Ain Shams University
Faculty of Engineering
Electronics and Communications Department

MEMS Inertial Sensors Characterization and Design

A thesis
submitted in partial fulfillment of the requirements of the degree of Master of Science in Electrical Engineering

Ahmed Mahmoud Mohamed Ali Mahmoud Omar
B.Sc. of Electrical Engineering
(Electronics and Communications Department)
Ain Shams University, 2010

Supervised by
Prof. Dr. Khaled Mohamed Wagih Sharaf
Dr. Ayman Hassan Abdel-Aziz Ismail

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Examiners' Committee

Title, Name and Affiliation	Signature
Prof. Dr. Elsayed Mostafa Saad	
Helwan University,	....
Faculty of Engineering,	
Electronics and Communications Engineering Dept.	
Prof. Dr. Mohamed Amin Dessouky	
Ain Shams University,	....
Faculty of Engineering,	
Electronics and Communications Engineering Dept.	
Prof. Dr. Khaled Mohamed Wagih Sharaf	
Ain Shams University,	....
Faculty of Engineering,	
Electronics and Communications Engineering Dept.	

Date: 30/07/2017

To My Wife And My Family.

Statement

This Thesis submitted in partial fulfillment for the requirements of a Master of Science degree in Electrical Engineering Electronics and Communications Engineering Department.

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: Ahmed Mahmoud Mohamed Ali Mahmoud Omar

Signature : ....

Date:

Curriculum Vitae

Name: Ahmed Mahmoud Mohamed Ali Mahmoud Omar

Date of Birth: 04/12/1988

Place of Birth: Egypt

Last Academic Degree: B.Sc. in Electrical Engineering

Field of Specialization: Electronics and Communications

University Issued the Degree: Ain Shams University

Date of Issued Degree: 2010

Current job: Application Engineer

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Abstract

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MEMS gyroscopes suffer from mechanical quadrature error which results from mismatch in the geometry of the MEMS structure that happens during the fabrication process. The mechanical quadrature error causes direct coupling of the drive signal to the sense mode. The coupled quadrature error can be even larger than the angular-rate signal to be measured and can have serious impact on the gyro performance, especially bias stability, bias temperature sensitivity and dynamic range. Therefore, several mechanical and electrical techniques were proposed to address the quadrature problem.

This work is driven by the need to eliminate the quadrature error, electrically, after the sensor has been manufactured. The objective is to prevent the quadrature error from limiting the dynamic range of the sense mode electronics and to eliminate the influence of the variations in quadrature error on the zero-rate output of the sensor which worsen the sensor performance regarding Bias Stability and Bias over Temperature.

Several electrical techniques for quadrature cancellation have been proposed. These techniques include synchronous demodulation, Open Loop and Closed Loop cancellation techniques. However, the effect of non-idealities on the effectiveness of these techniques was not reported. Since these techniques involve demodulation and modulation process, phase-error is the non-ideality that can have a great impact on these techniques.

In this work, mechanical quadrature error gyroscope, and its effect on the gyroscope system is explained. Different techniques for quadrature error cancellation, in mismatched mode gyroscopes, are presented and analyzed. The effect of phase error on the system performance in each technique is highlighted and closed form expressions for the phase error effect are derived.

Thereafter, quadrature cancellation system based on Open Loop, or Signal Injection, technique is adopted and implemented. The system is based on canceling the quadrature error at the input of the front-end circuit of the sense mode. This technique is very attractive for gyroscopes operating in open loop sense configuration and for gyroscopes that do not include electrodes for quadrature cancellation. The system-level analysis and design of the Open Loop quadrature cancellation loop are presented. In addition, circuit-level implementation of the key system blocks is conducted.

On the system level, the target overall system performance is defined, and accordingly the specifications and architecture of each block in the quadrature loop are defined. Stability analysis for the quadrature loop is studied with the aid of a MATLAB model. A SIMULINK model is implemented to study the transient behavior of the loop and evaluate the SNR of the system.

On the circuit level, a continuous-time Capacitance-to-Voltage Converter (C/V) with DC excitation signal is implemented, acting as the electronic interface with the capacitive MEMS gyroscope. An 8-bits Digital-to-Analog Converter (DAC) is implemented as a part of the feedback system. The DAC is designed as a differential binary-weighted capacitive DAC. The C/V and DAC circuits are designed on standard CMOS 0.18µm process.

The system achieves 12-bits linearity and Signal-to-Noise and Distortion Ratio (SNDR) of 74dB at 400kHz sampling rate for input signal bandwidth of 70Hz, while consuming 0.72mA from 1.8V supply.

Keywords: MEMS, Inertial Sensors, Gyroscopes, Accelerometers, Quadrature error, Quadrature cancellation, Capacitance-to-Voltage Converter, Digital-to-Analog Converter.

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Summary

This thesis is divided into seven chapters as follow:

Chapter 1 is an introduction including the motivation for this work, followed by the thesis outline.

Chapter 2 includes a background overview of MEMS inertial sensors and their characteristics and different techniques for interfacing with capacitive inertial sensors.

Chapter 3 explains the Mechanical Quadrature error in MEMS vibratory gyroscopes and the different proposed techniques to eliminate it, highlighting their advantages and drawbacks.

Chapter 4 focuses on quadrature cancellation based on Open loop Signal Injection technique and system design of the quadrature loop to be implemented.

Chapter 5 illustrates the circuit implementation of different blocks of the Open loop quadrature cancellation system and the behavioral model for the loop.

Chapter 6 presents the simulation results of individual blocks and the top level as well, including MATLAB simulations and circuit simulations.

Chapter 7 is the conclusion for this work and the suggested future work on this system either an optimization or extra features to be implemented.