AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
Electronics Engineering and Electrical Communications

Millimeter Wave Receiver Front End for Automotive Radar Application

A Thesis submitted in partial fulfillment of the requirements of
Master of Science in Electrical Engineering
(Electronics Engineering and Electrical Communications)

by

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Cairo, 2015

Faculty of Engineering – Ain Shams University
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Statement

This thesis is submitted as a partial fulfillment of Master of Science in Electrical Engineering, Faculty of Engineering, Ain shams University. The author carried out the work included in this thesis, and no part of it has been submitted for a degree or a qualification at any other scientific entity.

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Date: 26 July 2015

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Abstract

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Abstract

This thesis is an attempt to study millimeter wave receivers front end used for automotive radar applications. The phased array systems are founded to be the most suitable systems for radar application due to its ability of electronic scanning and steering. The FCC regulations for automotive short range radar (SRR) and long range radar (LRR) are chosen. A complete radar analysis using the radar equation for the FCC SRR and LRR standards are carried out with determination of each receiver front end specifications.

Different architectures of phased array systems for radar application are studied. A new concurrent dual-band phased array receiver architecture for down-converting the FCC automotive short and long range radar bands located at 25.5 GHz and 76.5 GHz is proposed. A new dual-band antenna array is proposed. In addition, a new concurrent down-conversion receiver is proposed including a dual-band low noise amplifier (DB-LNA) and a dual-band mixer (DB-mixer) using 65 nm CMOS technology.

The front end utilizes a new dual-band phased array receiver based on hybrid Weaver Hartley architecture. Mathematical formulation, including the effect of mismatch for the proposed architecture is provided. A behavioral modeling for the complete RF front-end with the overall radar system is presented, and the effect of noise, mismatch, and non-linearity are examined on the overall radar performance. The behavioral model simulation results show that to achieve a probability of detection of 0.9 and probability of false alarm of 10^{-4}, an RF front-end module with 5.5 dB and 7.5 dB NF and an LNA with an IIP3 of -10 dBm are required in the phased array receiver for the 25.5 GHz band and 76.5 GHz band, respectively.

The proposed dual-band antenna element is demonstrated using microstrip structure based on Bowtie antennas. The dual-band antenna array achieves bandwidth of 6 GHz and 4.5 GHz and an isolation of 13 dB and 15 dB for the 25.5 GHz band and 76.5 GHz band, respectively in an area of 51 mm $\times$ 3.6 mm.

The proposed concurrent DB-LNA and DB-Mixer are demonstrated targeting the FCC automotive SRR and LRR bands. The DB-LNA utilizes a second order dual-band matching network. The DB-LNA achieves a voltage gain of 16 dB and 10 dB and a noise figure of 3.5 dB and 8.2 dB at 25.5 GHz and 76.5 GHz, respectively, with a power consumption of 48 mW in an area of 0.166 mm^2. The DB-mixer utilizes a new dual-band output load network and a dual-band inductive series peaking. The DB-mixer achieves a maximum conversion gain of 8.5 dB and 9.25 dB and a noise figure of 6.6 dB 5.7 dB are achieved for lower and upper band, respectively, with total power consumption of 18.2 mW.

A full circuit integration is provided for the proposed single receiver module of the phased array receiver. The circuit simulation results show that a maximum overall conversion gain of 26 dB and 21 dB and a noise figure of 6 dB 8 dB are achieved for the lower and the upper band, respectively, with total single receiver module power consumption of 233 mW.

Summary

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Summary

The thesis is divided into seven chapters as listed below:

Chapter 1

Chapter 1 has been an introduction to the work, including an overview of automotive radar applications, motivations, and main contributions of this work.

Chapter 2

Chapter 2 introduces the basic theory of radar systems, the FCC regulations for automotive radar, the principle of operation of phased array systems, and a brief survey on wide-band and dual-band low noise amplifiers and mixers.

Chapter 3

This chapter presents the proposed concurrent dual-band phased array receiver, mathematical formulations including mismatched, and behavioral modeling for the over all system.

Chapter 4

In chapter 4, a new dual-band antenna array is introduced. The basic principle of its operation and the main design aspects of the antenna array are presented, In addition, the real implementation of the antenna array is demonstrated using microstrip structure.

Chapter 5

Chapter 5 deals with the circuit implementation of different building blocks of the system. Four different blocks have been designed and implemented using CMOS technology: (1) a wide-band dual-band low noise amplifier, (2) a dual-band mixer, (3) a wide-band 90° phase shifter, and (4) IQ mixers.

Chapter 6

Chapter 6 presents the full circuit integration of the single module of the system. Also, it presents the performance of the system using the circuit level.

Chapter 7

Chapter 7 concludes the thesis work with possible directions for future work.

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