dB up to 40°. The measured patterns show a 3-dB beamwidth of 5.3°–6.5° at 0–40°, and agree well with simulations (not shown for clarity purposes). The elevation beam has a beamwidth of ~5.3°. For array gain measurements, the procedure is quite complex due to the active silicon chip with 16 channels, mixers and IF amplifiers. Still, when the electronic chip gain is taken out, there is a ~4–5 dB difference between the gain and directivity at 78–80 GHz (\( D = (4\pi/\lambda^2) \times \text{Antenna-Area} = 30.6 \text{ dB} \)). The additional loss is due to the antenna ohmic loss (1.5 dB), antenna taper (1 dB), average transmission-line loss (1.5 dB), and transition loss (0.5 dB) between the antennas and the silicon chip.
The 16-element phased array has been implemented using a synthesized FMCW transmitter with a fixed (non-scanning) antenna, and mounted on a test car. The FMCW radar signal is also used as the local oscillator for the silicon chip I/Q receiver. A scanning image can then be taken using the scanning radar (Fig. 6). One can clearly see the door being opened in front of the radar showing the imaging capabilities of the phased array receiver.

IV. CONCLUSION

This paper presents the first automotive W-band phased-array radar with ±50° scanning capabilities. The silicon phased-array chip is packaged together with a microstrip antenna array using very low cost techniques. The phased array radar can be used for long-range cruise-control systems (±15° scanning) or for medium-range collision avoidance systems (±50° scanning).

ACKNOWLEDGEMENT

This work was supported by Intel Corporation and by the Toyota Research Institute of North America.

REFERENCES

