Ain Shams University

Faculty of Engineering

Electronics and Communications Department

Circuits and Systems for MEMS Based Sensors

A Thesis

Submitted in partial fulfillment of the requirements of a Master of Science degree in Electrical Engineering

Submitted by:

Mina Gad Saif Attia

B.Sc. of Electrical Engineering

(Electronics and Communications Department)

Ain Shams University, 2011

Supervised by:

Prof. Dr. Hisham Said Ramadan Haddarah

Dr. Ayman Hassan Abdel-Aziz Ismail

Cairo, 2017

Ain Shams University

Faculty of Engineering

Electronics and Communications Department

Examiners' Committee

Name: Mina Gad Saif Attia

Thesis: Circuits and Systems for MEMS Based Sensors

Degree: Masters of Science in Electrical Engineering

Title, Name and Affiliation	Signature
Prof. Dr. Elsayed Mostafa Saad Helwan University, Faculty of Engineering, Electronics & Communications Dept.	. . . .
Prof. Dr. Mohamed Amin Dessouky Ain Shams University, Faculty of Engineering, Electronics & Communications Dept.	. . . .
Prof. Dr. Hisham Said Ramadan Haddarah Ain Shams University, Faculty of Engineering, Electronics & Communications Dept.	. . . .

Date: 30/07/2017

Curriculum Vitae

Name: Mina Gad Saif Attia

Date of Birth: 28/09/1987

Place of Birth: Cairo, Egypt

First University Degree: B.Sc. in Electrical Engineering

Name of University: Ain Shams University

Date of Degree: June 2011

Statement

This dissertation is submitted to Ain Shams University for the degree of Master of Science in Electrical Engineering (Electronics and Communications Engineering).

The work included in this thesis was carried out by the author at the Electronics and Communications Engineering Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt.

No part of this thesis was submitted for a degree or a qualification at any other university or institution.

Name: Mina Gad Saif Attia

Date: 20/03/2017

Acknowledgment

All praise is due to GOD, Most Loving, Most Gracious, Most Wise and Most Merciful whom I am nothing without him. I would like to thank GOD for teaching me all I know and giving me the strength, ability and patience to complete this work.

I would like also to express my gratitude to my mother and father who made me what I am today for their encouragement and motivation.

I also deeply appreciate my wife's tolerance and patience over working late to make this work possible.

I would like to also thank the rest of my family for their continuous encouragement.

I would like to show my gratitude to Dr. Ayman Ismail for teaching me some of the most important things in circuits design and his kindness to me and generous guidance.

I am deeply grateful to Dr. Hisham Haddara for teaching me the basics of electronic devices and giving me a share of his time out of a very tight schedule.

I also appreciate the help of Ahmed El-Shennawy because this work is based on some of his own work and the time he spend to help me to clarifying some of my misunderstandings related to this work.

I would like also to thank my colleagues at Si-Ware Systems for their kindness and generous sharing of knowledge.

Mina Gad Saif Attia
Electrical and Communications Department (ECE)
Faculty of Engineering
Ain Shams University
Cairo, Egypt
February 2017.

Abstract

Faculty of Engineering – Ain Shams University
Electronics and Communication Engineering Department

Thesis title: **"Circuits and Systems for MEMS Based Sensors"**
Researcher Name: **Mina Gad Saif Attia**
Degree: **Masters of Science in Electrical Engineering**

Abstract

Delta-Sigma ($\Delta\Sigma$) technique represents an optimum way for realizing force-feedback electromechanical systems, especially for capacitive sensors.

Operating the sensor in feedback mode provides many benefits, such as increased signal bandwidth, improved linearity and better temperature stability compared to open-loop mode.

However, with operating the sensor in feedback, the stability of the system becomes a concern, particularly in $\Delta\Sigma$ based systems and the higher the order of the system the harder it becomes to achieve stability. Hence, following a systematic design flow for these systems is essential.

While the design of stable electrical $\Delta\Sigma$ loops is well established, the design of electromechanical $\Delta\Sigma$ loops present challenge due to the nature of the capacitive sensor resonator.

In this work, a way to stabilize fifth-order $\Delta\Sigma$ based interface system for inertial capacitive sensors is introduced and a systematic design approach is proposed.

The design approach is based on noise transfer function (NTF) matching which translates the system design problem to an NTF design problem as in electrical $\Delta\Sigma$ loops.

The design approach is applied to the design of a fifth-order $\Delta\Sigma$ based interface for a capacitive accelerometer.

The sensor has a 0.12 μg proof-mass, a resonance frequency of 8 kHz, a displacement-to-capacitance factor of 3.22 pF/μm and a feedback factor of 0.7 μN/V^2.

The designed system achieves a signal-to-quantization noise ratio (SQNR) and signal-to-noise and distortion ratio (SNDR) of 181 dB and 131 dB respectively.

key words: Delta-sigma (ΔΣ), force-feedback, fifth-order, accelerometer interface, noise transfer function (NTF).

Summary

Faculty of Engineering – Ain Shams University

Electronics and Communication Engineering Department

Thesis title: **"Circuits and Systems for MEMS Based Sensors"**

Researcher Name: **Mina Gad Saif Attia**

Degree: **Masters of Science in Electrical Engineering**

Summary

The thesis is divided into seven chapters as listed below. Chapters 4, 5, 6 and 7 present the details of the research work of this thesis, while the earlier chapters serve as a background material:

Chapter 1

Chapter 1 explains the background, motivation, and objective of this work and also gives a brief summary for the thesis organization.

Chapter 2

Chapter 2 provides a comparison between conventional accelerometers and the miniaturized ones in addition to the basic theory of operation of microaccelerometers and their most common types.

Chapter 3

In Chapter 3, different interfacing techniques to the MEMS accelerometer sensor are introduced. The differences between open-loop and closed-loop sensing methods are outlined and then force-feedback concept is explained. In addition the different techniques to convert the sensed capacitance to voltage are presented.

Chapter 4

Chapter 4 discusses the different architectures of $\Delta\Sigma$ electrical modulators and how to transform the electrical $\Delta\Sigma$ modulator to an electromechanical modulator. Then the linear model of electromechanical modulators is explained.

Chapter 5

In Chapter 5 the proposed design approach of the $\Delta\Sigma$ based electromechanical sensor system is presented. The steps of matching the noise transfer functions of the electrical and the electromechanical modulators and how to solve the system equations to calculate the feedforward/feedback coefficients are introduced. The proposed approach ensures the system stability.

Chapter 6

In Chapter 6 all the simulation results that ensure the system stability and the transient performance of the fifth-order electromechanical modulator are presented.

Chapter 7

Conclusions from this work are discussed and directions for suggested future work are outlined.

Contents